Scientia Agraria Paranaensis – Sci. Agrar. Parana.
ISSN: 1983-1471 – Online

ABSCISIC ACID ON THE QUALITY OF TOMATO FRUITS

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SAP 22876 Received: 25/07/2019 Accepted: 11/10/2019
Sci. Agrar. Parana., Marechal Cândido Rondon, v. 19, n. 1, jan./mar., p. 38-42, 2020

ABSTRACT - The use of abscisic acid (ABA) in agriculture has increased in the last few years due to the increase in ABA commercial availability at lower costs. The objective of this study was to determine the effect of exogenous ABA on tomato fruit quality parameters such as soluble solids (SS), total and soluble pectins, titratable acidity (TA) and flesh firmness. Tomatoes from the cultivar 'Santa Clara' were the study followed a complete randomized block desig, with four treatments in five repetitions. The treatments were plants not treated with ABA (control), foliar sprayed with ABA at 500 mg L^{-1}, 150 mL drench with ABA at 500 mg L^{-1}, or foliar plus drench treated with ABA. After harvesting, the physicochemical characteristics of the fruits were evaluated in the laboratory. All treatments were weekly applied to the plants from anthesis to harvest at fully maturity. Root treatment increased SS by up to 26.12%, increased ratio SS/TA, firmness and decreased soluble pectin. According to the results, it can be concluded that the application of ABA to leaves and roots can improve fruit quality by increasing the SS, ratio SS/TA. The method of application affects the SS content.
Keywords: *Solanum lycopersicum* L., firmness, pectin, plant hormone, soluble solids.

ÁCIDO ABSCÍSICO NA QUALIDADE DE FRUTOS DE TOMATE

RESUMO - Nos últimos anos o uso do ácido abscísico (ABA) na agricultura cresceu devido ao aumento da produção comercial de ABA a custos mais baixos. O objetivo deste estudo foi analisar o efeito da aplicação externa de ABA nos parâmetros de qualidade dos frutos de tomate como sólidos solúveis (SS), pectina total, pectina solúvel, acidez titulável (AT) e firmeza da polpa. Para condução do experimento foram utilizados tomate da cultivar 'Santa Clara' e o ensaio foi conduzido em delineamento de blocos casualizados com quatro tratamentos em cinco repetições. Os tratamentos consistiram em plantas não tratadas com ABA (controle), pulverização foliar com ABA a 500 mg L^{-1}, tratamento radicular com 150 mL de solução de ABA a 500 mg L^{-1}, ou combinação de foliar e radicular. Após a colheita foi avaliado as características físico-química dos frutos em laboratório. Todos os tratamentos foram aplicados semanalmente às plantas desde a antese até a colheita na maturidade. O tratamento da raiz aumentou o teor de SS em até 26,12%, aumentou a firmeza e diminuiu a pectina solúvel. De acordo com os resultados, pode-se concluir que a aplicação de ABA nas folhas e raízes pode melhorar a qualidade dos frutos, aumentando a relação SS/AT, e o método de aplicação afeta o conteúdo do SS.
Palavras-chave: *Solanum lycopersicum* L., firmeza, hormônio, pectina, sólidos solúveis.

INTRODUCTION

Tomato (*Solanum lycopersicum*) is one of the most cultivated and consumed vegetable worldwide. Quality and yield of tomatoes are determined by genetic and environmental factors, which influence the levels of vitamins, antioxidants, soluble solids, titratable acidity, and other compounds in the fruit. More than 60% of the dry matter is made up of sugars and organic acids and it is essential that high level of sugars and acidity are balanced (LIU et al., 2009; GOMES et al., 2017).

Abscisic acid (ABA) is a plant growth regulator involved in many plant processes such as on mechanisms determining fruit quality (BURAN et al., 2012; ZAHARAH et al., 2013; ZHANG; WHITING, 2013; BALATE et al., 2018). Endogenous ABA may accelerate ripening as ABA levels increases rapidly after the

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beginning of fruit ripening (SUN et al., 2010). Southern high-bush blueberries treatment with exogenous ABA delays fruit ripening and promotes fruit softening (BURAN et al., 2012). ABA has been used in grapevine for color enhancement and improvement of fruit repining (GU et al., 2011).

Exogenous ABA improved the uptake of sugar into vacuoles in immature apple fruits (YOMAKI; ASAKURA, 1991), and increased the sugar concentration of developing citrus fruit (LENG et al., 2014). In tomato, ABA treatment is reported to increase soluble solids (SS) and decreased firmness as a result of high ethylene production (ZHANG et al., 2009; SUN et al., 2012).

Due to the high cost of ABA, it was not until recently a considered as commercially alternative for the horticultural industry. However, the cost of ABA has reduced dramatically in recent years and, therefore is now available for commercial use, offering a new tool for fruit improvement in horticulture (GU et al., 2011). The objective of this study was to determine the effect of exogenous ABA on the tomato fruit quality parameters such as soluble solids, total pectin, soluble pectin, titratable acidity, flesh firmness.

MATERIAL AND METHODS

Tomato seeds cultivar 'Santa Clara' were sown in a 78 cell plastic trays and germinated in a protected environment (non-heated greenhouse) from February to July 2016, in Lavras (Minas Gerais, Brazil), which is located at the latitude 21°14'S, longitude 45°00'W and altitude 918,8 m. The climate of the region, according to the climatic classification of Köppen, is *Cwa* (mesothermal) with dry winters and rainy summers (ALVARES et al., 2013).

At 35 days after sowing, plants were transferred to the greenhouse (30 m long, 10 m wide and 3.0 m height, covered by plastic film [150 μm]). Plants were grown of 10 L pots filled with soil. The experiment set up was a complete randomized block design, with four treatments and five replications per treatment. Each replication was composed by 10 plants. ABA treatments were applied as foliar, root and combination of root and foliar.

The foliar application consisted of 0.0 mg L^{-1} (deionised water) or 500 mg L^{-1} of ABA sprayed to the plants. All sprayed solutions contained 0.5 mL L^{-1} of Maxx organosilicone (Sumitomo Chemical, NSW, Australia) a surfactant. The plants were sprayed until foliage dripping. Root treatment consisted of 150 mL of 500 mg L^{-1} ABA drenched once a week. The combination of root and foliar treatments consisted of both treatments (500 mg L^{-1} foliar spray + 500 mg L^{-1} drenched) applied simultaneously to the same plants. All treatments were made from anthesis to mature green. Plants were drip irrigated twice a day, in the morning and afternoon.

The soil chemical and physical analysis showed pH in $CaCl_2$ = 5.4; K^+ = 70 mg dm^{-3}; P = 2.91 mg dm^{-3}; P-Rem = 27.41 mg L^{-1}; Ca^{+2} = 2.12 $cmol_c$ dm^{-3}; Mg^{+2} = 0.74 $cmol_c$ dm^{-3}; OM = 1.64 dag kg^{-1}; H+Al = 3.35 $cmol_c$ dm^{-3}; SB = 3.04 $cmol_c$ dm^{-3}; V = 47.6%; and granulometry of 46% sand, 36% clay and 18% of silt.

One month before transplanting the soil was corrected with the addition of 1.43 Mg ha^{-1} of dolomite in order to increase base saturation to 70% and follow the fertilization program according to soil recommendation of the Minas Gerais State (GOMES et al., 1999).

Fifteen days after transplant (DAT), plants were treated with deltamethrin, acephate, triflumuron, and thiamethoxam for pest management. The treatment followed the necessary recommendation. At 30, 45 and 60 DAT plants were treated with azoxystrobin and iprodione for disease management.

In each replication, 16 whole fruit, from the first cluster, without any visual symptom of blossom-end rot or diseases, were harvested and crushed. A sub-sample of 5.0 g were analyzed in triplicate. Total and soluble pectin was determined as proposed by McCready and McComb (1952) and was quantified as the percentage of galacturonic acid, according to the colorimetric method described by Bitter and Muir (1962).

Soluble solids (SS) were determined in the juice by direct reading on a digital refractometer (Hanna, HI 96801, USA) and the results were expressed as a percentage. Titratable acidity (TA) was determined by titration of 5 mL of juice diluted in 50 mL of deionized water with NaOH solution (0.1 mol L^{-1}) using phenolphthalein as an indicator. The results were expressed as the percentage of citric acid. The pH was measured with the pH meter Tec-3MP (Tecnal, Brazil). Firmness was determined with a digital penetrometer, 5 mm (Instruntherm, PTR-300, Brazil) and the result expressed as Newton (N mm^2).

Analysis of variance (ANOVA) was performed for each variable using the R software package (R CORE TEAM, 2018). The mean values were compared by Scott-Knott's test ($p>0.05$).

RESULTS AND DISCUSSIONS

ABA treatments resulted in higher SS content in tomato fruit, compared with non-treated fruit (Table 1). Other studies have also shown that external ABA can improve SS content in tomato (SUN et al., 2012; BARICKAMAN et al., 2016), in grape (KOYAMA et al., 2014), and mango (ZAHARAH et al., 2013). In addition, external ABA has been shown to increase SS in tomato during ripening through the activity of sucrose synthase (SUS) and the over expressing SUS genes (BASTIAS et al., 2011).

The root ABA treatment had the highest SS concentration, increasing SS by up to 26.18% compared to controls, whereas the combination of foliar and root ABA treatments increased by 16.24% and the foliar ABA treatment increased by 13.80%. Regardless of the application method deployed, ABA increased SS in tomato fruit, but the method of application did affect final SS content in the fruit. In blueberries, ABA treatment increased SS when applied after cuticular fractures have happened (KONDO; INUE, 1997), and in grape, the SS increased when ABA was applied in "véraison" stage (KOYAMA et al., 2014).

Although the previous studies were focused on ABA application in postharvest (ZHANG et al., 2009; ZAHARAH et al., 2013), in this study it was found that ABA treatment enhances SS content, improving fruit quality and taste. Fruit quality is determined by high sugar content and appropriate sugar/acid ratio (RIPOLL et al., 2014). Furthermore, ABA is associated with the fruit ripening through ethylene increase (ZHANG et al., 2009), because a number of pathways of metabolites of fruit ripening were affected when the ABA inhibitor biosynthesis was applied in tomato fruits (SUN et al., 2012).

TABLE 1 - Soluble solids (SS), titratable acidity (TA), ratio and pH values in tomato fruit treated with exogenous ABA (foliar, root, and foliar/root.) and control (deionised water) applied from anthesis to mature green.

Treatments	SS (%)	TA (mg 100 g^{-1})	Ratio SS/TA	pH
Control	4.23 c	0.24 b	17.25 a	4.44 a
Foliar	5.10 b	0.30 a	17.03 a	4.35 b
Foliar/Root	4.85 b	0.26 b	18.78 a	4.41 a
Root	5.73 a	0.30 a	19.10 a	4.36 b
CV(%)	3.02	7.78	0.38	0.28

The averages followed by the same letters in the columns not differ from each other according to the Scott-Knott test, at 5% probability. CV(%) = coefficient of variation (%).

The results demonstrated that titratable acidity improved in foliar and root ABA treated fruit when comparing with non-treated fruit (Table 1). The level of acidity is a parameter that affects the tomato taste such as flavour and astringency. These results are in agreement with reported in the literature: the decrease in organic acidity followed by exogenous ABA application has been reported in tomato (ZHANG et al., 2009; BARICKMAN et al., 2016), in mango (ZAHARAH et al., 2013) and in grape (KOYAMA et al., 2014). Furthermore, treating tomato with ABA promotes carotenoids synthesis and reduces organic acids concentration (BARICKMAN et al., 2016).

Fruit juice pH decreased in foliar and root ABA treatments. The pH ranged from 4.35 to 4.43, the lowest pH being observed in ABA foliar treatment and the highest in the control, non-treated fruit. The acidity not only influences the tomato taste but also affects the processing quality of tomato. In processing tomato a pH below 4.6 it is desirable in order to control microbial spoilage and enzyme inactivation (GARCIA; BARRETT, 2006). In addition, Gu et al. (2011) found that different rates and timing of ABA application in grape reduce sightly both TA and pH.

The statistical analyses of the results indicate there were no differences in SS/TA ratio (Table 1). The balanced taste is determined by the SS/TA ratio. The best tomato taste is a combination of high sugar concentration and moderately high acids, low sugar and high acids result in a sour tastes, high sugars and low acids a bland taste and low sugars and low acids is a tasteless fruit (CUARTERO; FERNÁNDEZ-MUÑOZ, 1998). Tomato containing more than 0.3% TA and 3% SS, and the ratio SS/TA more than 10 are considered high-quality fruits (MENCARELLI; SALTVEIT, 1988). Our results demonstrated that foliar and root ABA treatments slightly improved the SS/TA ratio, hence better taste. Although the control treatment had greater ratio than foliar treatment, the TA content in control treatment is less than 0.3%.

External ABA significantly decreased soluble pectin in fruit tissue, whereas the total pectin increased only in ABA foliar treatment (Table 2). The soluble and total pectin content are directly related to the firmness of the fruit. Fruit softening is caused by cell wall structure breakdown resulting in soluble pectin increase due to activity of wall degradation enzyme activity (enumerar as enzimas), therefore, high concentration of soluble pectin decrease fruit firmness (MAJIDI et al., 2014). This study found that ABA root treatment decreased soluble pectin by 34.50%, ABA applied in both roots and foliar decreased by 12.90%, and ABA foliar treatment decreased soluble pectin by 12.20%, relative to the control treatment.

TABLE 2 - Total and soluble pectin in tomato fruit under 3 ABA treatments applied from anthesis to mature green.

Treatment	Total Pectin (mg 100 g^{-1})	Soluble Pectin (mg 100 g^{-1})	Firmness (N mm^{-2})
Control	393.81 b	128.27 a	12.14 b
Foliar	587.80 a	112.53 b	13.78 b
Foliar /Root	407.19 b	111.69 b	14.36 a
Root	378.33 b	84.08 c	15.62 a
CV(%)	3.55	2.73	3.55

The averages followed by the same letters in the columns not differ from each other according to the Scott-Knott test, at 5% probability. CV = coefficient of variation.

ABA treatments increased fruit flesh firmness, excluding foliar treatment that did not differ statically with control. ABA applied to the root increased flesh firmness by 22.30%. The combination of foliar and root ABA treatments increased fruit flesh firmness by 15.50 % and 11.91 %, respectively. Our results are in this aspect contradict some reports in the literature. Tomato fruit harvested at the mature green stage and treated with ABA were softer than non-treated fruit (ZHANG at al., 2009), and ABA treatment decreased mango firmness during ripening by promoting ethylene biosynthesis that led to fruit softening (ZAHARAH et al., 2013). The contradiction may result in the fact that in these experiments ABA was applied in post-harvest.

In our study, ABA sprayed to the plant or added to the roots reduced pectin solubilization, therefore maintaining higher levels of pectins bound to the cell wall, which contributed to higher fruit flesh firmness. This discrepancy may be due to the fact that ABA application in whole plant would reduce plant transpiration by closing the stomata (ASTACIO; VAN IERSEL, 2011; FREITAS et al., 2014) and therefore would increase Ca uptake and concentration in the fruit (BARICKMAN et al., 2014; FREITAS et al., 2014), therefore maintaining and strengthening wall cell integrity and fruit firmness (HO; WHITE, 2005). Dipping fruits in solution of $CaCl_2$ during postharvest increases fruit firmness because Ca binds to the cell wall, increasing cell wall strength and limiting the activity of cell wall degrading enzymes that solubilise pectin (VICENTE et al., 2007), a fact that supports the previous explanation.

ABA is an important vegetable hormone studied mainly in the post-harvest of fruits and vegetables, however, in view of the results of this research, it is worth mentioning that the application of ABA during crop management can improve in aspects that affect the fruit quality. New experiments are underway to investigate the behaviour of ABA in factors that interfere in the quality of the fruit, such as in the controlling blossom-end rot in tomatoes.

CONCLUSION

ABA application to leaves and roots can improve fruit quality by increasing the SS, ratio SS/TA.

The method of application affects the SS content.

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