Ethylene Inhibitors Delay Fruit Drop, Maturity, and Increase Fruit Size of ‘Arlet’ Apples

Ross E. Byers,¹ D.H. Carbaugh,² and L.D. Combs³

Virginia Polytechnic Institute and State University, Alson H. Smith, Jr., Agricultural Research and Extension Center, 595 Laurel Grove Road, Winchester, VA 22602

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Abstract. Aminoethoxyvinylglycine (AVG) applied as a spray to ‘Arlet’ apple trees inhibited fruit drop and increased the pull force necessary to detach the fruit. AVG delayed the loss of fruit firmness, starch degradation, fruit shriveling, and red color development. 1-Methylcyclopropene (1-MCP), applied as a gas or spray to trees in the field, did not affect fruit drop or pull force. The combination of AVG + 1-MCP (spray or gas) provided better control of fruit drop, slowed the loss of fruit firmness, starch degradation, and decrease in pull force than AVG alone. Thirty five days after the optimum harvest date, fruit firmness from trees sprayed with AVG + 1-MCP was maintained at 74.3 N. Fruit of the control was significantly lower at 61.4 N firmness. The delay in harvest caused untreated control fruit stems to turn brown and die, but stems on AVG treated trees remained green and fruit continued to grow. In the 35 days after the optimum harvest date, treated fruit increased 2.5 cm in fruit diameter. Chemicals used: Aminoethoxyvinylglycine (AVG), 1-Methylcyclopropene (1-MCP), and trisiloxane ethoxylate methyl ether (an organosilicone surfactant, Silwet L-77).

Fruit of many apple cultivars may abscise before adequate color or maturity develops. Growers may begin to harvest earlier than the optimum maturity date because adequate labor is often unavailable to harvest large orchards of a single cultivar. Early harvest may lead to poorer fresh and processed fruit quality and poorer fruit storability. Early harvest can also result in lower yields, because fruit that remains on the tree may continue to increase in size (Curtis, 1961; Shallenberger et al., 1961). Chemical sprays that delay preharvest

fruit drop and maturity for an additional 2 to 4 weeks may increase crop value by increasing yield, fruit size, quality, and price by as much as 20% (Byers and Eno, 2002). In addition, compressed harvest periods may present several practical problems such as inadequate numbers of picking bins, trucks, and cold storage equipment to handle more fruit in a short period of time.

Chemical control of preharvest fruit drop has been studied for many years (Batjer and Moon, 1945; Batjer and Thompson, 1946; Batjer and Thompson, 1947; Edgerton and Hoffman, 1948; Edgerton, 1947; Gardner et al., 1940; Harley et al., 1946; Mattus and Moore, 1954; Mattus et al., 1956; Smock et al., 1954; Southwick et al., 1953; Thompson 1952). At one time naphthaleneacetic acid (NAA), 2,4,5-trichlorophenoxypropionic acid (2,4,5-TP), and daminozide (Alar) were registered to delay preharvest apple drop. Daminozide hastened red color development, delayed fruit maturity and fruit drop (Batjer and Williams et al., 1966; Edgerton and Blanpied, 1970; Pollard, 1974).

The registration of daminozide was withdrawn in 1989. When daminozide + NAA or 2,4,5-TP was used to control preharvest drop, a 2- to 4-week extension of the harvest period was possible for many apple cultivars.

The control of fruit drop with 2,4,5-TP was superior to daminozide or NAA, but it caused a hastening of maturity (Mattus and Moore, 1954; Mattus et al., 1956; Smock et al., 1954; Southwick et al., 1953). The optimum harvest period was shortened by 2,4,5-TP even though fruit were held on the tree adequately. Combinations of daminozide and 2,4,5-TP minimized fruit drop, caused negligible fruit ripening (Batjer and Williams, 1966; Edgerton and Blanpied, 1970; Pollard, 1974; Schomer et al., 1971; Smock et al., 1954), increased fruit color, and substantially extended the harvest season. The registration of 2,4,5-TP was cancelled in 1986.

Even though NAA was less effective than 2,4,5-TP or daminozide (Looney and Cochrane, 1981; Southwick et al. 1953; Thompson, 1952), more recent studies indicate that NAA was more effective when applied 3 to 4 weeks before the optimum harvest date followed by a second application 14 to 21 d afterward for cultivars grown in Virginia (Marini et al., 1993).

Other chemicals that have auxin-like activity will also delay preharvest fruit drop. They include: phenoxys (fenoprop, 2,4-DP), chloroxuron (Looney and Cochrane, 1981; Looney and Hogue, 1987; Marini and Byers, 1988; Marini et al., 1988a, 1989); benzoic acids (dicamba) (Marini and Byers, 1988; Marini et al., 1988b, 1989); and pyridines (triclopyr, lantrel, and fluroxypyr). Among these 2,4-DP and dicamba were superior to NAA because they were longer lasting and had few negative effects on fruit ripening (Marini and Byers, 1988; Marini et al., 1988a, 1988b).

Aminoethoxyvinylglycine (AVG), an ethylene-biosynthesis inhibitor (Shafer et al., 1995a, 1995b; Yu and Yang, 1979) suppresses ethylene production in apple fruit and other plant tissues (Autio and Bramlage, 1982; Bangerth, 1978). When applied within 1 month of harvest, AVG delays fruit ripening, suppresses preharvest and postharvest flesh softening, reduces watercore, reduces preharvest fruit drop, and increases fruit removal force (Autio and Bramlage, 1982; Bangerth, 1978; Byers, 1997 b, 1997c; Williams, 1980).

1-Methylcyclopropene (1-MCP) is an inhibitor of ethylene action that blocks ethylene

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¹Professor of horticulture and scientist-in-charge.

²Research specialist.

³Research specialist.

Table 1. Influence of 1-MCP and AVG on ‘Arlet’ apple fruit quality, shriveled fruit and brown stems at harvest (2000).

		Application method	Shriveled fruit (%)		Brown stem (%)		Starch (1 to 8 rating)				Pull force (kg)			
No.	Treatment ^a		10 Oct.	10 Oct.	8 Aug.	22 Aug.	31 Aug.	19 Sept.	10 Oct.	31 Aug.	19 Sept.	10 Oct.		
1	Control		60 abc ^y	67.5 ab	5.84 a	6.88 b	7.88 a	8.00 a	8.00 a	0.976 c	0.967 b	0.631 d		
2	1-MCP + buffer	Gas	88 a	74.0 a	6.36 a	6.94 b	7.96 a	7.96 ab	8.00 a	0.858 c	1.117 b	1.180 bc		
3	1-MCP + Silwet L-77	Spray	68 ab	56.2 abc	5.80 a	7.54 a	7.88 a	8.00 a	8.00 a	0.949 c	0.958 b	0.917 cd		
4	AVG (50 ppm) + Silwet L-77	Spray	20 cd	25.0 cd	4.00 b	5.44 c	7.40 b	7.96 ab	8.00 a	1.398 b	1.176 b	1.554 a		
5	AVG (50 ppm) + Silwet L-77	Spray	32 bcd	34.0 bcd	3.48 b	5.22 c	7.04 b	7.92 ab	8.00 a	1.557 b	1.212 b	1.321 ab		
	1-MCP + buffer	Gas												
6	AVG (50 ppm) + 1-MCP + Silwet L-77	Spray	0 d	6.0 d	4.08 b	5.30 c	7.00 b	7.76 b	8.00 a	1.893 a	1.539 a	1.217 abc		
Contrasts			Comparisons (<i>P</i> > <i>F</i>)											
1, 2, and 3 vs. 4, 5, and 6			AVG vs. none			***	***	***	***	NS	NS	***	**	***

^aSpray treatments were applied with a high-pressure hand-gun sprayer. 1-MCP was applied on 17 July (gas) and 18 July (spray), when fruit firmness was 114.3 N. Chemical rates were 1-MCP = 0.795 mg/30 m³ (gas) or 0.795 mg·L⁻¹ (spray); AVG = 50 mg·L⁻¹; Silwet L-77 = 0.624 mL·L⁻¹; buffer = 60 mL/135 m³.

^bMean separation within columns by Duncan's new multiple range test; ($P \leq 0.05$).

Table 2. Influence of 1-MCP and AVG on 'Arlet' apple fruit quality and return bloom (2000-01).

No.	Treatment ^a	Application method	Soluble solids (%)						Color (red side, %)						Color (green side, 0 to 5)						Visual % of spurs flowering (16 Apr. 2001)
			8	22	31	19	10	8	22	31	19	10	8	22	31	19	10				
			Aug.	Aug.	Aug.	Sept.	Oct.	Aug.	Aug.	Aug.	Sept.	Oct.	Aug.	Aug.	Aug.	Sept.	Oct.				
1	Control		13.6 a ^b	15.0 ab	15.5 a	15.4 b	14.9 c	36 ab	83 a	88 a	86 a	85 b	2.0 b	2.8 a	3.0 ab	3.4 a	3.6 ab	98.0 a			
2	1-MCP + buffer	Gas	14.2 a	15.6 a	16.0 a	15.9 ab	15.9 abc	42 a	80 a	82 abc	88 a	87 ab	2.3 a	2.6 ab	3.3 a	3.3 a	3.5 ab	99.5 a			
3	1-MCP + Silwet L-77	Spray	13.9 a	15.0 ab	15.4 a	15.7 ab	15.1 bc	38 ab	79 a	84 ab	85 a	90 a	2.2 a	2.5 bc	2.9 b	3.2 a	3.7 a	97.5			
4	AVG (50 ppm) + Silwet L-77	Spray	13.9 a	14.9 ab	15.5 a	15.6 ab	16.1 ab	36 ab	68 b	81 bc	86 a	89 ab	2.1 ab	2.1 d	2.3 c	3.4 a	3.6 ab	99.0 a			
5	AVG (50 ppm) + Silwet L-77	Spray	13.9 a	14.9 ab	15.5 a	15.6 ab	16.3 a	37 ab	60 bc	77 cd	83 a	89 ab	2.1 ab	2.2 cd	2.0 c	3.3 a	3.4 ab	99.0 a			
6	1-MCP + buffer	Gas																			
6	AVG (50 ppm) + 1-MCP + Silwet L-77	Spray	14.1 a	14.7 b	15.7 a	16.2 a	16.0 ab	33 b	55 c	75 d	85 a	87 ab	2.0 b	2.0 d	2.3 c	3.1 a	3.3 b	98.0 a			
Contrasts			NS			NS	NS	NS	***	***	NS	NS	NS	***	***	NS	NS	NS			
1,2, and 3 vs. 4,5, and 6			NS			NS	NS	NS	***	***	NS	NS	NS	***	***	NS	NS	NS			
AVG vs. none			NS			NS	NS	NS	***	***	NS	NS	NS	***	***	NS	NS	NS			

^aSpray treatments were applied with a high-pressure hand-gun sprayer. 1-MCP was applied on 17 July (gas) and 18 July (spray), when fruit firmness was 114.3 N. Chemical rates were 1-MCP = 0.795 mg/30 m³ (gas) or 0.795 mg·L⁻¹ (spray); AVG = 50 mg·L⁻¹; buffer = 60 mL/135 m³.

^bMean separation within columns by Duncan's new multiple range test ($P \leq 0.05$).

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responses in plants (Fan et al., 1999, Serek et al., 1995; Sisler and Serek, 1997). 1-MCP is a gas, which has been formulated as a powder that releases the gas when mixed with a buffered base or water. 1-MCP is currently being used commercially in the cut flower industry and in apple cold storages to prolong the postharvest quality of apples.

In a preliminary experiment in 1999, 'Golden Delicious' trees were gassed in the field with 1-MCP using 135-m³ silage bags to contain the gas. At the time of gassing, the control fruit averaged 82.3 N firmness, but 30 d after gassing whole trees, fruit measured 81.4 N flesh firmness when control fruit measured 62.3 N. In comparison, a spray formulation of 1-MCP + superior oil + buffer maintained 'Golden Delicious' fruit firmness at 70.7 N compared to the control at 62.3 N (Byers, unpublished). Fruit drop was not controlled by spraying or gassing with 1-MCP.

The objectives of these experiments were to investigate sprays of AVG or 1-MCP (gas or spray) for control of preharvest fruit drop and maintenance of on-tree fruit quality.

Materials and Methods

In 2000, thirty 5-year-old 'Arlet'/M.7 trees were selected for uniformity and blocked according to row and terrain into five blocks for six treatments (Tables 1, 2, and 3). 1-MCP was applied either as a gas or spray alone or in combination with AVG + Silwet-L-77. Dilute sprays were applied with a low-pressure hand-wand sprayer. Chemicals used (a.i.) were 1-MCP (EthylBloc) at 0.795 mg/135 m³ (gas) + proprietary buffer at 60 mL/135 m³, or 1-MCP at 0.795 mg/L⁻¹ (spray); AVG (ReTain) at 50 mg/L⁻¹; Silwet L-77 at 0.624 mL/L⁻¹ in sprays. Treatments were applied on 18 July at an estimated 4 weeks before the anticipated optimum harvest date (15 Aug.).

1-MCP was applied as a gas to individual trees in the field by enclosing trees in a 10-mil polypropylene silage bag (3.6 m in diameter and 6.4 m in height; however, the trees were only 3.2 m in height; thus the approximate volume gassed was 30 m³). Whole trees were gassed over night from 1800 HR on 17 July to 0800 HR on 18 July, and the bag was taken off early in the morning to prevent sunlight heating. Three grams of 1-MCP dextrose powder (0.795 mg a.i.) was placed in 60 mL of buffer near the trunk of the tree over night. The bag cylinder was tied at the top during gassing and was weighted at the bottom to fit snugly on the ground. Since fruit in a preliminary field test on 'Golden Delicious' trees delayed loss of fruit firmness, the field gassing technique using a 10 mil silage bag was considered adequate for 1-MCP to bind to the ethylene receptor sites. Application of 1-MCP was made within 30 min of aqueous mixing to reduce the potential loss of gas, which occurs within a few hours in water.

A 10-fruit sample was collected near fruit maturity from each tree for quality evaluations (flesh firmness, soluble solids concentration, starch staining, percentage red color, fruit scarring and/or russet, and incidence of water core).

Flesh firmness was measured on two sides of each fruit with an Effegi penetrometer (model FT327; McCormick Fruit Tech, Yakima, Wash.) fitted with an 11.1-mm tip. Soluble solids concentration (SSC) was measured with an Atago hand-held refractometer (model N1; McCormick Fruit Tech), using a composite sample of juice resulting from penetrometer testing of all replicates of each treatment. Each apple fruit was cut in half transversely, and severity of water core was rated on a scale of 0 to 5 (0 = none, 5 = severe). Flesh starch was evaluated by dipping half of each apple in iodine solution for about 15 s. The degree of staining was rated on a scale of 0 to 8, where 0 = staining of the entire cut surface and 8 = absence of starch (Poapst et al., 1959). Stem-end and side russet were rated as 0 = no russet to 5 = severe russet. In addition on 10 Oct. each of 10-fruit sampled from each tree was visually observed for obvious fruit shriveling and fruit that had senescing abscission zones and stems and recorded as 0 = yes or 1 = no, respectively.

Experimental procedures followed previous work on fruit drop and fruit quality (Byers, 1997 a, 1997b, 1997c; Marini et al., 1988 a, 1998b, 1989). Five to ten limbs per tree (with a minimum of about 50 fruit/tree) were selected and tagged to monitor fruit drop. At 7-d intervals, fruit remaining on these limbs were counted and the percentage of fruit drop was calculated. Fruit samples for testing fruit diameter, firmness, starch, SSC, percent red color, and green color were taken on 8 Aug., 22 Aug., 31 Aug., 19 Sept., and 10 Oct. and pull force on 31 Aug., 19 Sept., and 10 Oct. Data were analyzed by ANOVA and GLM procedures using SAS software (SAS Institute, 1985). Means were compared by Duncan's new multiple range test and single-degree-of-freedom contrasts as appropriate for the experimental design.

Results and Discussion

1-MCP (EthylBloc) applied as a gas or spray to 'Arlet' apple trees generally did not affect fruit drop (Fig. 1) or pull force (Table 1, treatments 2,3) required to separate fruit from the spur. AVG inhibited fruit drop (Fig. 1, treatment 4), allowed for continued fruit growth (Fig. 2), delayed loss of fruit firmness (Fig. 3), slowed starch degradation (Table 1), slightly inhibited red color (Table 2), maintained green background color (Table 2), and increased pull force (Table 1) compared to the control. The tank mix spray of 1-MCP (gas or spray) + AVG further inhibited fruit drop (Fig. 1, treatments 5 and 6) and promoted increased SSC, inhibited red color, maintained green background color when compared to AVG alone (Table 2). The combination of AVG + 1-MCP spray applied as a spray provided the best control of fruit drop (Fig. 1, treatment 6), maintenance of fruit firmness (Fig. 3), delaying starch degradation (Table 1), and increased pull force (Table 1) compared to the control. 1-MCP (gas) alone did not inhibit fruit drop (Fig. 1), the loss of firmness (Fig. 3) or starch degradation (Table 1), but pull force was greater than the control

Fig. 1. Influence of 1-MCP and AVG on fruit drop of 'Arlet' apples treated 18 July.

Fig. 2. Influence of 1-MCP and AVG on fruit diameter of 'Arlet' apples treated 18 July when fruit averaged 6.42 cm in diameter.

on 10 Oct. after most of the fruit had dropped (Table 2).

As the season progressed, fruit sprayed with AVG alone or in combination with 1-MCP (spray or gassing; Fig. 2, treatments 4, 5, and 6) continued to increase in diameter until 10 Oct. Fruit from the control and 1-MCP treatments (Fig. 2, treatments 1, 2, and 3) increased in diameter until 22 Aug. Those fruit reached a maximum, and later decreased in diameter (Fig. 2). Of the few, untreated fruit that remained on the tree on 10 Oct., 60% were shriveled to varying degrees; but none of the AVG or AVG + MCP sprayed fruit (Fig. 4, treatments 4, 5, and 6) were shriveled. The delay in harvest resulted in 1-MCP and/or nontreated fruit stems to turn brown, senesce, and dry while still attached to the tree, but trees sprayed with AVG or AVG + MCP had fruit stems that remained bright green and fruit continued to grow until

the last observations on 10 Oct. Assuming that 15 Aug. was the optimum harvest date based on fruit firmness, in the next 35 d (19 Sept.), trees sprayed with AVG + 1-MCP (treatment 6) maintained fruit firmness above 72 N (Fig. 3), increased 2.5 cm in fruit diameter (Figs. 2 and 4; Table 2), and substantially reduced fruit drop (Fig. 1). In addition, in the subsequent season (16 Apr. 2001) the number and quality of spurs flowering appeared unaffected by spray treatments even though the AVG treatments retained fruit 50 d past the optimum harvest date in 2000 (Table 2).

Since ethylene has been implicated in the process of fruit abscission (Walsh, 1977) and since AVG (a biosynthetic inhibitor of ethylene), inhibits preharvest fruit drop (Autio and Bramlage, 1982; Bangerth, 1978; Byers, 1997b, 1997c; Williams, 1980), it seems inconsistent that 1-MCP (an ethylene blocker), would

not inhibit preharvest fruit drop. However, in several experiments, 1-MCP applied either as a gas or spray did not inhibit fruit abscission of apple even though fruit softening was retarded (R. Byers, unpublished data) which indicated that 1-MCP did bind the ethylene receptor sites of the fruit but not the stem. In this 'Arlet' experiment, 1-MCP delayed the loss of firmness only on 22 Aug. (Fig. 3). Since AVG + 1-MCP was superior to AVG alone, the use of both apparently has some additive influences on delaying pedicle senescence, functional organic nutrient transport, and the abscission process.

Anatomical observation of fresh cut, 'Arlet' mature apple abscission zones showed senescent browning in the pith region of the control and 1-MCP (gas and spray treatments) and later in the pedicel cortex region (S. Wolf and R. Byers, unpublished data). AVG + 1-MCP maintained the cortical and vessel regions of the abscission zone, and the entire pedicle of the fruit, in a brighter green condition compared to fruit of the control or 1-MCP treated trees. McCown (1943) indicated that abscission could be initiated independently in the pith or the cortex of the pedicle and that the vessels (xylem, cambium, and phloem) were ruptured as a result of mechanical forces. The weight of the fruit usually caused the final fruit separation by tearing of the cortex and epidermis. The dramatic increase in fruit diameter and maintenance of fruit quality in 'Arlet', was probably the result of maintaining the cortical and phloem tissues in the pedicel and abscission zone from normal senescence and deterioration. Maintenance of these tissues in good conditions has great commercial potential for increasing fruit size, yield, crop value, and greater harvest window.

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Fig. 3. Influence of 1-MCP and AVG on fruit firmness (114.3 N) of 'Arlet' apples treated 18 July.

Fig. 4. Influence of AVG (Retain) and/or 1-MCP (EthylBloc) applied as a gas or spray to 'Arlet' apple trees. Fruit were harvested 10 Oct., 50 d after the typical harvest date of 22 Aug. Note that fruit on AVG-sprayed trees continued to enlarge and pedicel abscission zones were healthy and green when picked. In comparison, on 10 Oct., the control, MCP-gas, and MCP-spray fruit were shriveled, abscission zones were in various stages of senescence, and some pedicels were dead and dried while still attached to the tree.

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