EFFECT OF AMINOETHOXYVINILGLYCINE (AVG) ON PREHARVEST FRUIT DROP AND MATURITY OF APPLES[1]

CASSANDRO VIDAL TALAMINI DO AMARANTE[2], ANDERSON SIMIONI[3], CLARICE APARECIDA MEGGUER[3], LUIZ EDUARDO BASSAY BLUM[4]

ABSTRACT - Apple trees cultivars Gala and Fuji were sprayed four weeks before commercial harvest with aminoethoxyvinilglycine (AVG), at doses of 0, 125, or 250 mg L^{-1}, and assessed for preharvest fruit drop, fruit growth, and maturation on tree. In 'Gala', 64 days after AVG spraying, fruit drop for control treatment was 85%, and AVG (at 125 and 250 mg L^{-1}) reduced it to 10%. In 'Fuji', 64 days after AVG spraying, fruit drop for control was 6%, while treatments with AVG (at 125 and 250 mg L^{-1}) increased fruit drop to 10%. AVG was a powerful retardant of fruit maturation for 'Gala' but not for 'Fuji'. In 'Gala', the most affected attribute was the skin background color, followed, in decreasing order, by soluble solids content, the starch index, skin red color, the flesh firmness, and titratable acidity. In 'Gala', only flesh firmness retention was improved by increasing AVG dose from 125 mg L^{-1} to 250 mg L^{-1}. The AVG at 250 mg L^{-1} inhibited "Gala" late fruit growth but not 'Fuji'.

Index terms: *Malus domestica* Borkh., regulator, ethylene, fruit growth, fruit quality.

EFEITO DO TRATAMENTO COM AMINOETOXIVINILGLICINA (AVG) NA QUEDA PRÉ-COLHEITA E NA MATURAÇÃO DOS FRUTOS EM MACIEIRAS

RESUMO - Macieiras, das cultivares Gala e Fuji, foram pulverizadas quatro semanas antes do início da colheita comercial dos frutos com aminoetoxivinilglicina (AVG), nas concentrações de 0; 125 ou 250 mg L^{-1}, e avaliadas quanto à queda de frutos na pré-colheita, o crescimento e maturação dos frutos. Na cultivar Gala, 64 dias após a pulverização com AVG, a queda pré-colheita no tratamento-controle era de 85%, mas os tratamentos com AVG (125 e 250 mg L^{-1}) reduziram esta queda para 10%. Na cultivar Fuji, 64 dias após a pulverização com AVG, a queda de frutos no tratamento-controle era de 6%, e os tratamentos com AVG (125 e 250 mg L^{-1}) aumentaram esta queda para 10%. Tratamentos com AVG retardaram substancialmente a maturação dos frutos da cultivar Gala, mas não da 'Fuji'. Na cultivar Gala, o atributo mais afetado foi a cor de fundo da casca, seguido, em ordem decrescente, pelo conteúdo de sólidos solúveis totais, índice de iodo-amido, cor vermelha da casca, firmeza de polpa e acidez titulável. Na cultivar Gala, apenas a retenção de firmeza de polpa foi significativamente aumentada com o aumento na concentração de AVG de 125 mg L^{-1} para 250 mg L^{-1}. A concentração de 250 mg L^{-1} inibiu o crescimento final de frutos na cultivar Gala, mas não na 'Fuji'.

Termos para indexação: *Malus domestica* Borkh., Biorregulador vegetal, etileno, crescimento de frutos, qualidade de frutos.

INTRODUCTION

Aminoethoxyvinilglycine (AVG) is a potent inhibitor of ethylene biosynthesis that inhibits the conversion of S-adenosyl methionine to 1-aminocyclopropane-1-carboxylic acid (Yang & Hoffman, 1984). Pre and postharvest applications of AVG have been evaluated for enhancement of production and quality attributes of climacteric fruits.

Preharvest abscission and ripening of apples are events regulated by ethylene (Masia et al., 1998; Ward et al., 1999). Apple fruit abscission shortly before harvest is the most frequent recurring problem, thereby reducing potential yield. Ethylene stimulates increasing synthesis and activity of cellulase and polygalacturonase in the abscission zone of apple causing preharvest fruit drop (Ward et al., 1999). Apple growers often utilize the synthetic auxin, naphthaleneacetic acid (NAA), which can suppress preharvest fruit abscision, but the product does not delay fruit maturation on the tree (Masia et al., 1998). On the other hand, AVG can reduce fruit ethylene production, reducing preharvest fruit drop and the incidence of premature fruit ripening on the tree (Bramlage et al., 1980). The product may increase yield by reducing preharvest fruit drop and increasing fruit size of late harvested fruit. Delaying harvest may provide flexibility for scheduling of labor, fruit processing and packaging, cold storage, and marketing.

Pre and postharvest treatments with AVG suppressed ethylene production and delayed ripening of pear (Romani et al., 1983; Clayton et al., 2000), peach (Ju et al., 1999), kiwifruit (Manriquez et al., 1999), avocado (Starrett & Laties, 1991), and muskmelon (Shellie, 1999). In 'Golden Delicious' apples, AVG sprayed four weeks before harvest inhibited ethylene production, reduced preharvest drop, delayed fruit maturation on the tree and fruit ripening and softening during storage (Bramlage et al., 1980; Autio & Bramlage, 1982; Masia et al., 1998). Bramlage et al. (1980) found that the magnitude of delayed ripening in apples was dependent on cultivar and AVG concentration. Preharvest treatments with AVG reduced cuticular free phenolics, alpha-farnesene accumulation and oxidation, and scald development on apples (Ju & Bramlage, 2000). AVG sprays reduced the incidence of water core and maturity cracking in apples particularly when the harvest was delayed beyond the optimum harvest date (Autio & Bramlage, 1982). However, AVG might impair fruit quality by inhibiting volatiles production (Fan et al., 1998; Mir et al., 1999; Harb et al., 2000) and development of red color of the skin (Layne et al., 2000; Wang & Dilley, 2001). Nevertheless, the application of ethephon after treatment with AVG reversed the negative effect of AVG on fruit flavor and red color development of the skin in apples (Mir et al., 1999; Wang & Dilley, 2001).

This work was conducted to study the effects of different doses of AVG, sprayed four weeks before commercial harvest, on preharvest drop, fruit growth and maturity of 'Gala' and 'Fuji' apples.

MATERIALS AND METHODS

The experiment was conducted in a commercial orchard in Lages, Santa Catarina State, Southern Brazil. Twelve-years-old apple trees, cultivars Gala and Fuji, grafted on Marubakaido rootstock, were sprayed four weeks before commercial harvest with aminoethoxyvinilglycine (AVG; ReTain™, 15 % a.i. p/p, Abbott Laboratories Inc. – Agricultural Products, IL, USA), at doses of 0, 125, or 250 mg (a.i.) L^{-1}, and assessed for preharvest fruit drop, fruit growth and evolution of fruit maturity on the tree. 'Gala' apples were sprayed on 16 January 2001 and 'Fuji' apples were sprayed on 2 March 2001.

The experiments to investigate the effects of different doses of AVG on preharvest fruit drop of 'Gala' and 'Fuji' followed a completely

1 (Trabalho 049/2002). Recebido: 12/03/2002. Aceito para publicação: 26/09/2002.
Ph.D., Centro de Ciências Agroveterinárias (CAV), Universidade do Estado de Santa Catarina (UDESC), Cx. Postal 281, CEP 88502-970, Lages, SC, Brasil. E-mail: amarante@cav.udesc.br.
2 Estudante do Curso de Agronomia, Centro de Ciências Agroveterinárias (CAV), Universidade do Estado de Santa Catarina (UDESC), Cx. Postal 281, CEP 88502-970, Lages, SC, Brasil. Bolsista de Iniciação Científica do CNPq.
3 Ph.D., Centro de Ciências Agroveterinárias (CAV), Universidade do Estado de Santa Catarina (UDESC), Cx. Postal 281, CEP 88502-970, Lages, SC, Brasil. E-mail: a2lbb@cav.udesc.br.

randomized block design with five replicates. Whole trees were blocks and single-scaffold limbs per tree were the experimental units. Three branches in the medium part of each tree were labeled, and each branch was separated from the surrounding branches by plastic sheets and sprayed with the AVG solutions containing an organo-silicon surfactant (0.1% v/v Silwet L-77) up to dripping. The treatments were applied in a random distribution on separate branches of each tree. All the fruit from each limb were counted and marked with a waterproof ink pen. The percentage of dropped fruit was evaluated weekly until 64 days and 84 days after AVG spraying on 'Gala' and 'Fuji', respectively.

To investigate the effects of different doses of AVG on fruit growth and maturation on 'Gala' and 'Fuji' tree, three branches in the medium part of each of 40 trees in the same row were labeled, and each branch was sprayed with the AVG treatments described above. All fruits from each labeled branch of four replicate trees were harvested and assessed for average fruit weight and maturity, starting at the date of AVG spraying until 64 and 91 days after the treatment for 'Gala' and 'Fuji', respectively. Samples of 20 fruit of uniform size per replicate were assessed for maturity at each harvest date. Skin background color was assessed by means of a color chart (ENZA New Zealand International) on a scale of 1 (dark-green) to 8 (yellow-green). Flesh firmness (*N*) was determined on two sides of each fruit using a hand held penetrometer (Effegi FT 327, fitted with an 11.1 mm diameter head). Soluble solids content (SSC; °Brix) was determined with a hand refractometer (Abbe Atago) on a composite juice sample collected during the pressure test. The starch pattern index (using the starch iodine test) was scored on a scale of 1 to 5, where 1 indicates the least and 5 the most starch to sugar conversion. Titratable acidity (meq. malic acid/100 mL) from juice composite samples of five fruits was determined by titrating to pH 8.2 with 0.1N NaOH.

Statistical analysis of the data was performed using the SAS system (SAS, 1990). Analysis of variance (ANOVA) was performed using the PROC GLM procedure; the best fit was achieved using the PROC REG or PROC NLIN procedures. Percentage data was transformed to arc sin $[(x+5)/100]^{1/2}$ before being submitted to the ANOVA.

RESULTS AND DISCUSSION

Preharvest fruit drop on 'Gala' was much higher than on 'Fuji' (Figure 1). AVG was highly effective in suppressing fruit drop of 'Gala' while on 'Fuji' the product slightly increased fruit drop. On 'Gala', 64 days after AVG spraying, fruit drop for the control treatment was 85%, and AVG at 125 mg L^{-1} and 250 mg L^{-1} reduced this number to 10% (Figure 1A). In 'Fuji', 64 days after AVG spraying, fruit drop for the control was 6%, while treatments with AVG at 125 mg L^{-1} and 250 mg L^{-1} increased fruit drop to 10% (Figure 1B).

On 'Gala', the increase of fruit weight was similar between treatments until 30 days after spraying the trees (Figure 1C). At the end of this period, fruit weight averaged between treatments was 151 g. Thirty-five days latter, fruit treated with AVG at 125 mg L^{-1} had an increment of fruit weight of 12.5%, increasing to 170 g. However, 'Gala' treated with AVG at 250 mg L^{-1} did not show further increments in weight 30 days after treatment (Figure 1C). On 'Fuji', fruit weight was not affected by AVG (Figure 1D). For this cultivar fruit growth showed a bell shape curve, with an increase in fresh matter accumulation until 45-50 days after spraying, followed by a decrease thereafter. This decrease of fruit weight might indicate a mobilization of reserves from the fruit to the wood as a result of changes of physiological status of the trees towards dormancy in autumn (Faust, 1989).

AVG at 250 mg L^{-1} seems to be toxic for 'Gala', inhibiting late fruit growth, but not for 'Fuji' (Figure 1). This might indicate different sensibility of these cultivars to AVG. High doses of AVG also reduced fruit size at harvest of apples (Williams, 1980) and peaches (Dekazos, 1981) and caused leaf chlorosis in muskmelon (Shellie, 1999). Considering that AVG inhibits enzymes that use the cofactor pyridoxal phosphate, such as ACC synthase (Yang & Hoffman, 1984), it might be foreseen that a high dose of the product is able to inhibit other metabolism processes in the plant required for fruit growth in some apple cultivars.

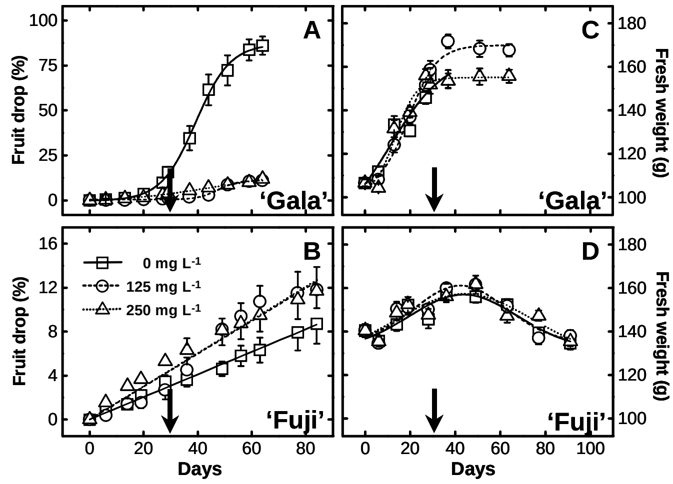

FIGURE 1 - Effect of AVG on preharvest fruit drop (A, B) and fruit growth (C, D) of 'Gala' and 'Fuji' apples. Arrows indicate the initial commercial harvest for the control treatment of each cultivar. The bars represent the standard error of the means (n = 5). The *x* axis represents days after AVG spraying. Note the difference on fruit drop scale for 'Gala' and 'Fuji' (A, B).

AVG had a more substantial effect in delaying fruit maturation on trees of 'Gala' than 'Fuji' (Figure 2). On 'Gala', only flesh firmness retention was substantially improved by increasing AVG dose from 125 mg L^{-1} to 250 mg L^{-1} (Figure 2F); for the other attributes, no additional benefit was achieved by using the highest AVG dose (Figure 2).

On 'Gala', the most expressive effect of AVG was the retention of skin background color, followed, in decreasing order, by the delay on changes of soluble solids content, starch pattern index, red color development of the skin, flesh firmness, and titratable acidity (Figure 2). The linear models adjusted for the evolution of skin background color, soluble solids content, starch pattern index, skin red color, and titratable acidity indicated that fruit treated with AVG (125-250 mg L^{-1}) required additionally 53, 40, 34, 28, and 8 days, respectively, to achieve the same level of maturity of the control treatment at the commercial harvest (Figure 2). The loss of flesh firmness was delayed in about 12 and 20 days with AVG at doses of 125 mg L^{-1} and 250 mg L^{-1}, respectively, in comparison to the control (Figure 2F).

On 'Fuji', changes in skin background color, soluble solids content, starch pattern index, skin red color, titratable acidity, and firmness were delayed by AVG (125-250 mg L^{-1}) in 10, 9, 10, 11, 4, and 2 days, respectively, in comparison to the control fruits harvested at the commercial maturity (Figure 2).

The results show that 'Gala', which produces high quantities of ethylene (Saquet & Streif, 2000) and, therefore, is highly susceptible to preharvest fruit drop and rapid maturation on the tree, substantial commercial benefits may be achieved with the use of AVG. On 'Gala', AVG at 125 mg L^{-1} may increase yield by reducing premature fruit abscission and by increasing fruit size of late harvested fruit. On the other hand, 'Fuji' produces small amounts of ethylene (Saquet & Streif, 2000) and AVG lack the capacity to reduce fruit drop and to delay fruit maturation on the tree. In fact, AVG seems to be toxic on 'Fuji', causing an increase of fruit drop in comparison to untreated controls (Figure 1B).

On 'Gala', considering flesh firmness to characterize fruit maturity, the treatment with AVG at 125 mg L^{-1} delayed fruit harvest in 12 days. This delay in fruit harvesting would result in an increase of fruit weight average of 9%. This treatment also suppressed preharvest fruit drop. The preharvest drop of the control at commercial harvest was 16%, while fruit treated with AVG at 125 mg L^{-1} and harvested 12 days latter had a preharvest drop of 3%. Therefore, AVG at 125 mg L^{-1}, by delaying fruit harvest in about 12 days allowed an increase of fruit yield of more than 20%.

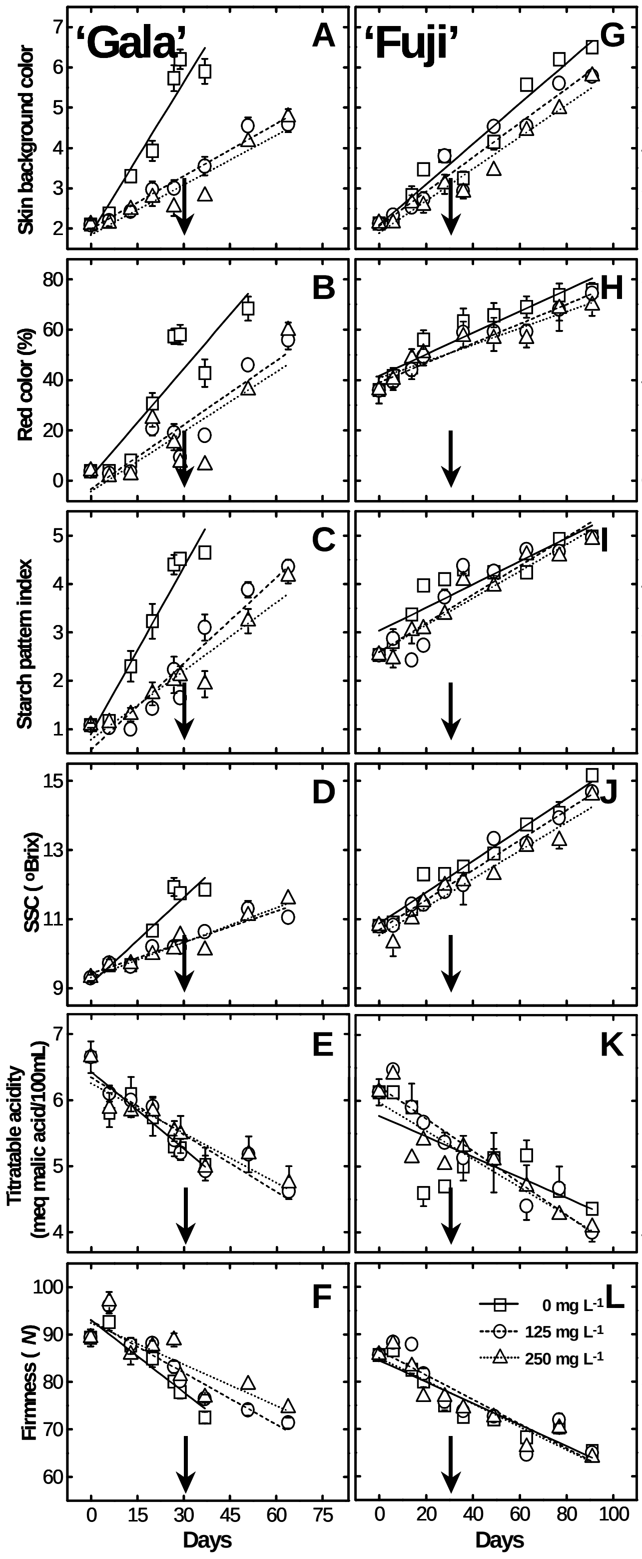

FIGURE 2 - Effects of AVG on skin background color (A, G), red color of the skin (B, H), starch pattern index (C, I), soluble solids content (SSC; D, J), titratable acidity (E, K), and flesh firmness (F, L) of 'Gala' (on the right) and 'Fuji' (on the left) apples. The bars represent the standard error of the means (n = 4). Arrows indicate the initial commercial harvest for the control treatment of each cultivar. The *x* axis represents days after AVG spraying.

However, ethylene biosynthesis inhibition by AVG on 'Gala' apples had differential impacts on different maturity attributes. The visual aspect might fail to match the fruit sensory attributes. The fruit might have poor skin color (dark-green background and deficient red color development) while still being able to mobilize starch, soften, and lose acidity on the tree. This might result in misjudgment during scheduling of harvesting time to achieve the best storage potential of AVG treated fruit. The reduced red color of the skin from AVG treatments impacts negatively on fruit quality. Nevertheless, this negative effect of AVG can be reversed by the application of ethephon close to the harvest (Wang & Dilley, 2001).

CONCLUSIONS

1. AVG substantially suppressed preharvest fruit drop and delayed fruit maturity on 'Gala' but not on 'Fuji';
2. On 'Gala', the AVG dose of 125 mg L^{-1} might be used commercially to delay fruit harvest and increase yield by reducing premature fruit abscission and increasing fruit size of late harvested fruit;
3. Fruit treated with AVG had poor skin color (dark-green background and deficient red color development) while still being able to mobilize starch, soften, and lose acidity on the tree.

ACKNOWLEDGMENTS

The authors are grateful to Yakult S.A. (Lages, SC) for their support in conducting the field works.

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