Response of Several Apple Cultivars to Methyl Bromide Fumigation

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SUMMARY. 'Fuji', 'Gala' and 'Jonagold' apples (*Malus × domestica* Borkh.) from either regular-atmosphere (RA) or controlled-atmosphere (CA) storage can be fumigated with methyl bromide (MeBr) with minimal effects on fruit quality. Some quality loss, particularly in internal color, was possible at 48 and 56 g·m⁻³ MeBr doses for 'Fuji', 'Gala', and 'Jonagold' apples from CA storage. 'Braeburn' apples from either RA or CA storage were not good candidates for MeBr fumigation, particularly at 10 °C. Observed internal damage indicated that 'Braeburn' apples from RA or CA cannot be fumigated with MeBr. Apples with watercore displayed increased internal breakdown after fumigation with MeBr. Regardless of cultivar, only apples of superior quality could tolerate the stress of MeBr fumigation.

Exporting agriculture commodities is a major concern for growers and shippers in the United States. Quarantine barriers are established to prevent the spread of agriculture pest from one country to another. Methyl bromide (MeBr) is being used as a fumigant for disinfestation of agriculture commodities, including fruit. A major disadvan-

tage of MeBr fumigation is that dosage, time, and temperature required to eliminate the insect in question often injures fruit.

Apples are fumigated with MeBr to control restricted insects pest, but the tolerance of fruit to MeBr on fruit quality has been questioned. MeBr injury to apples is widely reported, but results vary due to different cultivars, dosage, fumigation temperature, and storage time necessary for the injury to appear (Chapman, 1940; Claypool and Vines, 1956; Kenworthy, 1944; Kenworthy and Gaddis, 1946; Lay-Yee, 1993; Phillips et al., 1938; Phillips and Monro, 1939). Phillips et al. (1938) reported that 'Delicious', 'Stark', and 'Baldwin' apples were not injured with MeBr fumigation. Kenworthy and Gaddis (1946) reported that 'McIntosh', 'Stark', 'Cortland', 'Golden Delicious', and several other cultivars were not injured when fumigated with MeBr, but 'Delicious', 'Wealthy', 'Orleans', and 'York' developed external and internal injury after fumigation. Sproul et al. (1976) reported injury to 'Granny Smith' and 'Crofton' apples after MeBr fumigation, but this injury was eliminated when diphenylamine was used before fumigation. Drake et al. (1988) reported internal injury in 'Delicious' but not 'Golden Delicious' or 'Granny Smith' apples fumigated with high doses (56 g·m⁻³) of MeBr, and injury to 'Delicious' apples was not apparent until after prolonged storage. Drake et al. (1990) also reported that internal injury observed with 'Delicious' was related to time and temperature of MeBr exposure. Conflicting results with 'Braeburn', 'Fuji', 'Gala', and 'Granny Smith' apples after exposure to MeBr has been reported by Lay-Yee (1993).

Most of the research on fumigation with MeBr for apples was conducted using traditional cultivars. Only limited information is available on recently introduced cultivars and their response to MeBr. In addition, the response of 'Delicious' and 'Fuji' apples with watercore to MeBr is a concern as related to internal quality. 'Fuji' apples during particular growing seasons are subject to watercore (Yoshida et al., 1995). The present study was conducted in 1994 and 1995 to determine the response of 'Braeburn', 'Delicious', 'Fuji', 'Jonagold', and 'Gala' apples to MeBr fumigation.

Materials and methods

'Braeburn', 'Fuji', 'Gala', and 'Jonagold' apples were obtained from local commercial warehouses during 1994 and 1995 for regular-atmosphere (RA) and controlled-atmosphere (CA) storage. Apples from CA were obtained in February 1994. Apples from RA were obtained in October 1994 and 1995. Before fumigation, test apples were conditioned at 6 or 10 °C for 24 h. Apples were fumigated with MeBr at doses of 0, 16, 32, 48, or 56 g·m⁻³ at 6 or 10 °C. Apples ('Delicious' and 'Fuji') with a known amount of watercore were obtained from three commercial warehouses in October 1995. Apples with watercore were fumigated with MeBr at 56 g·m⁻³ at 10 °C with controls, stored, and evaluated. Fumigations were conducted at normal atmospheric pressure in 28.3-L fiberglass chambers (model 55300 vacuum desiccator; Labconc, Corp., Kansas City, Mo.) equipped with continuously circulating fans during the 2-h exposure. A 50% load factor (v/v) was achieved by placing 40 apples in each chamber. After aeration, the apples were boxed and placed in RA storage at 1 °C for 30 or 60 d. After each storage period, the quality of 18 apples from each cultivar, MeBr dose, exposure time, and warehouse (replication) was assessed. The experimental design was a completely randomized block split-split plot, using MeBr levels as the main plots, temperatures as the subplots, and storage time and ripening as the sub-subplots. Nine apples were evaluated immediately after removal from storage. The other nine apples were held at 21 °C for 7 d before evaluation. A factorial design was used for data analysis using MeBr treatment (five levels), temperature (two levels), storage time (two levels), and ripening (two levels).

Quality factors evaluated were firmness, external and internal color, soluble solids concentrations (SSC), titratable acidity (TA), and visual disorders (scald and internal breakdown). Firmness was determined by a texture analyzer (TA-XT2; Scarsdale, N.Y.) equipped with a 1.1-cm probe and reported as Newtons (N). External and internal color was determined with a chromameter (model CR 300; Minolta, Osaka, Japan) using the Hunter L*, a*, b* system and calculated hue (h°) values (Hunter and Harold, 1987).

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Three values for external color were determined for an equal distance around the circumference of the apple. Internal color was measured by cutting each apple in half horizontally and immediately reading the exposed flesh surface of the calyx end. The average value of nine apples was reported for color analyses. SSC of the extracted juice was determined with an Abbe-type refractometer calibrated at 20 °C. TA was determined using a titrator (model TTT 85; Radiometer, Copenhagen). Juice extracted from the apples was titrated to pH 8.2 with 0.1 N NaOH and values were expressed as percent malic acid. Visual observations for disorders were conducted by two laboratory personnel familiar with apples. Analysis of variance was determined by SAS (1985) as a factorial design, and means were separated by the Waller-Duncan test ($P = 0.05$).

Results and discussion

REGULAR ATMOSPHERE. Fumigation with MeBr for codling moth (*Cydia pomonella* L.) had no detrimental effect on firmness or SSC of 'Fuji', 'Gala', or 'Jonagold' apples from RA storage

(Table 1). Fumigation altered TA of these three cultivars. In all three cultivars, TA increased as the dose increased. The increase in TA occurred at 32 g·m⁻³ MeBr for 'Fuji' and 'Jonagold' apples and at 48 g·m⁻³ for 'Gala' apples. This increase in TA was not coupled with a change in SSC and was probably due to MeBr rather than to a loss of moisture content of the fruit.

'Fuji' apples exhibited slightly higher SSC after fumigation at 10 than at 6 °C with no change in firmness or TA. Firmness, SSC, and TA of 'Gala' apples decreased when fumigated at 10 rather than 6 °C. There was no change in firmness, SSC, or TA for 'Jonagold' apples after fumigation at 10 °C. Increasing temperature of fumigation from 6 to 10 °C increased SSC and decreased firmness and TA in 'Delicious' apples (Drake et al., 1988). Changes in apple quality as a result of temperature during fumigation was not observed in this study.

There was some change in the external color of 'Fuji', 'Gala', and 'Jonagold' apples after MeBr fumigation (Table 1). Discoloration of the external surface area of 'Fuji' apples

was manifested by increased L* and decreased a* values as the fumigation dose of MeBr was increased. Hue values of 'Fuji', 'Gala', and 'Jonagold' did not change due to MeBr exposure and, thus, the change in external color is not perceptible to consumers (Hunter and Harold, 1987). A treatment temperature increase from 6 to 10 °C increased L* and decreased a* values slightly for the three cultivars, indicating reduced red color. Hue values did not change because of the higher fumigation temperature. Kenworthy and Gaddis (1946), Sproul et al., (1976), and Lay-Yee (1993) reported that MeBr can cause external discoloration of apples. In this study, we found this not to be a problem with 'Fuji', 'Gala', or 'Jonagold' apples.

Fumigation with MeBr had a major adverse influence on the quality of 'Braeburn' apples (Table 2). MeBr fumigation resulted in a 18% to 47% loss of firmness. This firmness loss for 'Braeburn' apples after MeBr fumigation was present only after ambient temperature ripening of 7 d. Before ripening, firmness was acceptable (>54 N) at all doses of MeBr fumigation and both fumiga-

Table 1. Influence of methyl bromide (MeBr) on fruit quality of 'Fuji', 'Gala', and 'Jonagold' apples fumigated at 6 and 10 °C after regular-atmosphere (RA) storage, 1994-95.

MeBr (g·m ⁻³) and fumigation temp (°C)	Firmness (N)	SSC (%)	Acidity (% malic)	External Hunter color		h°
				L*	a*	
Fuji						
0	63.1 a ^z	15.1 a	0.30 b	51.4 b	20.6 a	42.5 a
16	63.5 a	15.2 a	0.31 b	51.8 ab	19.9 ab	43.6 a
32	63.4 a	15.3 a	0.34 a	52.3 a	19.9 ab	43.6 a
48	63.8 a	15.1 a	0.34 a	52.6 a	19.4 ab	44.4 a
56	64.3 a	15.2 a	0.34 a	52.3 a	18.8 b	44.6 a
6	63.9 a	15.1 b	0.32 a	51.4 b	20.3 a	43.2 a
10	63.3 a	15.3 a	0.32 a	52.8 a	19.2 b	44.3 a
Gala						
0	55.6 a	13.9 b	0.27 b	48.5 a	30.5 b	31.9 a
16	56.6 a	13.9 b	0.26 c	48.8 a	31.2 ab	31.3 a
32	54.9 a	13.9 b	0.28 b	48.5 a	31.7 a	30.2 a
48	56.6 a	14.1 a	0.30 a	49.5 a	31.9 a	31.9 a
56	56.5 a	14.0 ab	0.30 a	49.6 a	31.5 ab	30.8 a
6	56.7 a	14.0 a	0.30 a	48.1 b	31.9 a	31.3 a
10	55.4 b	13.9 b	0.28 b	49.9 a	30.8 b	31.9 a
Jonagold						
0	45.3 a	14.8 a	0.36 b	56.7 b	24.1 a b	44.9 ab
16	45.4 a	14.7 a	0.38 ab	59.8 a	21.6 b	50.0 a
32	44.5 a	14.7 a	0.39 a	57.3 ab	23.4 ab	46.1 ab
48	44.6 a	14.9 a	0.40 a	57.4 ab	23.7 ab	45.8 ab
56	44.1 a	14.7 a	0.39 a	56.4 b	25.3 a	43.1 a
6	45.0 a	14.8 a	0.38 a	56.2 b	24.2 a	44.1 b
10	44.6 a	14.7 a	0.39 a	58.9 a	22.8 b	47.9 a

^zMeans in a column within treatments not followed by a common letter are significantly different ($P = 0.05$), using Waller-Duncan test.

Table 2. 'Braeburn' apple quality as influenced by the interaction of methyl bromide (MeBr) dose, fumigation temperature, and ripening after regular-atmosphere (RA) storage.

Temp (°C)	Ripening (d)	MeBr (g·m ⁻³)	Firmness (N)	Acidity (% malic)	Hunter color				h°	Visual internal discoloration ^z
					External		Internal			
					L*	a*	L*	*b		
6	0	0	59.2 a ^y	0.47 a	58.9 a	26.4 a	75.1 a	24.4 c	94.6 a	0.1 c
		16	62.0 a	0.50 a	58.5 a	25.7 a	76.2 a	24.6 b	93.6 a	0.1 c
		32	59.7 a	0.50 a	60.0 a	26.6 a	75.3 a	25.1 a	95.3 a	0.1 c
		48	59.4 a	0.47 a	60.9 a	29.9 a	76.6 a	25.0 ab	94.7 a	0.1 c
		56	57.8 a	0.47 a	60.6 a	26.5 a	76.1 a	24.7 abc	95.0 a	0.1 c
	7	0	52.8 b	0.44 b	60.6 a	28.2 a	74.9 a	26.4 a	94.2 a	0.1 c
		16	54.2 b	0.48 b	61.1 a	28.5 a	73.8 ab	26.2 a	94.7 a	0.1 c
		32	53.3 b	0.47 b	59.9 a	27.6 a	75.3 a	26.2 a	94.2 a	0.1 c
		48	50.0 b	0.47 b	61.0 a	27.9 a	74.3 a	26.4 a	93.7 a	16.7 b
		56	40.9 c	0.39 c	59.9 a	27.0 a	71.6 b	25.3 b	89.8 b	53.3 a
10	0	0	58.0 a	0.48 a	58.6 a	24.9 a	76.4 a	24.5 b	86.8 b	0.1 c
		16	55.9 a	0.48 a	58.7 a	24.8 a	75.9 a	24.6 b	94.7 a	0.1 c
		32	58.3 a	0.50 a	59.0 a	25.0 a	77.3 a	24.6 b	94.0 ab	0.1 c
		48	55.6 a	0.52 a	61.3 a	26.1 a	77.2 a	24.6 b	95.0 a	0.1 c
		56	55.0 a	0.52 a	59.1 a	24.9 a	76.2 a	24.4 b	94.0 ab	0.1 c
	7	0	52.6 b	0.43 b	58.9 a	26.3 a	75.0 a	26.1 a	93.9 a	0.1 c
		16	50.9 b	0.41 b	59.5 a	27.0 a	75.7 a	25.9 a	94.1 a	0.1 c
		32	51.0 b	0.46 ab	59.3 a	26.7 a	76.0 a	26.4 a	94.3 a	5.0 c
		48	41.1 b	0.43 b	59.2 a	26.7 a	70.4 b	24.6 c	88.9 b	62.5 b
		56	27.0 c	0.32 c	50.9 b	20.5 b	58.9 c	19.9 d	74.1 c	100.0 a

^zN = 60. Percent fruit with visual internal discoloration.^yMeans in a column, within temperature groups not followed by a common letter are significantly different ($P = 0.05$), using Waller-Duncan test.

tion temperatures. After fumigation temperatures of 6 or 10 °C and 7 d of ripening, firmness levels of 'Braeburn' apples were marginal at all doses of MeBr fumigation. This firmness loss for 'Braeburn' apples was particularly apparent at doses of 48 and 56 g·m⁻³ MeBr.

SSC of 'Braeburn' apples was not influenced by MeBr or temperature of fumigation. The dose of MeBr and fumigation temperature reduced TA of 'Braeburn' apples. Contrary to the results for 'Fuji', 'Gala', and 'Jonagold' apples, TA of 'Braeburn' apples was

reduced by MeBr, temperature of fumigation, and days of ripening. MeBr fumigation at 56 g·m⁻³ at 6 and 10 °C reduced firmness and TA content of 'Braeburn' apples. Reduced TA coupled with constant SSC may reduce the flavor of the apple and impact

Table 3. Effects of methyl bromide (MeBr) on fruit quality of 'Braeburn' and 'Fuji' apples fumigated at 6 and 10 °C after 4 months controlled-atmosphere (CA) storage.

MeBr (g·m ⁻³) and fumigation temp (°C)	Firmness (N)	SSC (%)	Acidity (% malic)	Hunter color				Internal visual score (1 to 4) ^z
				External		Internal		
				L*	h°	L*	h°	
Braeburn								
0	87.6 a ^y	14.7 a	0.50 a	54.7 a	46.2 a	73.6 a	92.7 a	2.9 b
16	86.9 a	15.0 a	0.52 a	54.9 a	45.9 a	74.1 a	92.7 a	3.8 ab
32	87.8 a	15.0 a	0.52 a	55.5 a	45.8 a	74.3 a	92.8 a	1.7 c
48	87.8 a	14.9 a	0.53 a	55.4 a	46.1 a	73.8 a	93.0 a	1.3 c
56	87.4 a	14.8 a	0.52 a	55.0 a	45.4 a	74.2 a	93.0 a	5.0 a
6	87.9 a	14.9 a	0.54 a	55.1 a	45.9 a	73.7 b	93.0 a	2.2 b
10	87.1 a	14.9 a	0.49 b	55.1 a	45.8 a	74.2 a	92.7 a	3.7 a
Fuji								
0	64.5 a	15.8 b	0.22 c	44.8 a	35.0 a	73.5 a	91.0 a	0.4 b
16	65.6 a	16.1 ab	0.25 b	45.9 a	36.6 a	73.6 a	90.6 ab	0.1 b
32	65.6 a	16.3 a	0.25 b	46.7 a	36.9 a	73.6 a	90.2 b	0.1 b
48	65.0 a	16.3 a	0.26 a	46.2 a	35.0 a	73.7 a	90.4 ab	1.3 a
56	65.5 a	16.1 a	0.26 a	45.9 a	35.3 a	73.8 a	90.9 ab	1.7 a
6	65.2 a	15.9 b	0.24 b	45.8 a	35.9 a	73.4 a	90.9 a	0.5 b
10	65.3 a	16.3 a	0.25 a	46.0 a	35.7 a	73.9 a	90.3 b	1.3 a

^zRated on a scale of 1 to 4 (1 = excellent; 2 = good; 3 = fair; 4 = poor).^yMeans in a column within treatments not followed by a common letter are significantly different ($P = 0.05$), using Waller-Duncan test.

consumer acceptance. MeBr fumigation, 56 g·m⁻³ at 10 °C with 7 d of ripening, reduced exterior color of 'Braeburn' apples. L* and a* values were reduced 9 and 5 units, respectively, resulting in a darker-colored apple, but with no apparent change in hue values. Reduction in exterior color at the highest doses of MeBr produced a scald-like injury on the surface exterior of the 'Braeburn' apples. A change of this magnitude in the exterior color would reduce the marketability of this cultivar.

The interior color of 'Braeburn' apples was reduced by high doses of MeBr at 56 g·m⁻³ at 6 °C and 48 or 56 g·m⁻³ at 10 °C. This reduction in internal color was evident as changes in L* and b* values. Hue values for 'Braeburn' apples were reduced at 48 and 56 g·m⁻³ at 1 °C after ripening. Change in Hunter color values resulted in apples with a very dark yellow to brown interior color. Visual observations of the internal color of 'Braeburn' apples concurred with the objective evaluations of internal color reduction due to MeBr fumigation. Using MeBr at 48 or 56 g·m⁻³ at 6 or 10 °C resulted in apples with a very high percentage of unacceptable interior color after ripening. Subjective color reduction was much greater at the higher fumigation temperature of 10 than at 6 °C.

Internal discoloration of 'Fuji'

apples was related to MeBr fumigation, particularly at the highest dose of 56 g·m⁻³ (Table 3). Hunter b* and hue values increased with the higher doses increasing the dark yellow internal color. Only the 56-g·m⁻³ dose was different in color from the control and only by 0.4 Hunter b* and 0.7 hue units, but this slight change would not be visible to human perception (Hunter and Harold, 1987). Discoloration in 'Fuji' apples was observed for all MeBr fumigation doses. Change in the internal color of 'Fuji' apples was not related to temperature of fumigation and was present at 6 and 10 °C. Internal discoloration of apples due to fumigation has been reported for many cultivars. Recently, Lay-Yee (1993) reported internal discoloration of 'Braeburn' and 'Fuji' apples as a result of MeBr fumigation but reported no problems with 'Gala' and 'Splendor'. Although changes in the internal color of 'Fuji' apples were noted, this change would probably not be noticed by the consumer.

There was no internal discoloration of 'Gala' apples due to MeBr fumigation (Table 4). There was a reduction in internal b* values for 'Gala' apples when temperature of fumigation was increased from 6 to 10 °C, but no change in L* or hue values was apparent. Internal yellow color of 'Jonagold' apples increased (higher b*) with increased doses of MeBr, but no change in lightness or color (L* or

hue values) was observed. Increased fumigation temperature from 6 to 10 °C increased b* and decreased hue values, resulting in a darker yellow internal color for 'Jonagold' apples fumigated at higher MeBr doses. Changes in the internal color of 'Gala' and 'Jonagold' apples were not obviously visible.

CONTROLLED ATMOSPHERE. No detrimental effect on firmness, SSC, or TA of 'Braeburn' or 'Gala' apples, or the firmness and SSC of 'Fuji' apples fumigated with MeBr was observed (Tables 3 and 4). Decreased firmness and SSC with increased TA was present in 'Jonagold' apples when MeBr fumigation dose was >16 g·m⁻³. Changes in the quality attributes of 'Jonagold' apples were slight, but fruit quality should be considered before fumigation with MeBr. 'Jonagold' apples lose quality very rapidly regardless of the type of storage (Drake, 1993), and only the highest quality apples are good candidates for the additional stress of fumigation. The TA of 'Fuji' apples increased as MeBr dosage increased, but SSC remained constant. Increased acid content for 'Jonagold' and 'Fuji' apples with increased MeBr doses would possibly help retain the flavor of these cultivars.

Neither the external nor internal color of 'Braeburn', 'Fuji', 'Gala', or 'Jonagold' apples changed as a result of MeBr. Other external and internal

Table 4. Effects of methyl bromide (MeBr) on fruit quality of 'Gala' and 'Jonagold' apples fumigated at 6 and 10 °C, after 4 months of controlled-atmosphere (CA) storage.

MeBr (g·m ⁻³) and fumigation temp (°C)	Firmness (N)	SSC (%)	Acidity (% malic)	Hunter color				Internal visual score (1 to 4) ^z
				External		Internal		
				L*	h°	L*	h°	
Gala								
0	61.5 a	14.0 a	0.34 b	47.9 a	28.8 a	78.3 a	93.3 a	0.1 b
16	60.9 a	14.1 a	0.34 b	48.7 a	29.1 a	78.3 a	93.1 a	0.8 b
32	62.8 a	14.5 a	0.37 a	49.0 a	29.1 a	78.8 a	92.7 a	2.5 a
48	60.7 a	14.4 a	0.36 a	48.5 a	28.0 a	78.5 a	93.2 a	3.8 a
56	61.2 a	14.1 a	0.37 a	47.7 a	26.7 b	78.4 a	93.3 a	3.3 a
6	61.8 a	14.1 b	0.34 b	48.3 a	28.1 a	78.4 a	93.2 a	0.3 b
10	61.0 a	14.3 a	0.37 a	48.4 a	28.6 a	78.5 a	93.1 a	3.8 a
Jonagold								
0	46.9 a	15.0 a	0.33 b	51.0 b	34.4 b	75.2 a	91.9 ab	0.1 b
16	46.4 ab	14.8 ab	0.34 b	53.2 ab	37.8 ab	75.5 a	91.8 ab	2.1 a
32	46.3 ab	14.7 b	0.36 a	53.9 a	41.1 a	75.4 a	92.2 a	1.7 a
48	46.9 a	14.6 b	0.37 a	53.5 ab	38.4 ab	75.2 a	92.1 ab	1.7 a
56	45.8 b	14.6 b	0.37 a	53.2 ab	37.5 ab	75.3 a	91.8 ab	1.3 a
6	46.8 a	14.6 b	0.36 a	53.7 a	39.3 a	75.4 a	91.9 a	1.2 a
10	46.1 b	14.9 a	0.35 a	52.3 b	36.3 b	75.3 a	92.0 a	1.5 a

*Rated on a scale of 1 to 4 (1 = excellent; 2 = good; 3 = fair; 4 = poor).

†Means in a column within treatments not followed by a common letter are significantly different ($P = 0.05$), using Waller-Duncan test.

Table 5. Watercore and internal breakdown of 'Delicious' and 'Fuji' apples as related to methyl bromide (MeBr) treatment, regular-atmosphere (RA) storage, and ripening.

Treatment	Delicious		Fuji	
	Watercore (%)	Internal breakdown (1 to 3) ²	Watercore (%)	Internal breakdown (1 to 3)
MeBr (g·m ⁻³)				
0	46 a ³	1.1 b	43 a	1.4 b
56	55 a	1.6 a	38 a	2.1 a
Storage (d)				
30	52 a	0.3 b	51 a	1.3 b
60	44 a	2.4 a	30 b	2.2 a
Ripe (d)				
0	52 a	0.1 b	47 a	1.1 b
8	46 a	2.7 a	34 b	2.4 a

²Rated on a scale of 1 to 3 (1 = none; 2 = moderate; 3 = severe).

³Means (pairs) in a column not followed by a common letter are significantly different ($P = 0.05$), using ANOVA.

color values were constant for 'Braeburn' and 'Gala' apples regardless of MeBr fumigation or temperature of fumigation. Internal hue color changes of 'Fuji' and 'Jonagold' apples attributed to fumigation dose were not constant.

Subjective (visual) scores for internal apple color changed as a result of MeBr fumigation and, as dose of MeBr increased, increased darkening of 'Braeburn', 'Fuji', 'Gala' and 'Jonagold' apples was observed (Tables 3 and 4). Methyl bromide altered the subjective internal color scores of 'Braeburn' apples, and this change was very apparent at the highest dose. 'Braeburn' apples treated with 56 g·m⁻³ were scored unacceptable due to the dark color. Fumigation with MeBr at 48 g·m⁻³ induced no change in the internal color scores of 'Fuji' apples with no color difference between the two highest doses of MeBr. At the 48- and 56-g·m⁻³ doses, the overall internal color of 'Fuji' apples was acceptable. Internal color of 'Gala' and 'Jonagold' apples darkened at the 16- and 32-g·m⁻³ doses. Without nonfumigated apples for comparison, it is doubtful that internal color scores of ≤ 3.0 would be identifiable by the consumer.

Increasing the temperature of fumigation from 6 to 10 °C reduced hue values of 'Fuji' apples. Reduced hue was <1 unit, but subjective scores were increased, indicating a more yellow color change in 'Fuji' apples fumigated at 10 °C. There were also increased visual scores for 'Braeburn' and 'Gala' apples fumigated at 10 °C, indicating a darker internal color for

those cultivars fumigated at 10 °C.

Methyl bromide fumigation of apples with watercore increased internal breakdown (Table 5). 'Delicious' and 'Fuji' apples fumigated with 56 g·m⁻³ MeBr at 10 °C exhibited more internal breakdown than similar control apples with watercore. No difference was observed in the amount of watercore present for 'Delicious' and 'Fuji' apples after either the 56-g·m⁻³ MeBr dose or control. As storage progressed from 30 to 60 d, internal breakdown also increased for both cultivars. Increased internal breakdown over time was also evident during ripening of apples held at 20 °C for 7 d. There were less 'Fuji' apples with watercore after 60 d of storage than at 30 d or after ripening, but there was more internal breakdown present.

Conclusions

Good-quality 'Fuji', 'Gala', and 'Jonagold' apples form either RA or CA storage can be fumigated with MeBr with minimal effects on apple quality. Some quality loss, expressed as darkening of the internal color, is possible at the high MeBr fumigation doses. Only the best-quality apples can be successfully fumigated regardless of the type of storage involved. 'Braeburn' apples are not good candidates for fumigation. 'Braeburn' apples incur major quality losses after fumigation. Quality losses in 'Braeburn' apples were particularly severe for apples from CA and RA storage. Apples with watercore displayed increased amounts of internal breakdown after fumigation.

Literature cited

- Chapman, P.J. 1940. Effect of methyl bromide on apple maggots in apples. *J. Econ. Entomol.* 33:817.
- Claypool, L.L. and H.M. Vines. 1956. Commodity tolerance studies of deciduous fruits to moist heat and fumigation. *Hilgardia* 24:297.
- Drake, S.R., H.R. Moffitt, J.K. Fellman, and C.R. Sell. 1988. Apple quality as influenced by fumigation with methyl bromide. *J. Food Sci.* 53:1710-1712, 1736.
- Drake, S.R., H.R. Moffitt, and J.P. Mattheis. 1990. Methyl bromide, time and temperature of exposure on apple quality. *J. Food Pres. Proc.* 14:85-92.
- Drake, S.R. 1993. Short-term controlled atmosphere storage improves quality of several apple cultivars. *J. Amer. Soc. Hort. Sci.* 118:486-489.
- Hunter, R.S. and R.W. Harold. 1987. The measurement of appearance. 2nd ed. Wiley, New York.
- Kenworthy, A.L. 1944. Injury to 'Williams' apples resulting from fumigation with methyl bromide. *Proc. Amer. Soc. Hort. Sci.* 45:141-145.
- Kenworthy, A.L. and C.H. Gaddis. 1946. Tolerance of apples varieties to methyl bromide fumigation. *Proc. Amer. Soc. Hort. Sci.* 47:64-66.
- Lay-Yee, M. 1993. Response of New Zealand apples to methyl bromide fumigation. *The Orchardist* 66:35-36.
- Phillips, W.R., H.A.U. Monro, and C.E. Allen. 1938. Some observations on fumigation of apples with methyl bromide. *Sci. Agr.* 19:7-20.
- Phillips, W.R. and H.A.U. Monro. 1939. Methyl bromide injury to apples. *J. Econ. Entomol.* 32:334.
- Sprout, A.N., J.B. O'Loughlin, A. Terauds, and S. Hardisty. 1976. The use of diphenylamine to protect apples from methyl bromide injury. *Austral. J. Agr. Res.* 27:541.
- Yoshida, Y., X. Fan, and M. Patterson. 1995. 'Fuji' apple. *Fruit Var. J.* 49:194-197.