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Investigation note

Effect of ammonium molybdate on the quality of feijoa fruits

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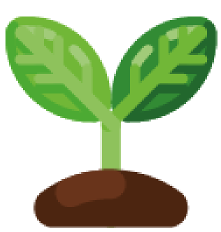
Abstract

Molybdenum is an essential micronutrient that is involved in several enzymes, including nitrate reductase. This trial aimed to evaluate the physicochemical quality and the pectin methylesterase activity in fruits from feijoa trees sprayed with 0, 100, 200, and 300 mg L^{-1} of ammonium molybdate. To this end, an experiment was set up in 2023 in a completely randomized block design with three replications. Spraying 200 mg L^{-1} of ammonium molybdate increased the weight and firmness of the fruits. It was found that the pulp and skin of fruits harvested from trees treated with 100 mg L^{-1} showed lower vitamin C content, with values of 0.33 and 0.55 mg g^{-1}, respectively. The application of molybdenum increased the content of total phenols in the pulp, with values that fluctuated between 3.72 and 3.66 mg g^{-1}. Nonetheless, only the doses of 100 and 200 mg L^{-1} affected the values for this secondary metabolite in the skin. Only an increase in antioxidant capacity was observed for the pulp, where the dose of 300 mg L^{-1} was similar to the control. The pulp and skin of the fruits evaluated decreased their total sugar content and the levels of pectin methylesterase activity. Molybdenum foliar spraying can be a viable alternative to improve the size, firmness, and phenol content in the fruit pulp, parameters widely valued in harvest quality and during postharvest handling and that give high nutritional value to feijoa fruit.

Keywords:

Acca sellowiana, bioactive compounds, plant nutrition.



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Feijoa (*Acca sellowiana*) belongs to the family Myrtaceae and is native to South America (Karsli, 2020). The fruit of this species is characterized by its exquisite flavor, smell, and high content of bioactive compounds (González-García *et al*., 2018). In addition, it is valued for its multiple benefits to human health (Do Amarante *et al*., 2017). However, it ripens rapidly and presents unattractive changes in the color of the pulp and seeds, altering its flavor (Fischer *et al*., 2020).

Despite the interesting functional and medicinal characteristics of feijoa fruit, there is little information related to mineral nutrition with molybdenum (Mo) and its impact on its bioactive and organoleptic components, mineral nutrition, and its response in the preservation of shelf life of the fruits (González-García *et al*., 2018). Mo is a micronutrient absorbed as molybdate that contributes to the absorption and use of N (Muñoz-Márquez *et al*., 2022). In addition, it is a structural component of pterin Moco (Mo cofactor), which in turn is part of around 40 enzymes that catalyze various redox reactions (nitrate reductase, xanthine dehydrogenase, sulfite oxidase and aldehyde oxidases) (Lopes-Oliveira *et al*., 2022).

Therefore, this trial aimed to evaluate the changes in physicochemical quality and in the activity of the pectin methylesterase enzyme in feijoa fruits in response to the preharvest foliar application of ammonium molybdate. The study was conducted in 2023 and the plant material consisted of feijoa trees of the cv. Mammoth 20 years old and with an average height of 3 m. The orchard is located in the San Martín Experimental Agricultural Field (19° 30' 00" north latitude; 98° 52' 46" west longitude; 2 254 masl) of the Department of Phytotechnics of the Chapingo Autonomous University (UACH), for its acronym in Spanish.

The treatments consisted of foliar spraying of 0 (control), 100, 200, and 300 mg L^{-1} of Mo in the form of ammonium molybdate $(NH_4)_6Mo_7O_{24}H_2O$ (Baker Analyzed®, USA) with an H-7986 backpack (Uline, USA) (20 L). The treatments were applied on three occasions at the end of July and beginning of September, between 8:00 and 9:00 h in 12 trees (three per treatment) with fruit size that fluctuated between 1 and 5 mm. The experiment was established in an experimental design of randomized complete blocks with three replications, where a tree was considered as the experimental unit.

The harvest of the fruits was carried out around the middle part of the tree; to do this, 30 fruits were selected per treatment, which were physiologically ripe and showed no physical damage caused by pests or diseases. For analysis, pulp and skin were separated from the fruit.

Weight (g), firmness (kg cm^{-2}), and total soluble solids (TSS) (°Bx) were determined with an H-9884 digital balance (Uline, USA) with a sensitivity of 0.01 g, a Chatillon® digital penetrometer (Ametek, USA) with a conical tip of 7 mm in diameter, and an Atago Pal-1 portable digital refractometer (Pocket®, Japan), respectively. The content of ascorbic acid (vitamin C) (mg g^{-1}) was quantified by the Folin-Ciocalteu colorimetric method described by Jagota and Dani (1982) with slight modifications.

The content of total phenols (mg g^{-1}) (Waterman and Mole, 1994), total sugars (mg g^{-1}) (Witham *et al*., 1971), and antioxidant capacity [VCEAC (vitamin C equivalent antioxidant activity), mg·g^{-1}] (Özgen *et al*., 2006) were determined. Finally, the activity of the pectin methylesterase (PME) (EC 3.1.1.11) enzyme was evaluated with the spectrophotometric procedure published by Hagerman and Austin (1986) (IU min g^{-1}). All results are expressed in fresh weight.

The data obtained was subjected to an analysis of variance and multiple separation of means with Tukey's test ($p \leq 0.05$). All analyses were performed using the SAS® analysis package version 9.0. Fruits from trees with the foliar application of 200 mg L^{-1} of ammonium molybdate significantly increased their weight and firmness compared to the control, keeping the total soluble solids (TSS) content unchanged (Table 1).

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Table 1. Weight, firmness, and total soluble solids content in feijoa fruits harvested from trees sprayed with ammonium molybdate.

Treatment (mg L^{-1})	Weight (g)	Firmness (kg cm^{-2})	TSS (°Bx)
100	29.62 c	1.95 b	13.43 a
200	69.94 a	3.02 a	12.9 a
300	52.88 b	2.06 b	15.03 a
Control	59.44 b	1.41 b	15.26 a
HLSD	9.67	0.69	2.56
CV (%)	14.05	25.4	13.94

Values with the same letter in the same column do not present statistically significant differences according to Tukey's test ($p \leq 0.05$). HLSD= honest least significant difference; CV= coefficient of variation.

The foliar supply of Mo increases nitrogen absorption as it is a cofactor of the active site of the nitrate reductase enzyme (Sabatino *et al*., 2019), key in the synthesis and accumulation of chlorophyll, a molecule specialized in the capture and transformation of light energy into chemical energy (ATP and NADPH) (Muñoz-Márquez *et al*., 2022).

On the other hand, Mo promotes the catalysis of nitrate (NO_3^-) to nitrite (NO_2^-), contributing to the accumulation of calcium, cellular turgor, and the delay of membrane lipid catabolism, as reported by Wójcik (2020) for Red Jonaprince apple trees when applying foliar sprays of Mo (sodium molybdate) (286 g ha^{-1}) in preflowering and full flowering.

The 100 mg L^{-1} dose of Mo decreased the vitamin C content in the pulp and skin, with 0.33 and 0.55 mg g^{-1}, respectively (Table 2). In contrast, values of 51.8 ±0.1 and 95 ±0.6 [mg 100 g fresh weight (FW)] are reported by Phan-Thi *et al*. (2019). These variations can be attributed to the state of ripeness of the fruit, extraction method, and cultivar (Muñoz-Márquez *et al*., 2022). On the other hand, for fruits of the hybrid tomato Ornela F1, Sabatino *et al*. (2019) report a significant increase in ascorbic acid content from 2 023.4 mg 100 g^{-1} (control; 0 µmol Mo L^{-1}) to 3 008.8 mg 100 g^{-1}, that is, 67.2%.

Table 2

Vitamin C and total phenol contents in feijoa fruits (pulp and skin) harvested from trees sprayed with ammonium molybdate.

Treatment (mg L^{-1})	Vitamin C (mg g^{-1})		Total phenols (mg g^{-1})	
	Pulp	Skin	Pulp	Skin
100	0.33 b	0.55 b	3.72 a	10.71 a
200	0.39 a	0.67 a	3.66 a	10.71 a
300	0.45 a	0.74 a	2.83 ab	8.64 b
Control	0.41 a	0.65 ab	2.14 b	7.16 b
HLSD	0.06 a	0.11	1.1	1.99
CV (%)	11.74	13.05	27.53	16.5

Values with the same letter in the same column do not show statistically significant differences according to Tukey's test ($p \leq 0.05$). HLSD= honest least significant difference; CV= coefficient of variation.

The total phenol content for pulp fluctuated between 2.14 and 3.72 mg g^{-1} but for skin, values between 7.16 and 10.71 mg g^{-1} were found (Table 2). In general, Mo treatments improved the phenol content in the skin and pulp. Nevertheless, the dose of 300 mg L^{-1} showed a similar statistical behavior, coinciding with what was reported by Karsli (2020) for skin and pulp in feijoa fruits for an unknown cultivar. These authors corroborate a ratio of 3:1 (skin vs. pulp) for the content of this secondary metabolite, responsible for the astringent flavor in the fruit skin. These results are

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important if we consider that feijoa is consumed as a seasonal fruit, that is, the entire product is used (Do Amarante *et al*., 2017).

Spraying Mo did not affect the behavior of the antioxidant capacity in the skin, whereas in the pulp, the doses of 100 and 200 mg L^{-1} showed significant values, of 9.7 and 9.92 VCEAC mg g^{-1}, respectively (Table 3). Likewise, the fruits of the trees treated with the dose of 300 mg L^{-1} were similar to the control in terms of this parameter.

Table 3. Total sugar content, antioxidant capacity, and enzymatic activity of pectin methylesterase in feijoa fruits harvested from trees sprayed with ammonium molybdate.

Treatment (mg L^{-1})	Antioxidant capacity (VCEAC mg g^{-1})		Total sugars (mg g^{-1})		PME (IU min g^{-1})	
	Pulp	Skin	Pulp	Skin	Pulp	Skin
100	9.7 a	17.86 a	94.88 b	55.86 ab	2.68 b	4.26 b
200	9.92 a	17.06 a	93.52 b	54.78 bc	3.6 b	4.51 b
300	9.48 ab	17.77 a	94.58 b	52.86 c	2.38 b	4.13 b
Control	8.86 b	16.66 a	99.3 a	58.06 a	6.02 a	6.47 a
HLSD	0.91	1.24	2.62	2.33	1.73	1.72
CV (%)	7.45	5.53	2.11	3.25	36.4	27.38

Values with the same letter in the same column do not show significant statistical differences according to Tukey test ($p \leq 0.05$). HLSD= honest least significant difference; CV= coefficient of variation; PME= pectin methylesterase.

In this sense, Do Amarante *et al*. (2017) assessed the antioxidant capacity in several feijoa genotypes with the ABTS method in hydroalcoholic and aqueous extracts; for this, they report values similar to those obtained in this study for pulp and skin, where the variation due to the effect of the extraction method and genotypes is evident. On the other hand, the pulp and skin of the fruits showed a significant reduction ($p > 0.05$) compared to their total sugar content and the enzymatic activity of the PME.

In contrast, Lopes-Oliveira *et al*. (2022), when evaluating the spraying of 180 L ha^{-1} [30 g Mo ha^{-1}] of potassium molybdate (K_2MoO_4) in hybrid corn P3707VYH (Pioneer®, USA) and soybeans genotype TMG 7062 RR (Tropical Breeding & Genetics®, Br), report an increase in the content of soluble sugars in the leaves as a result of an improvement in photosynthetic efficiency that in turn is linked to the participation of Mo in the modulation of the activity of the nitrate reductase enzyme.

Conclusions

Foliar spraying of 200 mg L^{-1} ammonium molybdate on feijoa trees increased the weight and firmness of the harvested fruits. There was a significant reduction in the vitamin C content in the skin and pulp of fruits from trees treated with 100 mg L^{-1}. On the other hand, the application of Mo improved the content of total phenols in the fruit pulp, whereas in skin, only the doses of 100 and 200 mg L^{-1} showed significant variation. The content of total sugars and the pectin methylesterase activity in skin and pulp showed a significant reduction due to the effect of foliar application of Mo.

The use of Mo as ammonium molybdate in preharvest represents a viable alternative to improve the size, firmness, and phytochemical value of the fruit, aspects widely appreciated in postharvest and in the implementation of a healthy diet. However, it is necessary to conduct more in-depth assessments to improve the understanding of physiology and biochemistry due to the effect caused by the foliar supply of Mo (different doses, sources, agronomic management, and feijoa cultivars) for the optimal production of this evergreen fruit tree.

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