EFFECTS OF ETHYLENE REMOVAL DURING STORAGE OF BRAMLEY'S SEEDLING

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ABSTRACT

Storing Bramley apples in 0.05 µℓ/ℓitre ethylene provided better control of superficial scald and retention of flesh firmness than 0.2 or 1 µℓ/ℓitre. Ceasing to scrub ethylene after 69 days resulted in poor control of scald but did reduce flesh softening in subsequent storage compared to unscrubbed fruit; between 140 and 230 days of ethylene scrubbed storage in a total of 313 days was required for scald control. Treatment with DPA controlled scald more successfully but fruit was softer than with low ethylene storage. Control of scald was poor for some fruit despite the maintainance of low ethylene concentrations in the storage atmosphere.

INTRODUCTION

A number of workers have shown that the removal of ethylene from controlled atmosphere storage results in improved retention of flesh firmness in some apple varieties (1,2). Control of superficial scald on Bramley's Seedling without the use of a post-harvest antioxidant treatment has also been achieved using low ethylene storage (3,4). It is generally established that to obtain a beneficial response in apples, the storage atmosphere concentration of ethylene should be maintained below 1 µℓ/ℓitre (3). However it is unclear how much below 1 µℓ/ℓitre the ethylene concentration needs to be and for how long it is necessary to maintain low concentrations. These are important considerations in the application of low ethylene storage on a commercial scale, affecting both ethylene scrubber sizing and operating costs.

Where there is a response to low ethylene it is to enhance the effects of low temperature and controlled atmospheres by further delaying and retarding certain developmental processes. Knee (1) has suggested that very low ethylene concentrations during the early stages in store are more important in delaying softening than the higher levels that may be seen later in low ethylene storage. It thus may not be necessary to store under a low ethylene regime for the entire storage period and the ethylene removal system could be switched off with little loss in benefits.

In this paper the effect of store ethylene concentration and period in an ethylene scrubbed atmosphere, on flesh firmness and incidence of superficial scald in Bramley's Seedling are considered. A semi-commercial trial comparing the use of low ethylene storage with the standard diphenylamine (DPA) treatment to control scald on Bramley apples is also described.

It has been generally assumed that maintaining a low ethylene atmosphere for Bramley apples would result in adequate control of superficial scald. Data are presented showing that this may not always be the case.

MATERIALS AND METHODS

Fruit used in these experiments was not given a post-harvest antioxidant treatment (except where stated) but was treated with a fungicide. All fruit was stored in 9% CO_2 (12% O_2) at 4°C.

Storage at fixed ethylene concentration

In 1982 Bramley apples from trees on MM.106 rootstock were picked on 17th September and stored in eight experimental storage cabinets (5) each containing 80 kg of fruit. Six cabinets were fitted with small scale catalytic converters for the removal of ethylene from the cabinet atmosphere (6), two unscrubbed cabinets were used as controls. For 35 days the ethylene concentration in all scrubbed cabinets was maintained below 0.05 µℓ/ℓitre, the ethylene removal rate for each cabinet was then adjusted, by varying the flow through the catalyst system, to achieve concentrations of 1, 0.2 and 0.05 µℓ/ℓitre (two cabinets at each concentration) for the remainder of the storage period.

Cessation of ethylene scrubbing before the end of storage

In 1983 Bramley apples from trees on vigorous rootstocks were picked on 22nd September and stored in six cabinets fitted with small scale catalytic converters and in two unscrubbed control cabinets, each containing 80 kg of fruit. Samples of fruit were removed from the ethylene scrubbed and control cabinets after 69, 141 and 232 days for further storage in 9% CO_2 at 4°C, without ethylene removal, in small containers (drums) each holding 10 kg of fruit.

In 1982 samples were transferred to drums from the cabinets used to store at fixed ethylene concentrations (see above) after 172, 236 and 277 days for further storage without ethylene removal.

Semi-commercial scale assessment of scald treatments

The catalyst system used in this trial has previously been described (4) and was originally designed for a 20 tonne Bramley store at EMRS. It was modified and installed on a 9 tonne store at the National Fruit Trials, Brogdale, Kent. The store was loaded with bulk bins of Bramley apples, not treated with an antioxidant, harvested on 12th September from trees on M.26 rootstock. An adjacent store without an ethylene scrubber was filled with diphenylamine (DPA) treated fruit (2000 mg/ℓitre ai) from the same source. Netted samples of 20 fruit were placed in the top of a bulk bin, immediately below an access hatch in each store, for periodic removal during storage.

Interaction of ethylene removal and harvest date

Some data from an experiment on the effect of harvest maturity on ethylene and scald control is presented to illustrate inadequate control of scald in low ethylene storage.

Fruit was harvested from Bramley trees on M.9 rootstock on 1st, 15th and 29th September 1983 (early, normal and late picks). Two samples from each harvest were stored in six cabinets (80 kg) and a catalyst system for ethylene removal was connected to one cabinet of fruit from each picking date.

Analytical methods

Flesh firmness was measured using a semi-automatic penetrometer with an 8 mm plunger (7). Superficial scald was assessed as the percentage of fruit showing symptoms of the disorder and as an index of severity on a five point scale based on the percentage area of the skin affected (8). An index maximum of 100 was recorded where more than 50% of the skin of all fruits in a sample was affected by scald. Farnesene was extracted from the fruit surface by immersion in ether and measured by gas chromatography (3). Oxidation products of α-farnesene were detected by measuring an absorption spectrum from 200 to 340 nm (9). Ethylene concentrations were measured by gas chromatography on an alumina column with a flame ionisation detector. Internal ethylene measurements were made using the method described by Mousdale and Knee (10) where a gas sample is removed from the core cavity of the apple, by syringe, through a hypodermic needle with side entry holes. Soluble pectin was analysed by the method described by Knee (11). Coreflush was assessed using an index of severity: slight 1, moderate 2, severe 3, giving an index maximum of 60 for a 20 fruit sample in which all fruits showed severe symptoms. Flesh breakdown was assessed using a similar index which additionally included a very slight, 0.5, category.

RESULTS

Storage at fixed ethylene concentration

During the first 35 days of storage, indicated by arrow in Figure 1, when very low (0.05 µℓ/ℓitre) concentrations were maintained in all scrubbed cabinets the ethylene production rates generally decreased. Subsequently when the controlled ethylene levels were established, taking a further 10-20 days, the ethylene production rate for the fruit held at 1 µℓ/ℓitre increased quite rapidly to over 0.2 µℓ/kg/hr. The fruit held at 0.2 and 0.05 µℓ/ℓitre showed a progressively delayed increase in production rate. During the remainder of storage ethylene production rate was directly dependent on the controlled ethylene concentration, reaching 0.2 µℓ/kg/hr after a total storage period of 80, 185 and 260 days for controlled concentrations of 1, 0.2 and 0.05 µℓ/ℓitre respectively. The ethylene concentration in the unscrubbed cabinets exceeded 1 µℓ/ℓitre in 10 days and 10 µℓ/ℓitre in 45 days, increasing to 50-100 µℓ/ℓitre for the remainder of storage.

Storage at 0.05 µℓ/ℓitre virtually halted the decline in flesh firmness in store (Fig. 2). At the end of storage (321 days) firmness was related to ethylene concentration with the unscrubbed fruit the least firm. After a simulated shelf-life of 12 days at 18°C the differences were still apparent. Soluble pectin increased more in the control fruit than in the low ethylene fruit (Fig. 3).

The effect of ethylene concentration on the incidence of superficial scald as measured by an index of severity is shown in Figure 4. Although storage at 1 µℓ/ℓitre had some effect on scald, it is interesting to note that, up to 280 days in store, scald development lagged behind that in control fruit by around 50 days, which was similar to the difference in time to reach 1 µℓ/ℓitre. Scald incidence was slow to increase in 0.2 µℓ/ℓitre fruit and did not appear until the final inspection (321 days) in 0.05 µℓ/ℓitre fruit when 6% of fruit were affected (index 1). The incidence of scald increased after a simulated shelf-life of 12 days at 18°C in the low ethylene treatments (Table 1).

Table 1. Effect of ethylene concentration in the storage atmosphere on the percentage of fruit affected and severity index of superficial scald

Cabinet ethylene concen- tration	Superficial scald							
	Control		1 μℓ/ℓitre		0.2 μℓ/ℓitre		0.05 μℓ/ℓitre	
	%	Index	%	Index	%	Index	%	Index
Days in store								
321	100	66	81	37	26	6	6	1
+12 days at 18°C	100	70	85	41	58	14	25	7

The internal ethylene concentration of stored fruit can provide an indication of the efficacy of ethylene removal. Table 2 shows that after 170 days only in 0.05 μℓ/ℓitre did a large proportion of fruit have an internal concentration similar to the cabinet atmosphere. At that time the control of ethylene

Table 2. Effect of ethylene concentration in the storage atmosphere on the percentage of fruit with high* internal ethylene concentration

	% of fruit with high* internal ethylene concentration		
Cabinet ethylene concentration	1.0 μℓ/ℓitre	0.2 μℓ/ℓitre	0.05 μℓ/ℓitre
Days in store			
172	50	40	5
236	50	55	15
277	90	60	30
321	95	80	55

* see text

production in 0.2 and 0.05 μℓ/ℓitre fruit appears similar. At the end of storage nearly all fruit in 1 and 0.2 μℓ/ℓitre and over half those in 0.05 μℓ/ℓitre had a high internal concentration and thus ethylene removal could be expected to be having little effect. "High internal concentration" refers to an internal level substantially greater than the cabinet atmosphere concentration (at least 0.1 μℓ/ℓitre greater for 0.05 and 0.2 μℓ/ℓitre fruit and at least 0.5 μℓ/ℓitre greater for 1 μℓ/ℓitre fruit).

When fruit was inspected for internal disorders at the end of storage, ethylene scrubbed fruit had less coreflush and flesh breakdown than unscrubbed control fruit but there was little difference between low ethylene treatments (Table 3).

Table 3. Effect of ethylene concentration in the storage atmosphere on coreflush and flesh breakdown at the end of storage

	Coreflush Index		Flesh breakdown index	
	On removal	+12 days at 18°C	On removal	+12 days at 18°C
Control	20.8	40	8	30.5
1.0 μℓ/ℓitre	10.5	21	4	11.5
0.2 μℓ/ℓitre	6.3	13.5	3.6	9.5
0.05 μℓ/ℓitre	11	16.5	4.5	8.5

Cessation of ethylene scrubbing

On transfer from scrubbed cabinets to unscrubbed drums ethylene concentrations increased to control fruit levels within 10 days. When fruit harvested in 1982 was transferred from scrubbed cabinets to drums after 172 days, scald development was found to be similar to continuously scrubbed fruit for a further 104 days (Fig. 5). There was little difference in scald incidence between unscrubbed fruit held continuously in cabinets and unscrubbed fruit transferred to drums; no scald was seen on fruit in 0.05 μℓ/ℓitre ethylene. Fruit transferred after 236 and 277 days and inspected after a further 90 or 50 days respectively also showed similar scald development to fruit held continuously in cabinets (data not presented). In the 1983/84 storage season fruit was inspected during storage after transfer at 69, 141 or 232 days. The effect of time in low ethylene storage on scald development is shown in Figure 6. No scald was visible on fruit from any treatment at 141 days. Subsequently low ethylene fruit transferred at 69 days showed similar scald development to control fruit, fruit that was scrubbed for 232 days developed similar levels of scald to continuously scrubbed fruit while fruit scrubbed for 141 days developed scald earlier than continuously scrubbed fruit. Flesh firmness of fruit transferred from scrubbed cabinets was similar at the end of storage (313 days) to fruit that was continuously scrubbed (Table 4). However control fruit transferred from cabinets was slightly firmer than fruit continuously stored in cabinets.

Table 4. Effect of period in ethylene scrubbed atmosphere on flesh firmness after 313 days in store

Days in store		Firmness (kg)	
Cabinet	Drum*	Scrubbed	Control
69	244	3.5	3.1
141	172	3.5	3.3
232	81	3.5	3.2
313	-	3.6	3.0

Firmness at harvest 3.9 kg
*Days in drum indicates period without ethylene removal after transfer from scrubbed atmosphere (scrubbed fruit)

Semi-commercial scale assessment of scald treatments

The ethylene concentration in the scrubbed store was maintained at less than 0.04 μℓ/ℓitre throughout 278 days storage (Fig. 7), except for a short period near the beginning of storage when the concentration was elevated by store atmosphere with a high ethylene concentration accidentally leaking from an adjacent room into the low ethylene store. In the unscrubbed store, ethylene increased to 1 μℓ/ℓitre in 40 days and continued to rise during storage to approximately 50 μℓ/ℓitre. After 233 days no symptoms of scald were visible on samples of fruit from either store. At the end of storage (278 days) scald had developed on 17% of fruit from the low ethylene store (index 5), no scald was visible on DPA treated fruit from the unscrubbed store. Fruit from the ethylene scrubbed store was firmer than the DPA treated fruit (Table 5) on removal from storage, and remained firmer after a further 7 and 14 days at 18°C. DPA treated fruit was slightly less yellow than low ethylene fruit (Hunter Colormeter 'b' value). When graded by a commercial packhouse (Table 6), fruit with visible symptoms of scald was either down-graded or sent for cider. Fruit in some bins from the low ethylene store was found to be more severely affected by scald than in other bins. It was also noted that in bins of scrubbed fruit rots were confined to individual fruits but in unscrubbed bins some rotting appeared to spread to adjacent fruits.

Table 5. Effect of ethylene removal on flesh firmness of Bramley apples stored in 9 tonne semi-commercial stores

	Firmness (kg)		
Treatment	Ex store (280 days)	+ 7 days at 18°C	+ 14 days at 18°C
Ethylene scrubbed	4.6	3.7	2.7
DPA (unscrubbed)	3.5	2.3	2.0

Firmness at harvest 4.6 kg

Table 6. Commercial grade-out of Bramley apples stored for 280 days in 9 tonne store

	Grade			Cider	Rots	Bitter pit
Treatment	I %	II %	III %	%	%	%
Ethylene scrubbed	51	25	11	7	3	3
DPA (unscrubbed)	61	23	1	5	5	5

Interaction of ethylene removal and harvest date

Storage in a low ethylene atmosphere provided little control of superficial scald particularly on fruit from the first and second picks (Table 7) and did not completely overcome the effect of harvest date. Scald on low ethylene fruits was light bronze in colour and on some fruit covered a large percentage of the skin surface. On control fruit the symptoms were mainly very dark sunken areas with some lighter patches. The α-farnesene concentration on the surface of control fruit was greater than on low ethylene fruit (e.g. 11.8 $\mu g/cm^2$ compared to 6.2 $\mu g/cm^2$ for pick 1), the oxidation products of α-farnesene were present in all samples. At the end of storage (24th July) the symptoms of scald on low ethylene fruit had developed to appear similar to those on the unscrubbed controls. It is clear from Table 8 that ethylene removal was still affecting flesh softening as low ethylene fruit was considerably firmer than control fruit. Ethylene concentrations had been slow to rise in the scrubbed cabinets containing fruit from the first two picks, taking 50 days to reach 0.05 µℓ/ℓitre and remaining generally below 0.2 µℓ/ℓitre.

Table 7. Effect of harvest date and ethylene removal on percentage fruit affected and severity index of superficial scald in Bramley apples stored until 3rd May

	Pick 1 (1st Sept)*		Pick 2 (15th Sept)*		Pick 3 (29th Sept)*	
	%	Index	%	Index	%	Index
Ethylene scrubbed	98	75	80	43	7.5	1.5
Control	100	84	100	64	75	17

*harvest date

Table 8. Effect of harvest date and ethylene removal on flesh firmness of Bramley apples stored until 24th July

	Firmness (kg)		
	Pick 1 (1st Sept)*	Pick 2 (15th Sept)*	Pick 3 (29th Sept)*
At harvest:	4.3	3.7	3.6
After storage:			
Ethylene scrubbed	3.9	3.5	3.0
Control	2.8	2.3	2.1

* harvest date

DISCUSSION

In the controlled ethylene concentration experiment, ethylene levels in all scrubbed cabinets were kept low initially, because it was felt that to establish the controlled levels at the beginning of storage may have allowed ethylene production rates to rise so that the control of ethylene would not have been possible, particularly for the fruit to be held at 1 µℓ/ℓitre. Indeed when the controlled concentrations were established the production rate of 1 µℓ/ℓitre fruit increased rapidly. It is not clear for that fruit how much the retention of flesh firmness and the reduction in scald were results of the initial period at low ethylene levels rather than because of subsequent storage at 1 µℓ/ℓitre. Although in the following season when fruit was transferred from low ethylene to unscrubbed atmosphere after 69 days, superficial scald symptoms developed at a similar rate to fruit stored continuously without ethylene removal. The effectiveness of scald control improved with reduced ethylene concentration and indicates that levels above 0.05 µℓ/ℓitre may result in unsatisfactory control. However a firmness benefit of storing at the higher concentrations was still evident. It seems that it may also be necessary to remove ethylene from the storage atmosphere for longer to control scald than to affect firmness. It is not surprising that ethylene removal was not required for the entire storage period when internal ethylene concentrations were high in increasing numbers of fruit. It would be interesting to see if, within a sample of low ethylene fruit, those with high internal concentrations were softer than fruit where ethylene production was still being controlled. Associated with reduced flesh softening in a low ethylene atmosphere was a smaller rise in soluble pectin which is consistent with previous findings for other apple varieties (1) and for Bramley's Seedling (6).

Although the fruit from the semi-commercial store fitted with an ethylene removal system was considerably firmer, the DPA treated fruit from the unscrubbed store was considered adequately firm, for a culinary variety, by the marketing organisation that monitored the grading of the fruit. Further the DPA treated fruit was preferred as scald had reduced the number of low ethylene fruit reaching grade 1, for which a lower incidence of bitter pit and rotting did not compensate. It is know that DPA reduces yellowing (12) and as no difference in green colour between low ethylene and ethoxyquin treated fruit was found by Dover (6) it is not likely that the low ethylene treatment enhanced yellowing in these fruit.

The poor control of scald by ethylene removal, on fruit from the harvest maturity experiment, occurred despite the maintainance of storage ethylene concentrations that would normally have been considered adequate. Because low ethylene levels were observed fruit inspection was delayed and it is not known when scald first developed. However, the severity of the disorder and the presence of the oxidation products of α-farnesene indicate an early appearance. The α-farnesene concentration on the skin of the low ethylene fruit was not excessive at 6.2 $\mu g/cm^2$, as 5 $\mu g/cm^2$ was measured on fruit stored at 0.05 $\mu \ell / \ell$itre after a similar storage period when no scald was visible. However as α-farnesene concentrations are known to decrease later in storage (13) when oxidation is taking place, earlier concentrations may have been higher. Thus it is possible that low ethylene storage did not control scald in this case because it did not sufficiently reduce α-farnesene production. It is interesting to note that the 1983 growing season was hot and dry which is known to increase the risk of scald (14). Although there is no evidence to suggest a rootstock effect on scald much of the previous work on ethylene removal to control scald on Bramley apples has used fruit from trees on more vigorous rootstocks, thus the possibility that scald may be more difficult to control with low ethylene in fruit from the more dwarfing rootstocks such as M.9 should not be ignored. The large effect of ethylene removal on flesh firmness in fruit from all picks does suggest that other developmental processes were affected and thus the fruit did not appear abnormally responsive to ethylene.

CONCLUSIONS

It would appear that for Bramley's Seedling the control of scald and the reduction in flesh softening by ethylene removal are affected by largely separate processes. A shorter period of time in a low ethylene atmosphere is required to reduced softening than to control superficial scald. Further, lower ethylene concentrations are required for scald control than for firmness retention. It is evident that factors other than ethylene concentration can determine the rate of development of superficial scald so that severe symptoms may develop despite low ethylene concentrations in the storage atmosphere. Until the factors are identified and their effects managed low ethylene storage cannot be considered a reliable alternative to the use of post-harvest antioxidants for the control of superficial scald on Bramley's Seedling. The use of ethylene removal to produce firmer fruit after storage can only be justified if a sufficient premium to cover the cost of the treatment is attracted which, because Bramley's Seedling is a culinary variety, may only occur if other fruit has softened to an unacceptable level.

ACKNOWLEDGEMENTS

Thanks are due to Dr. M. Knee for many helpful discussions and to Mr. L.E. Sharp and Miss J. Coppins for technical assistance. The author is also indebted to Mr. R. Savage of N.F.T. Brogdale for his help in running the semi-commercial trial.

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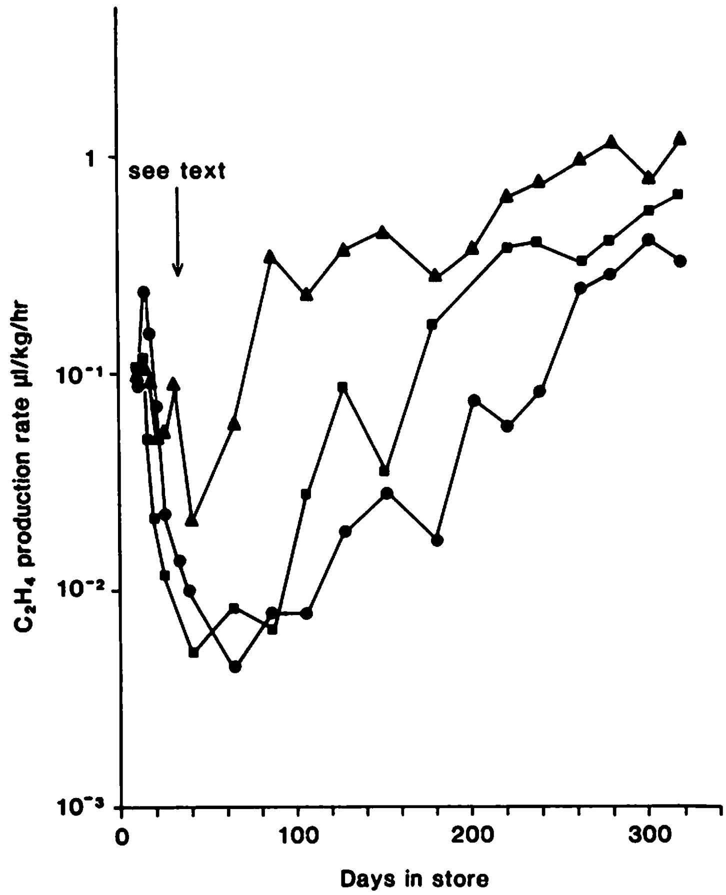

Fig. 1. Log ethylene production rate for various storage atmosphere concentrations. ● 0.05 µl/litre, ■ 0.2 µl/litre, ▲ 1.0 µl/litre.

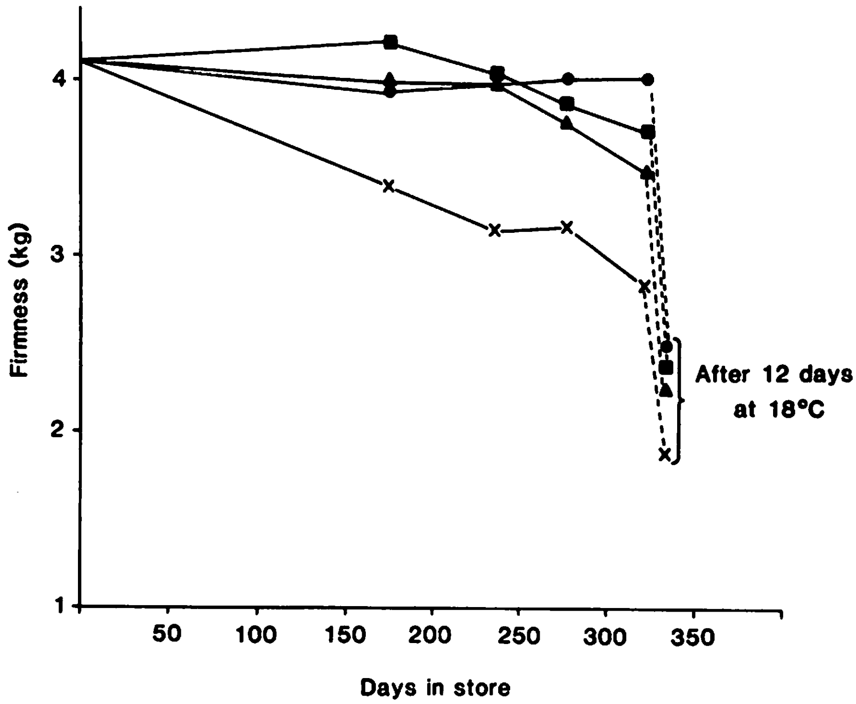

Fig. 2. Effect of ethylene concentration in storage atmosphere on the decline in flesh firmness. ● 0.05 μl/litre, ■ 0.2 μl/litre, ▲ 1.0 μl/litre, x Control (unscrubbed). —— firmness on removal from store, ----decline in firmness when fruit held at 18°C (12 days)

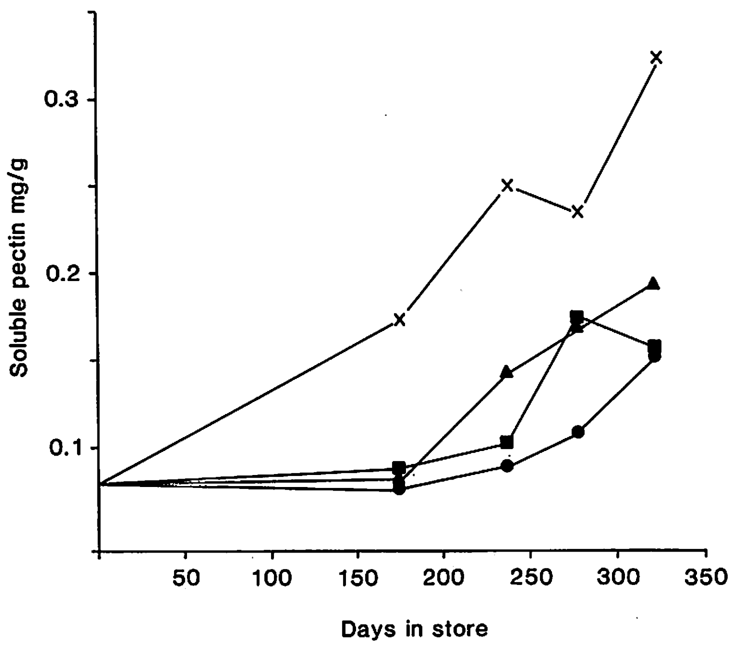

Fig. 3. Effect of ethylene concentration in storage atmosphere on increase in soluble pectin. ● 0.05 μl/litre, ■ 0.2 μl/litre, ▲ 1.0 μl/litre, x Control (unscrubbed).

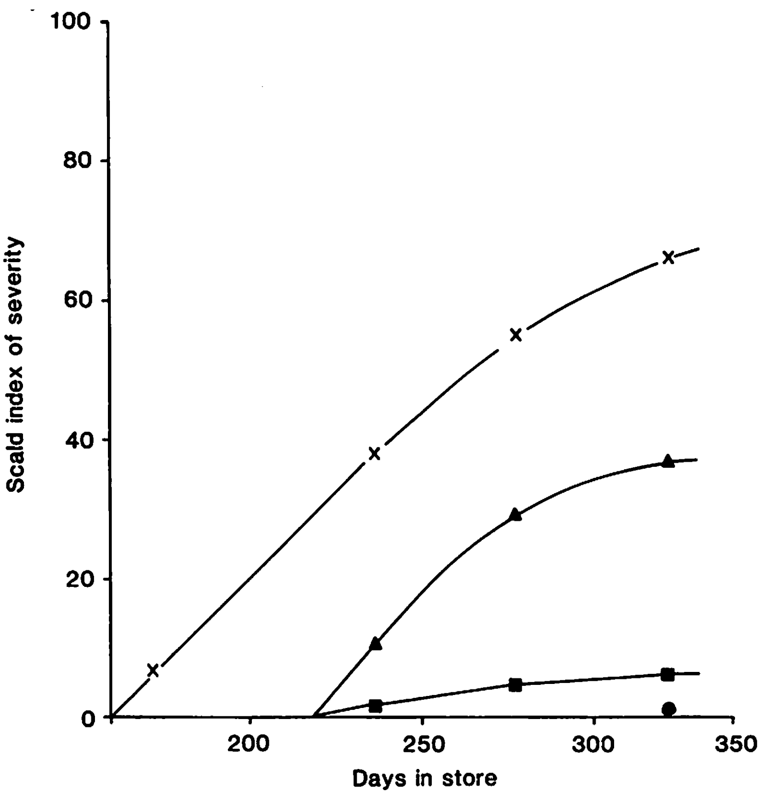

Fig. 4. Effect of ethylene concentration in storage atmosphere on the incidence of superficial scald as measured by an index of severity. ● 0.05 µl/litre, ■ 0.2 µl/litre, ▲ 1.0 µl/litre, x Control (unscrubbed).

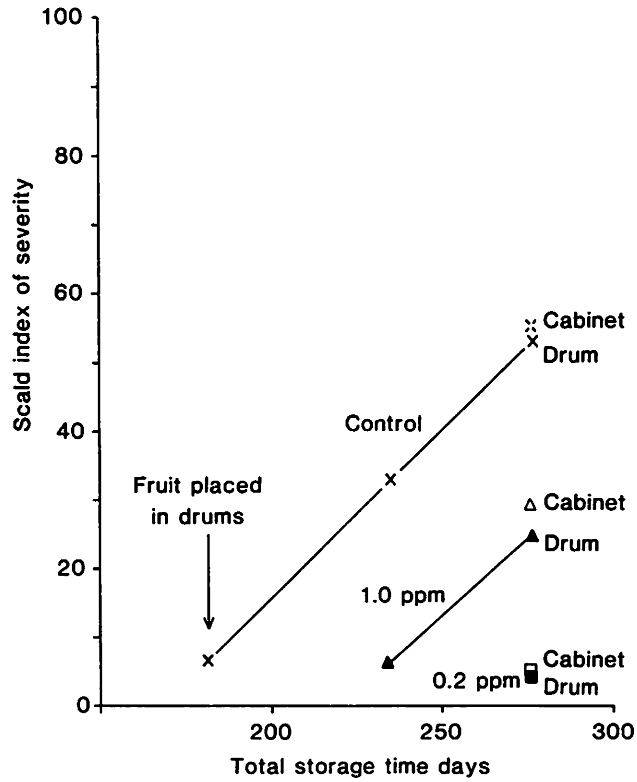

Fig. 5. Effect of ceasing ethylene removal on subsequent development of superficial scald as measured by an index of severity. Storage atmosphere ethylene concentration before transfer to drums. ■ 0.2 µl/litre, ▲ 1.0 µl/litre, x Control (unscrubbed). Incidence of scald in cabinet stored fruit. □ 0.2 µl/litre, △ 1.0 µl/litre, ⁙ Control.

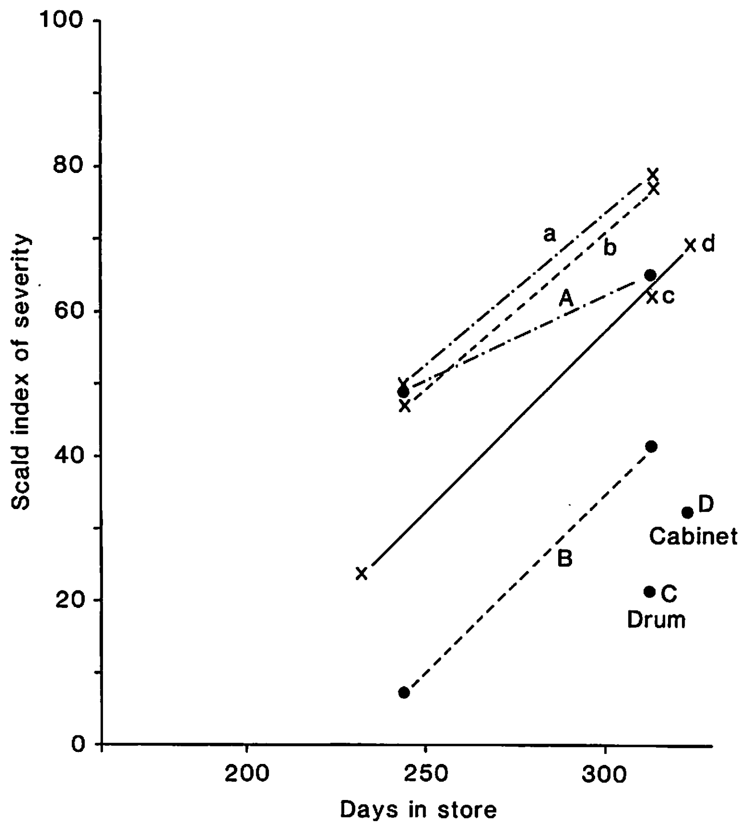

Fig. 6. Effect of period in ethylene scrubbed atmosphere on subsequent development of superficial scald as measured by an index of severity. ● Scrubbed, x Control (unscrubbed). Period in low ethylene atmosphere. A, 69 days, B, 141 days, C, 232 days, D, continuous.

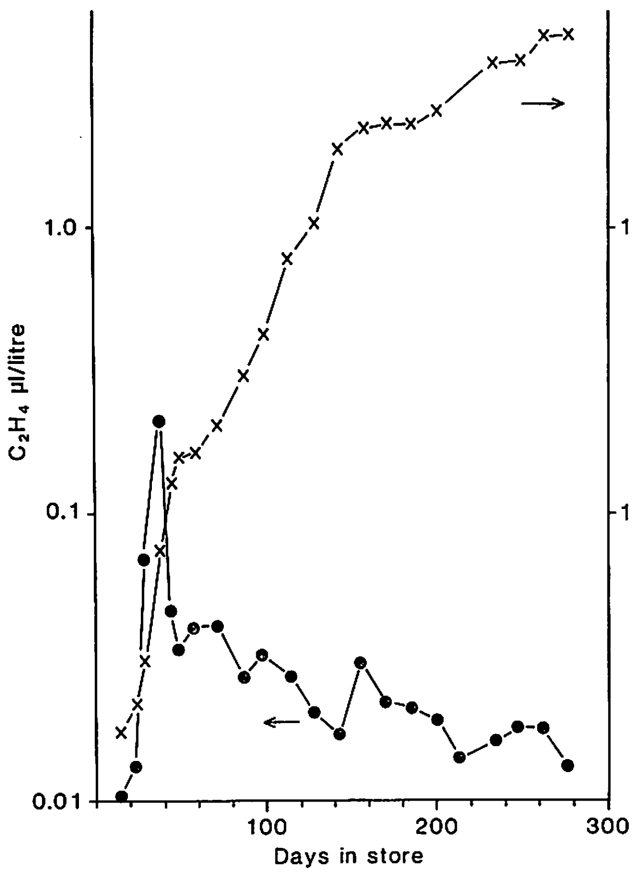

Fig. 7. Log concentration of ethylene in the storage atmosphere of 9 tonne semi-commercial stores. ● Ethylene scrubbed store, x DPA (unscrubbed) store.

The summaries of controlled atmosphere conditions for the various commodities are meant to be used only as general guidelines, not as recommendations. Local growing conditions can affect the response of a commodity to controlled atmospheres. The summaries represent the scope of CA conditions that have been used around the world.