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Organic Aminoethoxyvinylglycine Is an Effective Alternative for Reducing Apple Preharvest Drop

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Abstract. **Organic apple (*Malus* ×*domestica* Borkh.) growers lack effective strategies to manage preharvest drop. For susceptible cultivars, yield losses caused by preharvest drop can exceed 30% at the beginning of harvest. To address this issue, a formulation of aminoethoxyvinylglyine (AVG) designed for organic use was developed and compared with a commercially available AVG formulation. We evaluated the effects and interactions of the AVG formulation and application number on preharvest drop and fruit maturity in 2017 and 2018. We selected 30 pairs of mature 'Oregon Spur II Red Delicious'/'M. 111' trees planted at the Mountain Horticultural Crops Research and Extension Center in Mills River, NC, USA. Trees were planted with spacing of 2.7 × 6.1 m, trained to a central leader, and received plant protectant sprays that adhered to local recommendations throughout the growing season. Both AVG formulations were applied at 132 mg·L^{-1} at 3 or 3 + 1 weeks before the anticipated harvest. An untreated control was also included for comparison. The experiment had six replicates and a randomized complete block design with a 2 × 2 augmented factorial treatment structure. A one-way analysis of variance was performed and single degree of freedom contrasts were used to compare treatment groups of interest. During both years, organic and conventional AVG were equally effective for reducing preharvest drop and delaying fruit softening and starch hydrolysis at harvest. During one year, increasing the number of applications of AVG reduced cumulative fruit drop, delayed fruit softening at harvest, and reduced internal ethylene concentrations. Inconsistencies in responses across years may be explained, in part, by abnormally warm temperatures observed in 2018. AVG approved for organic use appears to be a promising preharvest drop management technology with efficacy similar to that of conventional AVG.**

Preharvest drop, the abscission of fruit before horticultural maturity, is an economically important production challenge for apple (*Malus* ×*domestica* Borkh.) growers because >30% yield loss can be observed at the beginning of harvest (Marini et al. 1993; Unrath et al. 2009). In addition to the selection of cultivars that do not exhibit preharvest drop and minimization of plant stress proximal to harvest, the use of plant growth regulators (PGRs) is the only management strategy available. Multiple commercially important apple cultivars are prone to preharvest drop, including 'Golden Delicious', 'Honeycrisp', 'McIntosh', 'Rome', and 'Red Delicious'. Fortunately, multiple PGRs for managing preharvest drop are commercially available.

For more than 80 years, the synthetic auxin, naphthaleneacetic acid (NAA), has been known to reduce preharvest drop of apple (Batjer and Martin 1945). NAA suppresses cellulase and polygalacturonase genes in the fruit abscission zone, which are associated with cell wall degradation (Li and Yuan 2008). NAA can be applied just before preharvest drop, is fast-acting, and can delay the onset for preharvest drop for 7 to 14 d, depending on the application pattern (Marini et al. 1993). However, NAA increases ethylene production (Li and Yuan 2008) and enhances fruit ripening and softening, particularly when applied with warm temperatures (Smock and Gross 1947), which may be unacceptable for fruit intended for long-term storage.

Aminoethoxyvinylglycine (AVG) is an ethylene biosynthesis inhibitor that was discovered in the 1970s (Boller et al. 1979). Although identified as a promising PGR for apple preharvest drop management (Bangerth 1978), product development was limited because of the widespread adoption of daminozide (Greene 2010). After the registration of daminozide was withdrawn in 1989, there was renewed interest in the development of PGRs to manage preharvest drop. AVG was registered in 1997 by Abbott Laboratories (ReTain®; Valent Biosciences, Libertyville, IL, USA). AVG responses are dose-dependent, and high rates of use can dramatically delay the timing of harvest (Schupp and Greene 2004). Starting in 2016, higher rates of AVG (up to 264 mg·L^{-1}) were included on the product label. AVG can be used on cultivars that are not prone to preharvest drop to extend and/or stagger the harvest period for labor management. In addition to reducing preharvest fruit drop, AVG delays the process of fruit maturation, including red color development.

The ethylene action inhibitor 1-methylcyclopropene (1-MCP) is widely used as a postharvest treatment for numerous horticultural commodities, including apples (Blankenship and Dole 2003). Ethylene perception is inhibited as 1-MCP irreversibly binds to ethylene binding sites, which delays fruit ripening. A sprayable formulation of 1-MCP was developed and registered in 2014 (Harvista™; AgroFresh Inc., Philadelphia, PA, USA). Fruit quality parameters, such as the starch pattern index, are used to determine application timing. Modified application equipment is required for sprayable 1-MCP because premature mixing with water can result in poor efficacy. Sprayable 1-MCP can delay fruit maturation, reduce preharvest drop, and extend the harvest period (Elfving et al. 2007; Yuan and Li 2008).

Arseneault and Cline (2016) summarized the results of 28 experiments that focused on apple preharvest drop management with PGRs. In general, NAA was inconsistent for managing preharvest drop and reduced fruit firmness during four of nine experiments. AVG consistently reduced preharvest drop and delayed the onset of maturity, although responses were impacted by rate and timing. The preharvest application of 1-MCP was also effective for managing preharvest drop and fruit maturity, although the number of published experiments was not as robust as those involving NAA and AVG. During some studies, superior preharvest drop control was reported when NAA was combined with AVG or preharvest 1-MCP (Yuan and Carbaugh 2007; Yuan and Li 2008); however, others did not observe an enhanced effect (Arseneault and Cline 2016; Robinson et al. 2010). PGRs have been valuable management tools for conventional apple production; however, PGR-mediated management of preharvest drop for organic apple producers has remained unavailable.

In the United States, more than 11,000 ha of apples are certified organic (Granatstein and Kirby 2020). The state of Washington accounts for 93% of the reported organic fresh volume in the country and 88% of the reported organic production area (Granatstein and Kirby 2019). Demand for fresh apples has increased, and consumer trends have simultaneously placed

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a premium on producing organic fruit. To adjust to the shift in consumer trends, the total acreage dedicated to organic tree fruit increased by 15% between 2018 and 2019 in Washington, with certified organic apples representing 18% of all apple hectares in the state (Granatstein and Kirby 2020).

With the increased organic production in major markets, an organically approved formulation of AVG was developed (ReTain® OL; Valent Biosciences). A 2-year study was conducted to compare the efficacy of a commercially available formulation of AVG (ReTain®) to that of an unregistered, organic formulation. Specifically, we evaluated effects and interactions of AVG formulation and application number on preharvest drop and fruit maturity. We hypothesized that there would be no difference between AVG formulations, and that increased application numbers would delay the onset of preharvest drop and fruit maturity.

Materials and Methods

Experiments involving mature 'Oregon Spur II Red Delicious'/'M. 111' trees planted at the Mountain Horticultural Crops Research and Extension Center in Mills River, NC, USA (lat. 35.428079°N, long. 82.563295°W, elevation 649 m), were conducted in 2017 and 2018. Trees were planted in 1992 with spacing of 2.7 × 6.1 m, trained to a central leader, and received plant protectant sprays that adhered to local recommendations throughout the growing season. The orchard was managed with conventional pesticide and fertilizer inputs. Two-tree plots were separated from adjacent plots by at least one buffer tree. Treatments were assigned in a randomized complete block design with six replications. Trees were blocked by crop density. Within each two-tree plot, one tree was designated for fruit drop counts and the other was designated for fruit sampling and subsequent quality assessments.

AVG formulated as ReTain® or ReTain® OL was applied at 132 $mg{\cdot}L^{-1}$. The formulations were applied during both years at 3 weeks before harvest (WBH) or 3 + 1 WBH. Treatments were applied on 16 Aug and 28 Aug in 2017, and on 15 Aug and 31 Aug in 2018. Two-tree plots served as an untreated controls in each block. Treatments were applied to two-tree plots using a tractor-mounted, PTO-driven air blast sprayer calibrated to apply 935 $L{\cdot}ha^{-1}$. All chemical treatments were applied in an aqueous solution with 0.1% (volume/volume) organosilicone surfactant.

Fruit drop counts were initiated at least 1 week before the anticipated harvest date for 'Red Delicious' and continued for a total of 7 weeks. Every week, the number of abscised fruit were counted and discarded on one tree per plot. Immediately after the final fruit drop count was conducted, all persisting fruit were harvested and counted. Cumulative fruit drop was calculated for each week.

Starting at the anticipated week of harvest (0 WAH), 12 fruit samples were collected from each tree designated for fruit quality evaluations. Fruit quality was evaluated weekly until 5 WAH. To determine the internal ethylene concentration (IEC), 1-mL gas samples from the core cavity were injected into a gas chromatograph (GC-8A; Shimadzu, Columbia, MD, USA) with a 3.175-mm stainless steel column packed with alumina (Supelco, Bellefonte, PA, USA). Fruit firmness was measured with a fruit texture analyzer (GS-20; Güss Manufacturing Ltd., Strand, Cape Town, South Africa). Juice samples were extracted using a potato ricer and tested to determine the soluble solids concentration with a digital refractometer (model PR-32 alpha; Atago, Bellevue, WA, USA). Fruit were cut in half at the equator, and the cut surface was dipped in an iodine solution. Iodine staining patterns were evaluated in accordance with the Generic Cornell Starch-Iodine Index Chart for apples (scale, 1–8) (Blanpied and Silsby 1992).

Historical temperature data were accessed from an onsite weather station (35.42721°N, 82.55888°W). The average daily air temperatures for Aug, Sep, and Oct were calculated, summarized, and reported. Specifically, the daily average, maximum, and minimum temperatures during the study period (2017 and 2018) and the preceding 10-year period (2007–16) were reported. Data were courtesy of the State Climate Office of North Carolina, North Carolina State University, and they were accessed on 30 Nov 2022.

Statistical analysis. The experiment was a 2 × 2 augmented factorial with six replications. A one-way analysis of variance was performed using PROC GLM (SAS 9.4; SAS, Cary, NC, USA) and single degree of freedom contrasts were used to compare treatment groups of interest.

Results

Effects and interactions of the AVG formulation and application number on apple preharvest drop and fruit quality were evaluated over a 7-week period. Interactions between these two factors were not observed in any measured response, suggesting that any effects of the AVG formulation and application number were independent. Significant effects of AVG formulation were rarely observed. However, significant effects of AVG (relative to the control) and application number were observed across several measured responses.

AVG reduced the cumulative preharvest drop compared with the control during harvest periods H1 and H2 (in years 2017 and 2018, respectively) and all subsequent fruit drop counts (Table 1). In 2017 and 2018, two applications of AVG reduced preharvest drop compared with a single application during later harvest periods (H3 and H4, respectively). Less than 10% fruit drop was observed with two applications of AVG until H5 during consecutive years. Conversely, the cumulative drop exceeded 10% for the control at H2 during both years. Both AVG formulations were equally effective for reducing the preharvest drop of 'Red Delicious' for the duration of the study.

AVG-treated fruit were firmer than the control fruit at H2, H3, and H4 during both years of the study (Table 2). Fruit from control trees had higher starch pattern index ratings than fruit from AVG-treated trees at H2 and H3 during both years of the study. In general, the application number had no effect on the starch rating (Table 3). Effects on soluble solids concentration were not of practical significance in 2017; however, in 2018, AVG reduced soluble solids concentrations across all sample dates relative to the control (Table 4). Two applications of AVG reduced the soluble solids concentration compared with a single application at H1, H3, H4, and H5.

During both years, AVG treatments reduced IEC compared with the control on all sample dates, with the exception of H2 (Table 5). In 2017, two applications of AVG reduced the IEC compared with a single application at H1, H2, and H4. However, application number had no effect on the IEC in 2018. ReTain® OL reduced the IEC compared with ReTain® at H3 and H4 in 2017; however, this effect was not observed in 2018.

Discussion

To our knowledge, this is the first report of a PGR that meets the requirements for organic use to manage preharvest drop. Conventional and organically approved AVG formulations were equally effective. This experiment was conducted in a conventionally managed orchard. Specific practices, such as nitrogen inputs and weed management, differed from those of organic production systems. Cultural management practices and environmental variations have been suggested to influence preharvest drop, although research is limited. Research involving organically approved AVG in organic production systems should be conducted in the future.

In general, the observed effects of AVG on preharvest drop and fruit quality are consistent with those of several studies (Greene 2005; Schupp and Greene 2004; Unrath et al. 2009). Regardless of the year, AVG provided significant preharvest drop control compared with the control beginning at H2. Orchardists interested in the greatest duration of preharvest drop control should use two applications of 132 $mg{\cdot}L^{-1}$ AVG. During both years, two applications provided significant drop control compared with a single application. This effect was present regardless of the formulation, indicating similar consistent activity of the organic formulation compared with the current conventional formulation.

In general, the formulation and application number did not influence fruit firmness. In the United States, apple fruit firmness is the primary edible quality factor that contributes to consumer preference; a minimum threshold of 62 N (13.9 lb) was suggested for consumer acceptance of multiple commercially important cultivars (Harker et al. 2008). During this trial, fruit from control trees were less than 62 N at 3 WAH. AVG delayed excessive fruit softening (<62 N) for an additional 1 to 2 weeks.

The effect of application number was inconsistent across years. During one of the two years, increasing the number of applications

Table 1. Effects of the formulation and application number of aminoethoxyvinylglycine (AVG) on the preharvest fruit drop of 'Oregon Spur II Red Delicious' apples in 2017 and 2018.[i]

		Preharvest drop (% of total)								
		2017								
Formulation[ii]	Application number	H[iii]-2	H-1	H0	H1	H2	H3	H4	H5	H6
Control			0.5	2.3	4.2	10.8	17.3	24.4	36.7	45.4
ReTain	1		0.6	1.7	2.5	5.8	11.4	18.3	31.4	42.3
ReTain	2		0.4	1.7	2.6	3.2	4.6	6.1	14.0	23.6
ReTain OL	1		0.3	1.2	2.9	4.8	8.5	12.0	22.4	31.8
ReTain OL	2		0.3	1.4	2.6	3.6	5.7	8.8	16.8	24.9
Significance[iv]	Control vs. AVG		0.6227	0.3243	0.1743	0.0027	0.0008	0.0007	0.0016	0.0177
	ReTain vs. ReTain OL		0.2718	0.5873	0.8173	0.8688	0.6914	0.5584	0.4462	0.3896
	1 vs. 2 applications		0.5776	0.8664	0.9230	0.2942	0.0458	0.0171	0.0072	0.0209
	Formulation × application number		0.4472	0.9596	0.8716	0.6887	0.3953	0.1464	0.1466	0.2672
		2018								
Control		0.3	0.8	2.4	8.7	13.8	23.8	36.4	41.9	49.5
ReTain	1	0.5	0.9	1.6	3.7	4.9	7.8	14.1	20.3	25.3
ReTain	2	0.3	0.8	1.4	2.1	3.1	5.0	9.5	11.8	16.2
ReTain OL	1	1.0	1.5	2.8	5.1	6.5	10.4	20.7	28.6	36.2
ReTain OL	2	0.4	1.0	1.6	2.8	3.8	6.2	10.1	13.9	17.7
Significance	Control vs. AVG	0.2786	0.5259	0.2758	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	ReTain vs. ReTain OL	0.2182	0.2537	0.1150	0.3145	0.4418	0.3961	0.2700	0.2293	0.1823
	1 vs. 2 applications	0.0680	0.2656	0.1356	0.0681	0.1430	0.1341	0.0257	0.0107	0.0052
	Formulation × application number	0.4835	0.5694	0.2700	0.7220	0.7593	0.7657	0.3636	0.4704	0.3105

[i] Treatment means of six replications.
[ii] ReTain® and ReTain® OL (Valent Biosciences, Libertyville, IL, USA) were applied at 132 $mg \cdot L^{-1}$. Treatments were applied on 16 Aug and 28 Aug in 2017, and on 15 Aug and 31 Aug in 2018.
[iii] H = weeks before or after the anticipated harvest. H-2 = 2 weeks before the anticipated harvest based on historical harvest dates and fruit maturity indices.
[iv] P(F). A one-way analysis of variance was performed using PROC GLM (SAS 9.4; SAS, Cary, NC, USA), and single degree of freedom contrasts were used to compare treatment groups of interest.

of AVG reduced cumulative fruit drop, delayed fruit softening at harvest, and reduced IEC. Inconsistencies in responses across years may be explained, in part, by the abnormally warm weather during Fall 2018. During this experiment, treatments were applied in August, and sampling dates occurred in September and October. In 2018, the average daily air temperature during September was 2.7 °C higher than the 10-year average (Table 6). Similarly, the average maximum and minimum daily air temperatures for September

Table 2. Effects of the formulation and application number of aminoethoxyvinylglycine (AVG) on the firmness of 'Oregon Spur II Red Delicious' apples in 2017 and 2018.[i]

		Fruit firmness (N)					
		2017					
Formulation[ii]	Applications	9 Sep (H0[iv])	20 Sep (H1)	29 Sep (H2)	4 Oct (H3)	12 Oct (H4)	19 Oct (H5)
Control		69.8	64.1	58.3	55.2	54.7	
ReTain	1	71.6	67.6	63.6	59.6	55.6	
ReTain	2	72.5	69.8	66.7	62.7	59.6	
ReTain OL	1	69.8	65.8	63.2	61.8	55.2	
ReTain OL	2	71.6	67.2	67.2	65.8	64.1	
Significance[iii]	Control vs. AVG	0.1963	0.0014	<0.0001	0.0003	0.1394	
	ReTain vs. ReTain OL	0.3156	0.0227	0.8754	0.0960	0.4148	
	1 vs. 2 applications	0.2564	0.0417	0.0071	0.0479	0.0097	
	Formulation × application number	0.8006	0.7232	0.5726	0.7686	0.3226	
		2018					
		11 Sep	18 Sep	24 Sep	2 Oct	8 Oct	16 Oct
Control		68.5	67.6	64.5	61.4	58.3	56.5
ReTain	1	72.1	67.6	66.3	64.5	64.1	60.9
ReTain	2	70.7	68.1	68.9	64.9	64.1	62.7
ReTain OL	1	69.8	66.7	66.7	63.6	63.2	60.5
ReTain OL	2	69.4	68.1	67.2	65.4	63.2	63.2
Significance	Control vs. AVG	0.0368	0.9933	0.0054	0.0007	<0.0001	0.0002
	ReTain vs. ReTain OL	0.0407	0.4669	0.6194	0.6539	0.1035	0.9277
	1 vs. 2 applications	0.4806	0.3974	0.0879	0.0664	0.8036	0.0826
	Formulation × application number	0.6598	0.5558	0.2072	0.3498	0.8252	0.8136

[i] Treatment means of six replications.
[ii] ReTain® and ReTain® OL (Valent Biosciences, Libertyville, IL, USA) were applied at 132 $mg \cdot L^{-1}$. Treatments were applied on 16 Aug and 28 Aug in 2017, and on 15 Aug and 31 Aug in 2018.
[iii] P(F). A one-way analysis of variance was performed using PROC GLM (SAS 9.4; SAS, Cary, NC, USA), and single degree of freedom contrasts were used to compare treatment groups of interest.
[iv] H = weeks before or after anticipated harvest. H0 = the week of anticipated harvest; timing was based on historical harvest dates and fruit maturity indices.

Table 3. Effects of the formulation and application number of aminoethoxyvinylglycine (AVG) on the starch index rating of 'Oregon Spur II Red Delicious' apples in 2017 and 2018.[i]

		Starch index rating (1–8)					
		2017					
Formulation[ii]	Applications	9 Sep (H0[iv])	20 Sep (H1)	29 Sep (H2)	4 Oct (H3)	12 Oct (H4)	19 Oct (H5)
Control		4.3	6.9	7.3	7.5	7.6	
ReTain	1	4.0	6.2	7.0	7.3	7.6	
ReTain	2	3.7	5.5	6.5	7.0	7.5	
ReTain OL	1	4.1	5.9	7.0	7.1	7.4	
ReTain OL	2	4.0	6.0	7.0	7.1	7.3	
Significance[iii]	Control vs. AVG	0.2391	0.0018	0.0075	0.0039	0.2395	
	ReTain vs. ReTain OL	0.4307	0.6691	0.1135	0.4331	0.0874	
	1 vs. 2 applications	0.5095	0.2063	0.1135	0.2460	0.2656	
	Formulation × application number	0.6819	0.1128	0.1845	0.3368	0.9363	
		2018					
		11 Sep	18 Sep	24 Sep	2 Oct	8 Oct	16 Oct
Control		5.3	6.5	7.7	7.8	7.9	8.0
ReTain	1	4.2	5.7	7.1	7.4	7.7	8.0
ReTain	2	4.0	5.3	6.6	7.2	7.8	7.9
ReTain OL	1	4.8	6.2	7.2	7.7	7.8	8.0
ReTain OL	2	4.7	5.8	7.0	7.2	7.8	8.0
Significance	Control vs. AVG	0.0038	0.0081	0.0051	0.0099	0.2602	0.1745
	ReTain vs. ReTain OL	0.0089	0.0464	0.2578	0.2164	0.4875	0.0725
	1 vs. 2 applications	0.4588	0.0690	0.0892	0.0051	0.8663	0.0725
	Formulation × application number	0.8119	0.9873	0.4180	0.3648	0.4875	0.5376

[i] Treatment means of six replications.
[ii] ReTain® and ReTain® OL (Valent Biosciences, Libertyville, IL, USA) were applied at 132 $mg \cdot L^{-1}$. Treatments were applied on 16 Aug and 28 Aug in 2017, and on 15 Aug and 31 Aug in 2018.
[iii] P(F). A one-way analysis of variance was performed using PROC GLM (SAS 9.4; SAS, Cary, NC, USA), and single degree of freedom contrasts were used to compare treatment groups of interest.
[iv] H = weeks before or after the anticipated harvest. H0 = the week of anticipated harvest; timing was based on historical harvest dates and fruit maturity indices.

Table 4. Effects of the formulation and application number of aminoethoxyvinylglycine (AVG) on the soluble solids concentration of 'Oregon Spur II Red Delicious' apples in 2017 and 2018.[i]

		Soluble solids concn (%)					
		2017					
Formulation[ii]	Applications	9 Sep (H0[iv])	20 Sep (H1)	29 Sep (H2)	4 Oct (H3)	12 Oct (H4)	19 Oct (H5)
Control		11.4	12.3	12.5	13.1	13.1	
ReTain	1	11.75	13.0	12.2	13.7	14.0	
ReTain	2	11.9	13.1	12.5	14.2	14.2	
ReTain OL	1	11.0	12.3	12.0	13.0	13.3	
ReTain OL	2	11.0	12.2	11.6	13.2	12.8	
Significance[iii]	Control vs. AVG	0.9521	0.4586	0.3541	0.4594	0.4519	
	ReTain vs. ReTain OL	0.0027	0.0590	0.1651	0.0862	0.0737	
	1 vs. 2 applications	0.7371	0.9668	0.9462	0.4137	0.8461	
	Formulation × application number	0.8931	0.7392	0.3609	0.7135	0.5384	
		2018					
		11 Sep	18 Sep	24 Sep	2 Oct	8 Oct	16 Oct
Control		11.0	11.2	11.6	12.0	12.7	12.2
ReTain	1	9.9	10.2	10.5	10.9	11.4	11.5
ReTain	2	9.5	9.9	10.4	10.3	10.9	11.0
ReTain OL	1	9.8	10.3	10.7	11.1	11.6	11.7
ReTain OL	2	9.8	10.0	10.3	10.7	11.3	11.5
Significance	Control vs. AVG	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003
	ReTain vs. ReTain OL	0.6587	0.5721	0.9215	0.0780	0.1465	0.0307
	1 vs. 2 applications	0.2304	0.0307	0.1756	0.0010	0.0337	0.0382
	Formulation × application number	0.1587	0.9098	0.2839	0.4481	0.5115	0.5144

[i] Treatment means of six replications.
[ii] ReTain® and ReTain® OL (Valent Biosciences, Libertyville, IL, USA) were applied at 132 $mg \cdot L^{-1}$. Treatments were applied on 16 Aug and 28 Aug in 2017, and on 15 Aug and 31 Aug in 2018.
[iii] P(F). A one-way analysis of variance was performed using PROC GLM (SAS 9.4; SAS, Cary, NC, USA) and single degree of freedom contrasts were used to compare treatment groups of interest.
[iv] H = weeks before or after anticipated harvest. H0 = the week of anticipated harvest; timing was based on historical harvest dates and fruit maturity indices.

Table 5. Effects of the formulation and application number of aminoethoxyvinylglycine (AVG) on the internal ethylene concentration of 'Oregon Spur II Red Delicious' apples in 2017 and 2018.[i]

		Ethylene concn in core cavity (mg·L^{-1})					
		2017					
Formulation[ii]	Applications	9 Sep (H0[iv])	20 Sep (H1)	29 Sep (H2)	4 Oct (H3)	12 Oct (H4)	19 Oct (H5)
Control		1.3	9.2	38.0	29.6	53.8	
ReTain	1	0.4	12.3	24.1	23.3	48.0	
ReTain	2	0.1	1.4	4.5	15.3	36.4	
ReTain OL	1	0.3	3.6	17.0	13.0	36.1	
ReTain OL	2	0.1	0.6	2.0	2.9	9.5	
Significance[iii]	Control vs. AVG	0.0038	0.1671	0.0004	0.014	0.0284	
	ReTain vs. ReTain OL	0.9536	0.1195	0.4065	0.0464	0.0311	
	1 vs. 2 applications	0.3968	0.0268	0.0053	0.108	0.0337	
	Formulation × application number	0.9919	0.1898	0.6939	0.8457	0.3838	
		2018					
		11 Sep	18 Sep	24 Sep	2 Oct	8 Oct	16 Oct
Control		2.99	14.84	17.32	24.49	38.41	28.65
ReTain	1	0.06	0.68	1.86	1.62	7.51	7.87
ReTain	2	0.03	0.21	0.27	0.54	1.64	3.75
ReTain OL	1	0.18	0.78	1.09	2.99	6.82	8.44
ReTain OL	2	0.01	0.26	0.28	0.74	1.80	2.12
Significance	Control vs. AVG	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	ReTain vs. ReTain OL	0.9354	0.9765	0.8438	0.7972	0.9426	0.8795
	1 vs. 2 applications	0.8674	0.8418	0.5380	0.5871	0.1495	0.1462
	Formulation × application number	0.9085	0.9926	0.8399	0.8483	0.9082	0.7547

[i] Treatment means of six replications.

[ii] ReTain® and ReTain® OL (Valent Biosciences, Libertyville, IL, USA) were applied at 132 mg·L^{-1}. Treatments were applied on 16 Aug and 28 Aug in 2017, and on 15 Aug and 31 Aug in 2018.

[iii] P(F). A one-way analysis of variance was performed using PROC GLM (SAS 9.4; SAS, Cary, NC, USA), and single degree of freedom contrasts were used to compare treatment groups of interest.

[iv] H = weeks before or after anticipated harvest. H0 = the week of anticipated harvest; timing was based on historical harvest dates and fruit maturity indices.

were higher than the 10-year average (1.9 °C and 3.9 °C, respectively). It was suggested that high temperatures after AVG application reduced the control of preharvest drop (Stover et al. 2003; Stover and Greene 2005). Additional research is warranted to gain a better understanding of the interactions between environmental factors, such as air temperature, and AVG efficacy.

Table 6. Summary of average daily air temperature data for select months across a 12-year period in Mills River, NC, USA.[i, ii]

Month	Avg air temperature[iii] (°C)	Maximum air temperature (°C)	Minimum air temperature (°C)
	2007–16		
Aug	22.0	28.8	17.1
Sep	18.9	25.7	13.8
Oct	12.8	20.3	6.6
	2017		
Aug	21.3	27.2	16.8
Sep	17.7	25.1	12.1
Oct	13.5	21.6	7.3
	2018		
Aug	21.4	28.1	16.7
Sep	21.6	27.6	17.7
Oct	14.4	21.1	9.5

[i] Data courtesy of the State Climate Office of North Carolina, North Carolina State University. Cardinal [data retrieval interface] available at https://products.climate.ncsu.edu/cardinal/request. Accessed 30 Nov 2022.

[ii] Weather station (FLET) located at 35.42721°N, 82.55888°W.

[iii] Means reported are the daily average air temperatures across each month of interest. Selected months correspond with the study period in 2017 and 2018.

As a growing sector of domestic apple production, the ability to manage preharvest drop during organic apple production could minimize economic losses and food waste. Additionally, flexibility in managing harvest timing is becoming increasingly important as labor costs increase and labor availability is uncertain. Our data suggest that organically approved AVG is a promising alternative with efficacy similar to that of a conventional formulation. An increased number of AVG applications delayed the onset of preharvest drop, although effects on fruit maturity were inconsistent across years.

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