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Short communication

Early spring inhibition of ethylene synthesis increases fruit set and yield of 'Rocha' pear trees in Southern Brazil

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ABSTRACT

Low fruit set is one of the main factors leading to poor yield of pear orchards in Brazil. Early spring exogenous application of aminoethoxyvinilglycine (AVG) has shown promising results to increase fruit set and yield in some pear cultivars. Therefore, the objective of this study was to evaluate fruit set, yield and fruit quality of 'Rocha' pear trees in response to different rates of AVG (0, 60, 80 and 100 mg L^{-1}) sprayed seven days after full bloom (DAFB). The study was performed during the 2016/2017 growing season, in an eight-year-old 'Rocha' pear orchard grafted onto quince rootstock 'BA29'. Flowers were collected in the field two days after AVG application and assessed for ethylene production rate. Fruit set, number of fruits per tree, average fruit weight, yield, projected yield, number of thinned fruits, fruit quality, seed number and return bloom were also assessed. AVG significantly reduced ethylene production rate while fruit set and yield were increased in a rate-dependent manner. Fruit weight was reduced but as a direct effect of higher crop load induced by AVG. Return bloom was negatively affected only in response to AVG 100 mg L^{-1}. These results implicate AVG as a potential tool to increase fruit set and yield of 'Rocha' pear trees in the climatic conditions of Southern Brazil.

1. Introduction

Pear (*Pyrus* spp.) is widely cultivated in the world, with an estimated production of 25.8 million tons in 2014. Cultivation in Brazil is incipient, with a production of 22,078 tons in 2013, which represents about 10% of domestic demand (FAOSTAT, 2017a). Concomitantly, 90% (189,300 tons) of the country's pears are imported, primarily from Argentina and Portugal (FAOSTAT, 2017b). This scenario clearly indicates market demand and presents opportunity for Brazilian growers to diversify the production of tree fruit crops.

The main problems for pear cultivation in Brazil are poor flower bud development (Pasa et al., 2011), excessive vegetative growth (Carra et al., 2016) and low fruit set (Hawerroth et al., 2011; Pasa et al., 2017). Moreover, a dearth of regionally relevant rootstock and scion performance data contribute to suboptimal yield and orchard efficiency. Harvestable yield is a result of several events, most notably, fruit set (Webster, 2002; Williams, 1970). Low fruit set of some pear cultivars has been reported in Brazil and worldwide (Hawerroth et al., 2011; Pasa et al., 2017; Sánchez et al., 2011). Flowers are pre-programmed to abscise after anthesis unless they receive a new stimulus commonly associated with pollination and fertilization (Jackson, 2003). However, even when these factors are suitable, pear trees frequently fail to produce adequate yields (Webster, 2002).

A successful fruit set is dependent on the transfer of viable and compatible pollen to the stigma, germination of pollen grains and timely growth of pollen tubes to the base of the style and ovary to fertilize the ovule. Alterations in any of these events may seriously impair fruit set and consequently yield (Sanzol and Herrero, 2001). To integrate pollen and pistil processes governing fertilization, Williams (1965) introduced a new concept, the effective pollination period

Abbreviations: AVG, aminoethoxyvinilglycine; DAFB, days after full bloom; FB, full bloom; EPP, effective pollination period; FF, flesh firmness; SSC, soluble solids content; C_2H_4, ethylene; SAM, S-adenosyl methionine; ACC, 1-aminocyclopropane-1-carboxylic acid

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(EPP). The EPP is determined by the ovule longevity minus the time lag required for pollen tubes to reach the ovule (Williams, 1970). EPP - depends not only on stigmatic receptivity, pollen tube kinetics and ovule development, but temperature, humidity, flower quality and chemical treatments (Sanzol and Herrero, 2001).

Low fruit set of pears has been partially attributed to ethylene, which is involved in the senescence and abscission of flowers (Greene, 1980; Martínez et al., 2013) and young fruits (Webster, 2002). The application of ethylene inhibitors such as aminoethoxyvinilglycine (AVG; ([S]-trans-2-amino-4-(2-aminoethoxy)-3-butenoic acid hydrochloride), may provide a potential tool to increase fruit set. AVG suppresses ethylene biosynthesis by inhibiting the enzymatic activity responsible for the conversion of S-adenosyl methionine (SAM) to 1-aminocyclopropane-1-carboxylic acid (ACC) (Yang and Hoffman, 1984). AVG has been used commercially to prevent preharvest fruit drop and to delay fruit maturity in apple trees by decreasing the ethylene production rate (Arseneault and Cline, 2016; Byers 1997; Rath et al., 2006; Robinson et al., 2010). Recently, AVG effectively increased fruit set of sweet cherry (*Prunus avium* L.) (Bound et al., 2014), walnut (*Juglans regia*) (Retamales and Petracek, 2010) and pear (Dussi et al., 2011; Einhorn and Wang, 2016; Pasa et al., 2017; Sánchez et al., 2011).

In a recent study, ethylene production rates of untreated flowers and fruitlets of 'Comice' and 'D'Anjou' pears peaked at 14 days after full bloom (DAFB) and was significantly and rate-dependently reduced by AVG (Einhorn and Wang, 2016). The partial inhibition of ethylene by 80–120 mg L^{-1} AVG was associated with a markedly higher fruit set and yield for both cultivars, but only when AVG was applied between 7 and 14 DAFB (Einhorn and Wang, 2016). A similar increase in fruit set and production was observed for 'Packham's Triumph' and 'Abate Fetel' treated with higher rates (between 100 and 400 mg L^{-1}) at 14 DAFB (Dussi et al., 2002, 2011; Sánchez et al., 2011). Given the limited information on the use of AVG to improve fruit set and yield of pears, the objective of this study was to evaluate ethylene production, fruit set, yield, and fruit quality of 'Rocha' pear trees in response to different AVG rates in the climatic conditions of Southern Brazil.

2. Materials and methods

2.1. Plant material

The experiment was performed in a commercial orchard in the municipality of São Joaquim, state of Santa Catarina, Brazil (Latitude 28° 17' 39" S, Longitude 49° 55' 56" W Greenwich, at 1350 m of altitude), during the 2016/2017 growing season. According to Köppen-Geiger classification, the climate of the studied region is a mesothermal humid (Cfb) temperate climate, constantly humid, without a dry season, and a characteristic cool summer. Average accumulation of temperatures below 7.2 °C is 800 h. Climatic conditions during the experiment are provided in Supplementary Fig. S1. The soil of the experimental field is an Inceptisol.

The experiment was performed in an eight-year-old orchard of 'Rocha' pear trees grafted onto quince rootstock 'BA29′. Trees were spaced 1 m between trees and 4 m between rows (2500 trees ha^{-1}) and trained to a central-leader system. Cultural practices during the experiment were similar in all treatments and performed according to commercial standards.

2.2. Experimental design and treatments

The experiment was arranged in a randomized complete block design with five replications. Each replication comprised a three-tree unit with the central tree as the experimental unit and the end trees as guards. All trees were selected by uniformity and size (canopy volume), then, grouped into blocks based on bloom density (number of flower clusters per tree at full bloom).

Treatments consisted of different rates of AVG (60, 80 and 100 mg L^{-1}) compared to untreated (control) trees. Trees were sprayed with AVG at 7 DAFB (19 September 2016). Full bloom was considered when approximately 50% of flowers were at anthesis stage. The AVG source was the commercial product ReTain® (Valent Bioscience Corporation, IL, USA), containing 15% of active ingredient. Solutions had a pH of ~6.5 and were supplemented with a non-ionic surfactant (Break-Thru®; BASF Corp., Research Triangle Park, NC), at a rate of 0.5 mL L^{-1} (0.05%). AVG was sprayed using a motorized backpack sprayer Stihl SR450 with a flow rate of 2.64 L min^{-1}. Trees were sprayed to runoff early in the morning, with temperatures ranging from 20 to 25 °C, relative humidity of 85%-95% and wind speed not exceeding 5 km $h^{-1.}$

2.3. Ethylene analysis

About 50 flowers per replicate were collected in the field two days after AVG application, placed in plastic bags, conditioned in a cooler and then immediately taken to the laboratory. After removing the flowers from the plastic bags, they were held for 20 min, to release wound ethylene, then weighted and placed in plastic tubes (50 mL) containing CaO (1 g per tube, to avoid CO_2 accumulation produced by respiration, which might inhibit ethylene production). Tubes were hermetically sealed with a rubber septum and left for 24 h at room temperature (22 ± 0.3 °C) (Adapted from Crisosto et al. (1992)). After 24 h, 1 mL of air was sampled from the tubes using syringes and analyzed for ethylene concentrations in a gas chromatograph equipped with a methanizer, a glass column (with 0.6 m and 3.2 mm i.d., packed with 80–100 mesh Poropak Q) and a flame ionization detector. Oven, detectors, methanizer and injector temperatures were set at 45, 120, 300 and 110 °C, respectively. Ethylene production rate (μL kg^{-1} h^{-1}) was calculated according to the following formula: Ethylene production rate = {C_2H_4 x (V-W) x (1/W) x (1/T)}, where: C_2H_4 in mg L^{-1}; V = volume of test tube (L); W = sample weight (kg); and T = time in test tube (h).

2.4. Fruit set, yield, fruit quality and return bloom

All flower clusters per tree were counted at full bloom (FB). After natural fruit drop (~ 40 DAFB), the number of fruit per tree was recorded to calculate fruit set, expressed as the number of fruit per tree divided by the number of flower clusters per tree. Trees were then hand thinned and the number of fruit removed was recorded. Return bloom was determined the ensuing year by counting the number of flower clusters per tree at FB. Full bloom occurred on 12 September 2016 and 07 September 2017 for the 2016/2017 and 2017/2018 growing seasons, respectively.

Fruit were harvested at commercial maturity on 07 February 2017 (149 DAFB). The total number of fruit per tree was counted and weighted (kg). From these data, the following parameters were calculated: yield (kg $tree^{-1}$); average fruit weight (g); and, projected yield (Mg ha^{-1}).

At harvest, 15 fruits per replicate (tree) were sampled for fruit quality analysis. Flesh firmness (FF) was measured with a digital firmness tester (Fruit Texture Analyzer, Güss Manufacturing, Strand, South Africa), using an 8 mm diameter probe, and expressed in Newtons. Sections of skin (2 cm in diameter) were removed at the widest point of the fruit on opposite sides prior to the determination of FF. A composite sample of fruit flesh per replicate was juiced, and 0.5 mL of juice was placed onto a digital refractometer (model PR-32, Atago Co., Tokyo, Japan) to determine soluble solids content (SSC), expressed as °Brix. The number of viable seeds per fruit was assessed by cutting the fruit in two halves and manually removing and counting the viable seeds of each fruit.

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