ENHANCING RED COLOR DEVELOPMENT WITHOUT OVER-RIPENING APPLES BY RETAIN™ FOLLOWED BY ETHEPHON TREATMENT

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Abstract: ***1999 Results:*** ReTain™ applied alone to 'Gala', 'Jonagold' and 'Empire' apples delayed maturity and the onset of the ethylene climacteric and delayed red color development. ReTain™ followed by ethephon delayed maturity and the onset of the ethylene climacteric *but* promoted red color development of both 'Gala' and 'Jonagold' when evaluated even a week before the commercial harvest date. Similar results were obtained with 'Empire'. Ethephon applied alone advanced maturity and stimulated ethylene production, ripening and red color development compared to ReTain™ alone. Color enhancement with ReTain™ plus ethephon in 1999 was better than in 1997 and 1998 and we attribute this to less environmental stress on the trees and to the higher rate of ethephon used in 1999. In the 1997 studies, the ripening-related effects of these treatments were reflected in the storability of fruit in CA storage. ReTain™ - and ReTain™ plus ethephon-treated fruit were still at preclimacteric ethylene levels after 6 mos. in CA storage with excellent retention of flesh firmness and shelf-life while ethephon and control fruits had significantly higher ethylene levels and softened more during storage and shelf-life evaluation. We anticipate similar treatment-related responses for fruits from the 1999 CA storage studies now in progress.

Collectively, our results indicate that an ethephon application following ReTain™ treatment may be useful to overcome the delay of red color development of apples treated with ReTain™ only and that this can be achieved without overly stimulating fruit ripening. Thus, a once-over harvest of 'Gala' and 'Jonagold' apples may be achieved with a significant reduction in harvest costs. We attribute the promotion of red color development of apples receiving ReTain™ treatment with a follow-up application of ethephon to the action of ethylene temporally-released from ethephon stimulating the development of the anthocyanin biosynthetic pathway while ReTain™ inhibits the development of the endogenous ethylene climacteric. Inhibiting endogenous ethylene production delays fruit from producing their own ethylene. We attribute maturation uniformity to the action of ReTain™ allowing the less mature fruits to gain maturity while slowing maturity development of the more mature fruits. Improved storability of ReTain™ plus ethephon-treated fruit is attributed to the same ethylene-related phenomena.

The Problem and Rationale for Experimentation: Multiple harvests are often necessary to achieve maximum yield of well colored 'Gala' and 'Jonagold' apples. Red color development can be improved and preharvest fruit abscission delayed by using NAA but this stimulates ethylene production and ripening. Ethephon, an ethylene-releasing chemical, can be used to improve red color development but this too stimulates fruit to produce ethylene and ripen. ReTain™ (aminoethoxyvinylglycine[AVG]), an inhibitor of ethylene production, delays maturity and fruit abscission but also delays red color development. *We tested our hypothesis that red color development of ReTain™-treated apples may be enhanced by a follow-up application of ethephon by ethylene action inducing the anthocyanin biosynthetic pathway without overly stimulating other ripening processes.*

Methods: Our experiments were conducted with 'Gala', 'Empire' and 'Jonagold' apples at the MSU CHES in 1997, 1998 and 1999. Treatments were:1) ReTain™ (50 gai/ac.) applied about 1 mo. prior to harvest; 2) ReTain™ followed by ethephon (86 gai/ac.in 1997 and 1998 and 114 gai/ac. in 1999) applied 1 to 2 wks. prior to harvest; 3) ethephon and 4) control (surfactant [Silwet^{R} L-77]only at 0.1%v/v). Three to 5 rootstock/training systems were used as replicates. Thirty fruits per treatment/replicate were harvested at 3-5-day intervals beginning 2 to 3 wks. prior to the estimated harvest commercial date. Samples (1 bu.) were also taken for evaluation of treatment effects following CA storage. Maturity parameters evaluated at harvest and after 1 wk. at 20°C included: red color, internal ethylene, flesh firmness, starch index and Brix (soluble solids). The results to-date for 1999 for 'Gala' and 'Jonagold' are summarized herein and confirm and extend our 1997 and 1998 results (Wang and Dilley, Proc. Mich. State Hort. Soc. 128:667-77).

Results: 1999 studies: 'Gala', 'Empire' and 'Jonagold' trees received ReTain™ or surfactant treatments on Aug. 5, Aug. 23 and Aug. 23, respectively. Ethephon or surfactant treatments were applied on Aug. 23 , Sept. 8 and Sept. 8, respectively. ReTain™ treatment, with or without a follow-up application of ethephon, clearly delayed the onset of the ethylene climacteric of 'Gala' as measured at harvest and after holding the fruits in air at 20C for 7 days (Fig. 1) and Table 1. No significant differences were observes between the ethephon-treated and control fruits (Table 1) which both entered the climacteric by the August 30 harvest date whereas the ReTain™ +/- ethephon treated fruits climacteric commenced about 10 days later. ReTain™ applied alone clearly delayed red color development compared to the control and ethephon-only treatments while ReTain™ + ethephon-treated fruits were intermediate in color development (Fig. 2 and Table 1). By the Sept. 9 harvest date, red color development was similar for fruits from all treatments at about 70-80 percent. Color development continued for fruits from all treatments while holding them in the dark at 20C for 7 days. Flesh firmness values at harvest were similar for fruits from all treatments (data not shown). But, after holding the fruits in air at 20C for 7 days, firmness values of the ReTain™ +/- ethephon fruits were similar and 5N firmer than the control and ethephon-only fruits (Fig. 2). Although the differences are not great, this separation of treatments with ReTain from the control and ethephon-only fruits is apparent. Starch conversion at harvest was clearly delayed in fruits from the ReTain™ +/- ethephon-only compared to control and ethephon-treated fruits (Fig. 3) and this delay persisted during 7 days in air at 20C. Brix values after holding the fruits for 7 days at 20C tracked closely with the treatment effects noted for starch index with the same parallel trends (Fig. 3). Brix values for ReTain™ +/- ethephon fruits were 0.8 % lower *per se* than the control and ethephon-treated fruits harvested August 25. This gap tended to narrow with the later harvest dates.

The onset of the ethylene climacteric of 'Jonagolds' treated with ReTain™ +/- ethephon was significantly delayed in fruits at harvest and this delay persisted after holding them in air at 20C for 7 days (Fig. 1 and Table 1). Ethephon stimulated the onset of the ethylene climacteric to begin before the first harvest that was made on Sept. 10, 1999. The control fruits climacteric onset was evident for fruits harvested on Sept. 20. ReTain™-only delayed and ReTain™ +ethephon enhanced red color development similar to that of the control and ethephon-only treatment (Fig.2 and Table 1). More importantly, ethephon applied to ReTain™-treated fruits stimulated red color development without inducing the

ethylene climacteric (Fig.1 and Table 1). ReTain™ +ethephon-treated fruits harvested on Sept. 20 were nearly as well colored as the fruits from the ethephon-only treatment and their color was similar to that of the control fruits. Flesh firmness of the ethephon-only treated fruits was lower than that of fruits from all other treatments (Fig. 2 and Table1). No significant differences were evident for the other maturity-linked development parameters (starch index and Brix values) measured (Table 1), between the control and ReTain™ + ethephon treatments and the values for these parameters generally fell between those for the ethephon treatment and the ReTain™-only treatment (Fig. 3). This was most notable for Brix values (Fig. 3) which can be largely explained by ethephon stimulating starch conversion and by ReTain™ delaying this process as a direct consequence of enhancing or delaying the ethylene-induced stimulation of respiratory metabolism, respectively.

Discussion: In the 1997 studies, the ripening-related effects of the treatments were reflected in the storability of fruit in CA storage. ReTain™ - and ReTain™ + ethephon-treated fruit were still at preclimacteric ethylene levels after 6 mos. in CA storage with excellent retention of flesh firmness and shelf-life while ethephon and control fruits had significantly higher ethylene levels and softened more during storage and shelf-life evaluation (Wang and Dilley 1999). We anticipate similar treatment-related responses for fruits from the 1999 CA storage studies now in progress.

Collectively, our results indicate that an ethephon application following ReTain™ treatment may be useful to overcome the delay of red color development of apples treated with ReTain™ only and that this can be achieved without overly stimulating fruit ripening. Thus, a once-over harvest of 'Gala' and 'Jonagold' apples may be achieved with a significant reduction in harvest costs.

We attribute the promotion of red color development of apples receiving ReTain™ treatment with a follow-up application of ethephon to the action of ethylene temporally-released from ethephon stimulating the development of the anthocyanin biosynthetic pathway while ReTain™ inhibits the development of the endogenous ethylene climacteric. Inhibiting endogenous ethylene production delays fruit from producing their own ethylene. We attribute maturation uniformity to the action of ReTain™ allowing the less mature fruits to gain maturity while slowing maturity development of the more mature fruits. Improved storability of ReTain™ plus ethephon-treated fruit is attributed to the same ethylene-related phenomena.

The results from our 1999 experiment largely confirm those we obtained in the 1997 and 1998 experiments conducted in a similar manner in the same research plot. The experimental design for these experiments used at least three different rootstocks for each of three cultivars and several training systems and with different tree spacings for each replication. Using this entrained background of built-in variability among the trees in the research plot used to assess treatment effects, our results have been very similar in three very different growing season environments. The 1997 growing season was hot and dry and the trees did not receive supplemental irrigation. In 1998, the season was hot but the trees were irrigated as needed. In 1999, the season was cool and rainfall was ample. Moreover, in 1997 and 1998 ethephon was applied at 84 g ai/A and, in 1999 at 114 g ai/A at two weeks before the predicted optimum maturity for each cultivar to trees that received an application of ReTain™ at a rate of 50 g ai/A four weeks earlier. This directly addresses the question of the generality of a predictable response from using these plant growth regulators in combination in a strategy to improve red color development of apples while not overly-stimulating fruit ripening. Thus, using this strategy may allow apple producers to derive the favorable attributes of each chemical while minimizing less favorable attributes when these are used alone (eg., ripening enhancement with ethephon used alone and color development delay with ReTain™ used alone). Commercial trials employing a staggered ReTain™/ethephon application schedule with several cultivars have given similar results in Washington (Anne Swindeman, Yakima, WA, personal communication).

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Literature cited:

Wang, Z. and Dilley, D.R. 1999. Enhancing anthocyanin production and maturity uniformity of apples without over-ripening. Proc. Mich. State Hort. Soc. 128:67-77.

Table 1. Statistically significant differences on the effect of ReTain™ at the commercial harvest date on internal ethylene, red color, flesh firmness, starch index and Brix values of Gala and Jonagold apples at harvest (0d) and/or plus 7 days (7d) at 20°C [z].

1999	95% LSD					
Cultivars	Treatment	Internal ethylene		Red color	Flesh firmness	Starch index	Brix value
		0d	7d	0d	7d	0d	7d
Gala	ReTain™	a	a	a	ab	a	a
	ReTain™+Eth	a	a	b	b	ab	ab
	Ethephon	c	b	c	a	c	ab
	Control	b	b	c	ab	bc	b
Jonagold	ReTain™	a	a	a	b	a	a
	ReTain™+Eth	a	a	b	b	a	a
	Ethephon	b	b	b	a	a	a
	Control	ab	b	b	ab	a	a

[z] Within columns and cultivars different letters indicate significant differences at p 0.05.

Fig. 1. Effect of ReTain™ +/- ethephon on internal ethylene of Gala and Jonagold apples. The bars indicate the standard error. Internal ethylene was measured for10 individual fruit randomly selected from each replicate of each treatment at harvest and also after 7 days at 20°C. In 1999, ReTain (50 g ai/A) plus 0.01% X-77 surfactant was applied about 5 weeks prior to the commercial harvest date and ethephon (114 g ai/A) plus 0.01% X-77 surfactant was applied about 2 weeks prior to the commercial harvest date while the control received surfactant only.

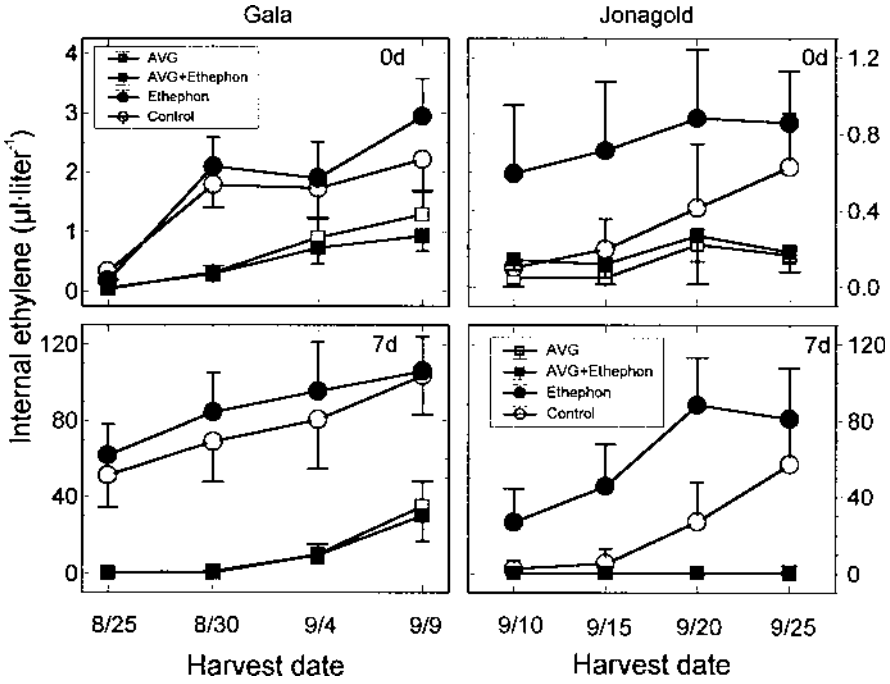

Fig. 2. Effect of ReTain™ +/- ethephon on red color and flesh firmness of Gala and Jonagold apples. The bars indicate the standard error. Red color and flesh firmness were measured for 10 individual fruit randomly selected from each replicate of each treatment at harvest (red color) or after 7 days at 20°C (flesh firmness). The treatments are the same as in Fig. 1.

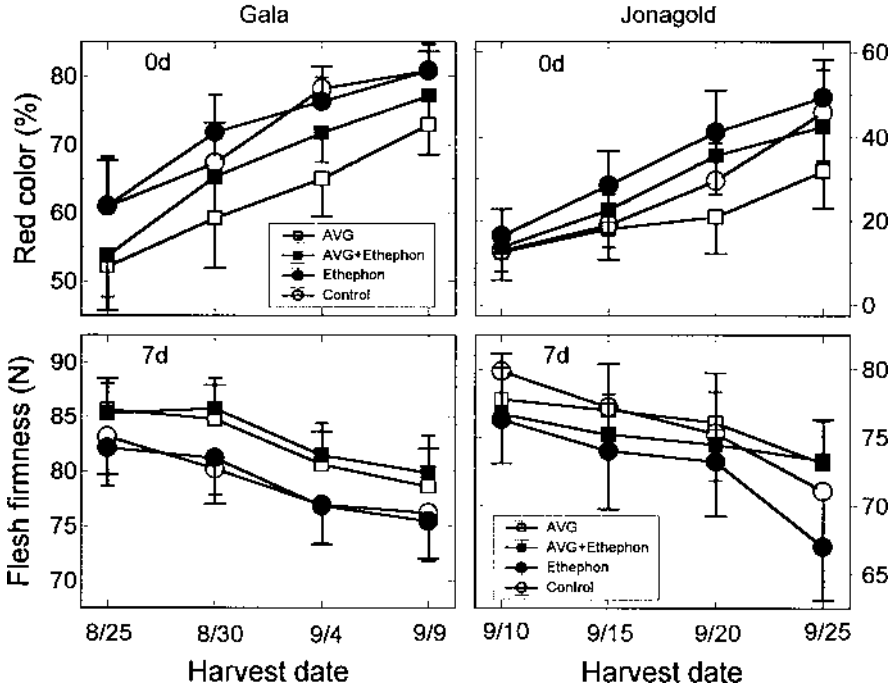

Fig. 3. Effect of ReTain™ +/- ethephon on starch index and Brix values of Gala and Jonagold apples. The bars indicate the standard error. Starch index and Brix values were measured for 10 individual fruit randomly selected from each replicate of each treatment at harvest (starch index) or after 7 days at 20°C (Brix). The treatments are the same as in Fig. 1.