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Pre- and Post-harvest Aminoethoxyvinylglycine (AVG) Application Affects Maturity and Storage of Pear Fruit

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Summary

AVG (aminoethoxyvinylglycine) was applied pre-harvest (125 ppm) a.i. at a single application 21, 14 or 7 days prior to the first commercial harvest and post-harvest to the pear cultivars 'Abbé Fétel' and 'Bartlett' to evaluate changes in fruit maturation. Fruit ripening was also monitored after 7 or 14 days of cold storage at 0 °C. The ripening indices most affected by the treatments were ethylene production and flesh firmness. The ripening of 'Abbé Fetel' fruit treated in pre-harvest was delayed by 5 to 15 days depending on harvest date. After 7 and 14 days of cold storage, the AVG treated fruits partially retained their unripe characteristics as compared with untreated fruits. Flesh softening was also partially retarded with post-harvest AVG dip treatment of 'Bartlett' fruit.

Zusammenfassung

Die Anwendung von Aminoethoxyvinylglycine (AVG) vor und nach der Ernte beeinflusst die Reife und die Lagerung von Birnenfrüchten. Um den Einfluss des Mittels auf die Fruchtreifung zu ermitteln, wurden die Birnensorten 'Abbé Fétel' und 'Bartlett' entweder 21, 14 bzw. 7 Tage vor dem im Erwerbsobstbau üblichen Erntetermin oder aber danach mit AVG (Aminoethoxyvinylglycerin, 125 ppm) a.i.) behandelt. Die Fruchtreifung wurde nach 7- bzw. 14-tägiger Lagerung bei 0 °C überprüft. Den größten Einfluss hatte die Behandlung auf die Reifindices Ethylenproduktion und Fruchtfleischfestigkeit. Die Reifung der vor der Ernte behandelten 'Abbé Fetel'-Früchte verzögerte sich in Abhängigkeit vom Erntetermin um 5–15 Tage. Während der 7- bzw. 14-tägigen Kühllagerung behielten die AVG behandelten Früchte teilweise ihren unreifen Zustand bei. Auch das Weichwerden des Fruchtfleisches war bei 'Bartlett'-Früchten, die nach der Ernte in AVG getaucht wurden, teilweise verzögert.

Key words. ethylene – fruit ripening – *Pyrus communis* L. – ReTain® – storage – quality parameters

Introduction

Aminoethoxyvinylglycine (AVG) inhibits ethylene production during fruit ripening by blocking the conversion of S-adenosylmethionine (SAM) to 1-aminocyclopropane-1-carboxylic acid (ACC) (BOLLER et al. 1979). Hence, it represents a very interesting tool for fruit-ripening control and post-harvest management.

AVG reduced fruit ethylene production and delayed ripening of apple fruit (BANGERTH 1978; AUTIO and BRAMLAGE 1982; GREENE 1983; MASIA et al. 1998; JU and CURRY 2000), dependent on cultivar and AVG concentrations (BRAMLAGE et al. 1980; AUTIO and BRAMLAGE 1982). Pre-harvest AVG application on peach inhibited ethylene emission and delayed flesh softening (BREGOLI et al. 2002); while post-harvest AVG dip delayed softening of nectarine (BYERS 1997), no clear-cut effects were determined on other fruit quality parameters such as soluble solids content (SSC).

In 'Bartlett' pear, pre-harvest AVG treatments either 14 or 7 days before harvest did not affect ethylene production at harvest, but delayed changes in skin colour, softening and starch content (CLAYTON et al. 2000). However fruit ripening characteristics after 4 months of cold storage at –1 °C was little affected by AVG pre-harvest treatments (CLAYTON et al. 2000; ROMANI et al. 1982). When 'Bartlett' and 'Anjou' pear fruits were infiltrated with AVG after harvest, ethylene production was inhibited in both cultivars, but softening and increasing of soluble pectin concentrations were detected only in 'Anjou' (WANG and MELLENTHIN 1977). The ripening stage at which the pears are exposed to AVG appears to affect the induced effects (NESS and ROMANI 1980).

The aim of the present study was to evaluate AVG as a controlling agent of fruit ripening in pear. Pre-harvest treatments with ReTain® (Valent BioScience Corporation), a commercial product containing 15 % AVG a.i., were applied to cv. 'Abbé Fétel' pear fruit, the most important commercial cultivar on the Italian market, and the main effects on maturity parameters were monitored. An infiltration experiment was also run on cv. 'Bartlett' fruit to explore AVG as a potential post-harvest tool for pear storage.

Materials and Methods

Plant material and experimental design

The trials were conducted at the University of Bologna's Cadriano experiment station near Bologna, Italy.

Twelve-year-old 'Abbé Fétel' pear trees grafted to quince were selected for their uniform size and fruit load and sprayed with AVG 125 ppm at the same concentration (ReTain® 0.83 g L^{-1}) 21, 14 and 7 days prior to first commercial harvest (17 September 2002). An organo-silicon surfactant was also applied (Silwet L-77®, ABG-7011, Valent Bioscience) in water at a rate of 0.5 ml L^{-1}. The experiment consisted of a randomised complete block design with treatments replicated across four blocks.

Fruit maturity at harvest

Forty 'Abbé Fétel' pears per treatment (10 fruits/replicate) were harvested 3 times at one-week intervals starting on 17 September (harvest 1). Fruits were immediately evaluated for ethylene production by sampling 10 ml of the gas headspace of a one-litre jar where each fruit was kept for 1 hour at 22 °C. Gas-chromatography analyses were performed with a Dani HT 86.01 (Dani, Milan, Italy) instrument fitted with a flame ionisation detector (FID) and a Porapak Q column (Supelco, Bellefonte, PA, USA). The carrier gas was nitrogen at a flow rate of 16 ml min^{-1}; oven temperature was 80 °C for the column and 150 °C for the injector and flame ionisation detector. The standard mixture for ethylene identification and quantification was 3.5 ppm C_2H_4, 5150 ppm CO_2, 28.81 % O_2 in N_2. Flesh firmness (FF) was estimated with a penetrometer (EFFE.GI, Ravenna, Italy), equipped with an 8-mm diameter probe, at the opposite side (equatorial position, skin removed) of each fruit.

The latter two fruit maturity parameters, ethylene production and flesh firmness, were considered to investigate differences in ripening process of fruits by interpolating the corresponding maturity stages of treated and untreated 'Abbé Fétel' pears.

Skin hue colour (°) was determined with a Minolta colorimeter (Model 310) over an average of two measurements performed at opposite fruit sides in the equator position. Soluble solids content (SSC) was determined in pear fruit mesocarp with an Atago digital refractometer (Optolab, Modena, Italy). Starch degradation in the pulp was estimated with 'Lugol Test' and an empirical scale (values ranging from 1 = high starch concentration, unripe fruits to 8 = low starch concentration, ripe fruits) was applied for classification.

Fruit quality after cold storage

Forty 'Abbé Fétel' pears per treatment were collected at harvest 1 and immediately stored at 4 °C in two different cold chambers to keep AVG treated fruits separate from the untreated ones. Fruits were analysed for ethylene production, skin hue colour, SSC, FF and starch accumulation as described above. AVG effects on maturity indices were evaluated:

– after 7 days cold storage at 4 °C;
– after 7 days cold storage plus 7 days shelf-life at 22 °C;
– after 14 days cold storage at 4 °C;
– after 14 days cold storage plus 7 days shelf-life at 22 °C.

'Bartlett' fruit dip: preliminary experiment

60 'Bartlett' pears were collected and 30 were dipped for 3 minutes in a water solution containing AVG 125 ppm (0.83 g L^{-1} ReTain®) and the surfactant Silwet L-77® at the concentration of 0.5 ml L^{-1}.; control fruits were dipped in water plus the surfactant. After treatment, fruits were kept separately in two chambers at 25 °C. Temperature and maturity indices (ethylene, FF and SSC) were monitored over 15 days.

Results

AVG applications 21 days and 14 days prior to harvest 1 were performed when the 'Abbé Fétel' pears were still in a pre climacteric stage. Only the last AVG treatment (7 days prior to harvest 1) was applied when fruit ethylene emission reached an average value of 2 µL C_2H_4 h^{-1} kg^{-1} at the beginning of the climacteric rise (Fig. 1).

The effects of AVG applications on maturity indices at one-week intervals (beginning on 17 September for harvest 1) are reported in Table 1. AVG treated fruits were generally characterised by firmer flesh as compared with untreated fruits; differences were detectable at all the harvests, the latter AVG application seven days prior to first harvest being the most effective on this parameter. The flesh firmness was statis-

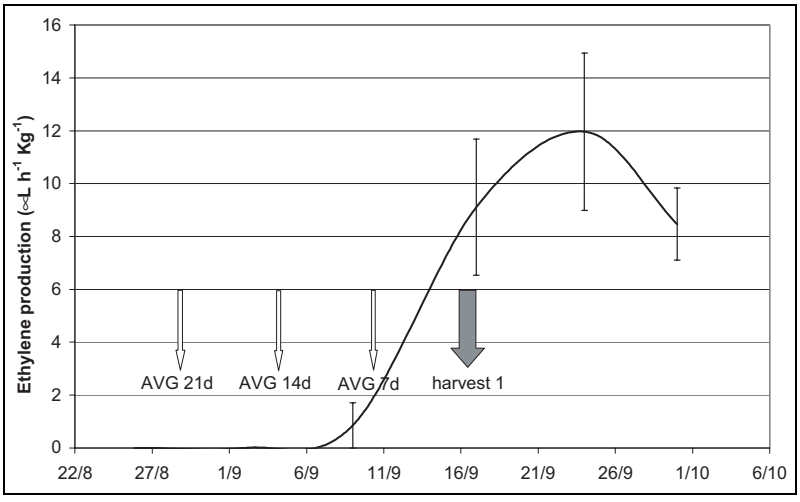


Fig. 1. AVG treatments (white arrows) and first harvest (black harrow) in relation to ethylene emission of untreated 'Abbé Fétel' pears (period of lime 22/08/2002 to 06/10/2002).

Table 1. Effects of AVG on ripening and quality parameters of 'Abbé Fétel' pears at harvests 1 (17 September), 2 (24 September) and 3 (30 September) in 2002.

Treatments	Ethylene prod. ($\mu L\ h^{-1}\ kg^{-1}$)	Firmness ($kg\ cm^{-2}$)	Skin hue colour (°)	SSC (°Brix)	Starch (Scale 0–8)	Weight (g)
Harvest 1						
Control	9.1 a*	3.4 b	125.6 a	14.7 a	5.2 b	276.9 b
AVG 7d	0.7 b	4.0 a	111.9 a	14.3 a	6.5 a	313.4 a
AVG 14d	1.2 b	3.9 ab	133.6 a	14.7 a	4.2 b	286.9 ab
AVG 21d	0.1 b	3.9 ab	110.2 a	14.5 a	5.4 ab	287.9 ab
Harvest 2						
Control	11.9 a	1.6 b	134.2 a	15.1 a	7.5 a	287.5 a
AVG 7d	1.9 b	3.4 a	126.7 a	14.2 b	7.4 a	311.5 a
AVG 14d	3.8 b	3.3 a	115.8 a	14.9 a	7.4 a	298.6 a
AVG 21d	3.5 b	3.5 a	118.1 a	14.6 ab	6.9 a	291.9 a
Harvest 3						
Control	8.5 a	2.2 b	137.8 a	15.0 a	7.2 a	281.1 a
AVG 7d	3.7 b	3.2 a	119.4 a	15.2 a	7.4 a	316.5 a
AVG 14d	3.7 b	2.9 a	121.3 a	14.6 a	7.0 a	289.8 a
AVG 21d	4.9 ab	2.7 a	118.5 a	15.2 a	6.8 a	295.5 a

*: values followed by the same letters did not statistically differ. Duncan Multiple Range Test, $P<0.05$.

tically different from all the other treatments in harvest 1.

Untreated pears produced considerably more ethylene as compared with AVG treated pears. Over the three harvests, control and AVG treated pears produced roughly 9 to 12 $\mu L\ C_2H_4\ h^{-1}\ kg^{-1}$ and 0.1 to 4.9 $\mu L\ C_2H_4\ h^{-1}\ kg^{-1}$, respectively. Other fruit maturity parameters, i.e. skin hue colour, SSC, starch accumulation, and fruit weight (see Table 1), were less effected by AVG applications.

AVG induced a delay in maturity of 'Abbé Fétel' pears (Fig.2 and 3). For ethylene production the delay in maturation, estimated by interpolating the maturity stages of treated with untreated fruits, was calculated as approximately 6–9 days at harvest 1. The delay is even higher for the following harvests: 10–12 days for harvest 2 and 12–15 for harvest 3. Small differences were calculated among AVG treatments. Similar delays were also determined by considering flesh firmness as the reference parameter for fruit maturity: a delay of 4 to 9 days was calculated for harvest 1; 9 to 10 days for harvest 2 and 11 to 15 days for harvest 3. The delay induced by the AVG application 7 days before harvest 1 was more marked than that for the other AVG treatments and for the second and third harvests (Fig. 3).

The AVG effects on ethylene production, flesh firmness and fruit skin colour were retained even after 7 days storage at 4 °C. As reported in Table 2 (treatment A), AVG treated pears produced lower amounts of ethylene than untreated pears, thus showing a similar condition to that recorded immediately after harvest 1. As regarding the flesh firmness parameter, AVG treated fruits retained their characteristic higher firmness as compared to untreated fruits after cold storage (see, especially, val-

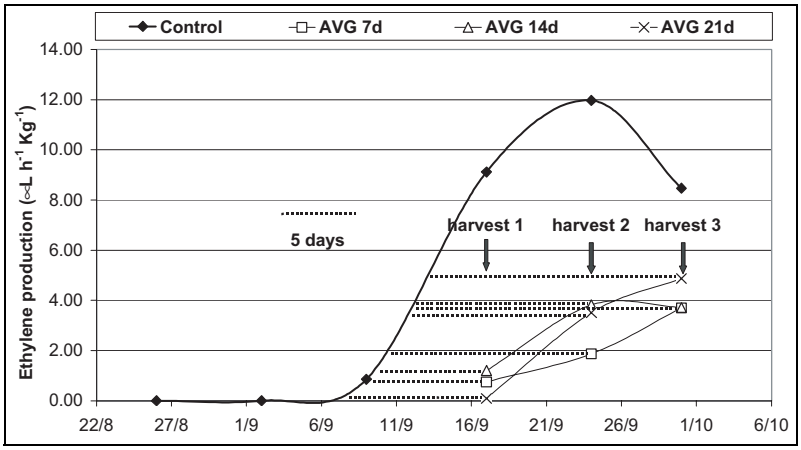


Fig. 2. Ethylene production during 'Abbé Fétel' fruit ripening. The delayed maturity of AVG treated pears at harvests 1, 2, and 3 is reported with the transposed harvest day (dotted line) for these treatments with respect to control (period of lime 22/08/2002 to 06/10/2002).

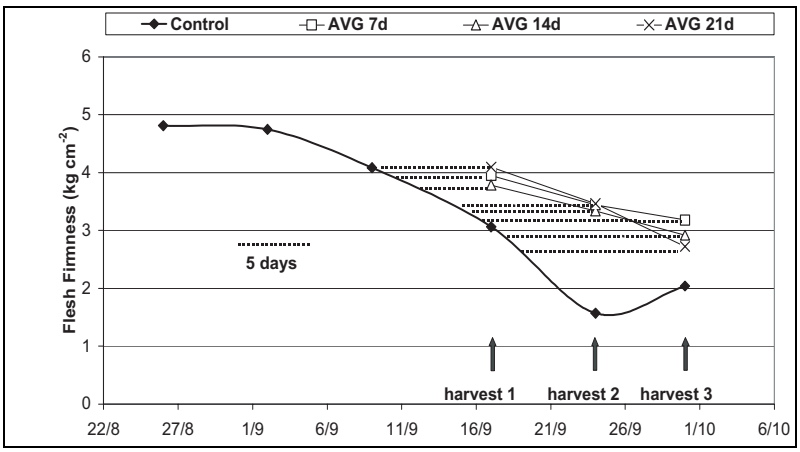


Fig. 3. Pulp firmness during 'Abbé Fétel' ripening. The delayed fruit maturity of AVG treated pears for harvests 1, 2, and 3 is reported with the transposed harvest day (dotted line) for these treatments with respect to control (period of lime 22/08/2002 to 06/10/2002).

Table 2. Effects of AVG on ripening and quality parameters of 'Abbé Fétel' pear fruits stored 7 days immediately after harvest 1 at 4 °C (treatment A) and 7 days at 4 °C plus 7 more days at 22 °C shelf-life conditions (treatment B).

	Ethylene prod. (μL h^{-1} kg^{-1})	Firmness (kg cm^{-2})	Skin hue colour (°)	SSC (°Brix)	Starch (Scale 0–8)	Weight (g)
Treatment A						
Control	10.3 a	3.9 ab	114.5 b	14.9 a	7.5 a	295.8 a
AVG 7d	2.0 ab	3.1 b	112.5 b	14.3 a	7.4 a	299.4 a
AVG 14d	0.0 b	4.1 a	111.0 b	14.9 a	7.1 a	266.3 a
AVG 21d	0.0 b	4.2 a	151.9 a	14.5 a	7.3 a	272.2 a
Treatment B						
Control	5.4 a	2.1 a	168.3 a	14.8 a	7.0 a	292.8 a
AVG 7d	2.8 a	3.0 a	127.9 a	14.9 a	6.7 a	292.2 a
AVG 14d	5.9 a	1.9 a	117.8 a	15.3 a	7.7 a	300.5 a
AVG 21d	2.4 a	2.6 a	119.4 a	15.5 a	7.2 a	237.7 a

*: values followed by the same letters did not statistically differ. Duncan Multiple Range Test, $P<0.05$

ues for AVG 14d and AVG 21d treatments). After 7 days cold storage, skin coloration of fruits treated with AVG 21 days prior to harvest 1 (skin hue angle 152 degree, corresponding to green colour) was significantly different from all the other treatments (skin hue angle around 110 degree, corresponding to yellow-green colour), therefore showing a tendency towards an "unripe" coloration of this group of fruits. SSC, starch accumulation, and weight showed no differences among treatments. When 'Abbé Fétel' pears were evaluated after 7 days cold storage plus 7 days at 22 °C (shelf-life, Table 2, treatment B), the differences noted above were markedly reduced and none was significant.

The same methodological approach was also applied after 14 days cold storage, followed by determination of ripening parameters before and after 7-day shelf-life period at 22 °C (data not shown). Differences were limited and rarely significant. The effect of treatment on flesh firmness was clear-cut on pears after 14 days cold storage for AVG 21 d only (FF: 4.0 kg cm^{-2}); correspondingly, ethylene emission was also low (2.9 μL h^{-1} kg^{-1}) as compared to other treatments. After 7 days at 22 °C, pears were completely ripe irrespective of pre-harvest AVG applications. Noteworthy were the differences in skin colour: pears treated with AVG 7 days prior to first harvest were fully ripened, showing a brownish-red skin colour (hue angle close to 15 degree). 'Abbé Fétel' pears in the other treatments were marked by a higher incidence of skin russeting, showing a tendency towards the green-brown area of reference L, a, b colour position (hue values above 60 degree).

Preliminary indications for post-harvest AVG treatments of 'Bartlett' pears are reported in Fig. 4. Two main fruit quality parameters (ethylene emission and flesh firmness) were monitored for 15 days after dipping pears. Ethylene emission apparently was not affected by AVG application; only in the last analytical run untreated pears produced more ethylene, registering the highest trial values (about 11 μL h^{-1} kg^{-1} for control fruits vs. 5 μL h^{-1} kg^{-1} for AVG treated fruits). AVG dipped 'Bartlett' fruits showed less softening, an effect that was detectable soon after treatment and reached maximum expression 8–10 days later. It also appeared as a temporary phenomenon, given that close values were detected 12 days after treatment (average FF approximately 0.5 kg cm^{-2}). SSC determination did

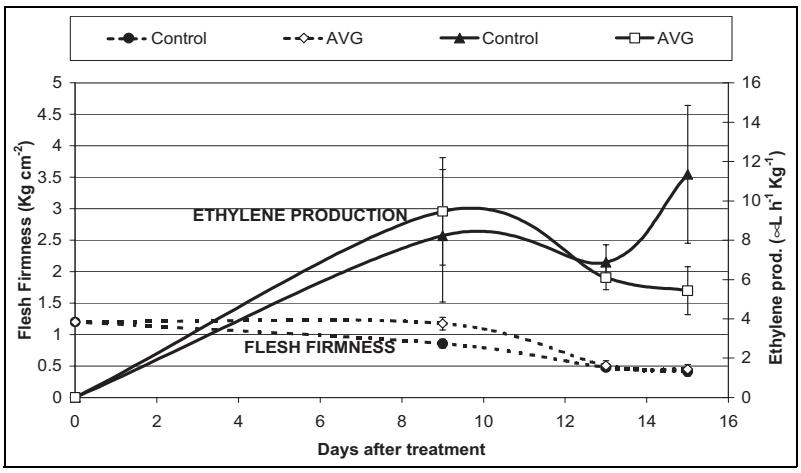


Fig. 4. Post-harvest dip of 'Bartlett' fruits: AVG effects on ethylene emission (solid lines) and on flesh firmness (dotted lines).

not evince any clear effect of AVG applications on 'Bartlett' pears content (data not shown).

Discussion and Conclusion

AVG treated 'Abbé Fétel' pears showed delayed ripening under our conditions. AVG application 7 days prior to harvest 1 induced significant effects on ethylene production and flesh firmness. The first AVG application (21 days prior to harvest 1) and the last harvest date, gave a time span of AVG influence on fruit maturity of approximately 35 days. This delay in fruit ripening was mainly due to an inhibition of ethylene biosynthesis, followed by reduced softening in flesh firmness, as reported for 'Bartlett' pear by NESS and ROMANI (1980), apple (BRAMLAGE et al. 1980; WILLIAMS 1980; AUTIO and BRAMLAGE 1982) and peach (BYERS 1997; BREGOLI et al. 2002). However, pre-harvest AVG treatments of 'Bartlett' pear delayed fruit maturation with firmer flesh, but not in ethylene production compared with untreated pears (CLAYTON et al. 2000). As suggested by ROMANI et al. (1983), this discrepancy between delayed maturation without ethylene reduction may reflect physiological differences in fruit development when AVG was applied before harvest.

After a short period of cold storage (7 or 14 days at 4 °C), 'Abbé Fétel' pears pre-harvest treated with AVG ripened more slowly as compared with untreated fruit. By the end of storage, there was no residual effect of AVG after a few days at room temperature. As suggested by AUTIO and BRAMLAGE (1982) for early and late season apple cultivars, internal fruit ethylene levels were likely sufficient to induce ripening regardless of storage temperature or AVG treatments.

Post-harvest ripening of 'Bartlett' pears was delayed after fruit dip in AVG water solution. Fruit flesh softening was reduced, thus confirming the indications of previous studies on pear (WANG and MELLENTHIN 1977; NESS and ROMANI 1980), apple (JU and CURRY 2000), and peach (BYERS 1997).

To conclude, AVG can be considered for its potential as a chemical tool to delay the final stages of pear fruits ripening, therefore representing a valuable approach for the optimisation of the final phases of fruit maturation, time of harvest, storage and commercialisation.

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