Combining Controlled Atmosphere Storage and Ethanol Vapors to Control Superficial Scald of Apple

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Abstract. The effects of ethanol vapors, controlled atmosphere (CA) storage, and a combination of both on superficial scald development on 'Granny Smith' apples (*Malus × domestica* Borkh.) are reported. The major result was that ethanol vapors, applied in cold storage, prevented scald development over a week at 20 °C in apples that had been CA-stored for 4 months, then left for 1 month in cold air storage. Interrupting CA storage aimed to reproduce industry practices when fruit in part of storage rooms has to be sold and the remaining fruit is held in air for later sale. The estimated cost and further development of this method are discussed.

Diphenylamine (DPA) and ethoxyquin treatments to alleviate superficial scald are not permitted by certain importing countries. Ethanol vapor treatment on 'Granny Smith' apples has shown promising results in reducing scald (Ghahramani and Scott, 1998; Scott et al., 1995, Wang and Dilley, 1996). Controlled atmosphere (CA) storage can also reduce scald (Chen et al., 1985; Little et al., 1982), and initial low O₂ storage may reduce scald, partly through stimulation of ethanol production by the fruit (Little et al., 1982; Wang and Dilley, 2000). Here we report the combined effects of ethanol and CA (2 kPa O₂ + 1 kPa CO₂). The gas levels in CA are close to industry standards.

Materials and Methods

Fruit was picked early in the season (6 Oct. 1999) from a local orchard (Montauban, in southwestern France). Fruit diameter was >80 mm, with firmness at 69 N and starch index at 3 on a 10-point scale, where 1 = 100% starch and 10 = 0% starch. Fruit was cooled overnight and kept at 1 °C for a week before being exposed to ethanol vapors. The experiment was run in 660-L cabinets, which were flushed

with air or N₂ to control the atmosphere when necessary. Eight boxes (12 kg of fruit/box) were placed in each of four cabinets in a cold room held at 1 °C, and the following treatments were applied: air (control); air + ethanol; CA; and CA + ethanol. Ethanol vapors (8 g·kg⁻¹ of fruit) were delivered by placing trays containing ethanol-soaked vermiculite among the fruit to control evaporation as described by Scott et al. (1995). We used this amount because the cabinet headspace was larger (≈85% of total volume) than that in the bags used in previous experiments (≈60% of total volume), in which 3 g·kg⁻¹ gave good scald control (Ghahramani and Scott, 1998). To avoid loss of ethanol during CA, ethanol was applied by remote opening of the lid of the tray of vermiculite after the initial N₂ flush. The headspace ethanol concentration was measured with a Dräger pump (model "Accuro"; Lübeck, Germany), using Dräger tubes (ref. "alcohol 25/a"). Ethanol concentration, averaged for both cabinets, reached 300 ± 100 µL·L⁻¹ in the headspace within the first week of treatment and then declined linearly to 50 µL·L⁻¹ over 8 weeks. Two boxes of fruit per treatment were withdrawn after each storage period, and the

apples were placed at 20 °C for 7 d to allow scald to develop. Scald severity was rated using three replicates of 15 fruit, each randomly chosen from each set of two boxes, and a 4-point scale described previously (Watkins et al., 1995). Two-way ANOVA was performed on ethanol and atmosphere data for each storage time (SigmaStat 2.0; SPSS, Chicago).

Results and Discussion

Ethanol alone had little effect in controlling scald (Table 1). A concentration of 300 µL·L⁻¹ of ethanol in the headspace may not be sufficient, as Wang and Dilley (1996) found that 1000 µL·L⁻¹ was required for effective scald control on 'Law Rome' apples.

The CA treatment controlled scald (Table 1), limiting our ability to detect an additive effect between ethanol and CA. Therefore, all CA treatments were concluded after 4 months of storage, and fruit was stored in air for an additional month, as may occur in industry when fruit in part of a storage room has to be sold and the remaining fruit is held in air for later sale. After 5 months of storage, CA fruit developed scald on up to 10% of their surface, the score averaging 1.33 (Table 1). This corresponded to only 5% saleable fruit, according to a commercial scoring system similar to scald incidence scores (Westercamp et al., 2000). Fruit that had been treated with CA + ethanol developed only traces of scald (Table 1), corresponding to 99% saleable fruit (Westercamp et al., 2000), and the interaction between CA and ethanol was significant ($P \leq 0.001$) after 5 months of storage (Table 1). It was already significant after 3 months of storage ($P \leq 0.05$); however, the strong protective effect of CA masked the ethanol effect.

Based on the French price of ethanol without taxes, i.e., equivalent to U.S.\$0.70/L (personal communication with a distillery director), the cost to treat 10 kg of apples under our conditions would be U.S.\$0.07. In France, the average cost of DPA treatment (including depreciation of drenching equipment) is equivalent to U.S.\$0.05 per 10 kg of apples. So both costs are of the same order, and we expect that the amount of ethanol used can be reduced in practice, where the headspace is typically less (70% compared with 85% in our experiments). Further work is necessary to determine the optimum ethanol treatment; we may have used more than required, as no scald occurred in the best combination treatment.

Table 1. Superficial scald development in 'Granny Smith' apples as a function of four storage regimes at 1 °C, followed by 1 week at 20 °C. Scores for scald were: 0 = 0%; 1 = 1% to 10%; 2 = 11% to 33%; 3 = 34% to 66%; and 4 = 67% to 100%. Controlled atmosphere (CA) was ended after 4 months and fruit were transferred to air for an additional month. Results represent means for three replicates of 15 fruit each.

Storage time (months)	Score for scald				Interaction CA × ethanol
	Air	Air + ethanol	CA	CA + ethanol	
3	2.25 a ^z	1.68 b	0.03 c	0.03 c	*
4	2.05 a	2.03 a	0.00 b	0.00 b	NS
5	2.47 a	2.30 b	1.33 c	0.03 d	***

^zMean separation within rows by Tukey's test, $P \leq 0.05$.

NS, *, *** Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

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Possible advantages of the ethanol treatment would be that it: does not corrode metallic parts; could be used in organic production; requires no additional handling or drenching; and results in fewer problems with rotting due to contaminated drenching mixes, and with disposal of these mixes. Possible disadvantages would be: taxes; fire hazard (ethanol is flammable above 3.5% in air above 13 °C); conversion of red pigments in apple to a purple/brown at high doses, although this may be reversible (R. Holmes, personal communication); off-flavor at high doses; and prohibited use of ethanol on food in some countries. Adding a denaturant could avoid the taxes applied to ethanol used in beverages (K. Scott,

personal communication). Use of initial low O₂ stress (Little et al., 1982; Wang and Dilley, 2000) may be more economical than ethanol vapor treatment for storage operations having adequate O₂ control.

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