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Effect of the harvest date, calcium and other chemicals on the quality and storability of 'Golden Smoothie' apples

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ABSTRACT

Objective: Apples cultivated in Mexico generally are smaller and softer than those produced in other geographical latitudes considered as optimal for apple production. The aim of this evaluation was determine the effect of applications with calcium, nitrogen, potassium, magnesium, sulfur and naphthaleneacetic acid (NAA), as well as the harvest date on the quality of apple fruits.

Methodology: 'Golden Smoothie' apple trees were treated foliarly with $CaCl_2$ with and without NAA, and with a mixture of N, K, Mg and S or gypsum applied to soil for two years. Apples were harvested at 141 (regular harvest date), 161 (mid-late harvest) and 171 days (late harvest) after full bloom (DAFB) and evaluated for quality at harvest time and during their storage at 0 °C for up to 179 days.

Results: Foliar applications of $CaCl_2$ significantly increased the calcium content in fruit and leaves, but fruit quality, including firmness, was not influenced. Fertilization of soil with the mixture of nutrients, including $CaSO_4$, did not influence the fruit quality. Lately harvested fruit was 14.9% heavier but 17.1% softer than fruit picked at the commercial harvest date. Delaying of fruit harvest reduced about 43 d the storability of fruit. Based in these results, the relative softness of apples grown in Mexico is not related with its calcium content, hence unlikely to be overcome with the application of this mineral.

Conclusions: Even in the control fruits, both seasons, the stored fruits do not show some physiological disorder as bitter pit.

Keywords: Fertilization, posharvest, fruit firmness, physiological disorder

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INTRODUCTION

The largest apple-producing region in Mexico is in the Chihuahua state (SIAP, 2019). This region faces some problems compromising apple quality and production. Apple (*Malus* × *domestica* Borkh.) orchards in this region are established at <30 ° north latitude, which is below of the typical latitude of the regions with the highest apple production in the world (~40 °). This causes a low cold accumulation by trees during winter, reducing fruit yield. The high fluctuation of daily temperatures in the region, frequently of 25 °C, related with the altitude of these orchards (1900 to 2100 masl), negatively affects the

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tree dormancy and blooming, and consequently, the fruit yield and quality (Palmer *et al.*, 2003). Trees of these orchards frequently show a prolonged blooming period, which usually affect the overlap of flowering periods of pollinizers with the producer cultivars, reducing the pollinizing rate and fruit yield (Soto-Parra *et al.*, 2020). Furthermore, summer photoperiod in Chihuahua is shorter than that of regions located at latitudes ≥ 40°, limiting the vegetative and fruit growth (Lakso & Goffinet, 2013). This condition is exacerbated by the use of black nets to prevent hail damage, reducing even more the exposition of fruits and trees to sun light, reducing the photosynthetic activity and development of fruit color (Guerrero *et al.*, 2002). These adverse conditions collectively compromise all quality attributes of fruit, especially fruit firmness (Olivas, 2012). Ornelas-Paz *et al.* (2018) observed that the apples cultivated in Chihuahua were very soft, presumably as a consequence of a delayed commercial harvest date. Firmness is one the most important quality attributes of apples, determining their acceptance by consumers and storability (Hoehn *et al.*, 2003). Several cultivation practices are currently being tested by apple producers in Chihuahua to improve fruit quality, including improvements on orchard nutrition and handling of the harvest date. The nutrition of apple trees with calcium has been proposed as an alternative to increase the firmness of apples because calcium ions prevent dissociation of pectin chains and cohesion loss between cells, retarding postharvest fruit softening (Ornelas-Paz *et al.*, 2018). Calcium applications also prevent the development of physiological disorders (*e.g.* bitter pit) in apple fruit (Donahue *et al.*, 2018). Calcium reduces the respiration rate and ethylene production, delaying ripening and retarding loss of firmness (Tyagi *et al.*, 2017). However, the success of nutrition with calcium can be influenced by several factors, including the application of other chemicals and nutrients. Application of naphthaleneacetic acid (NAA), for example, can reduce vegetative growth by inhibiting photosynthesis and favors calcium accumulation in fruits (Amarante *et al.*, 2020). On the other hand, a high availability of other minerals as N, K and Mg can reduce the assimilation of calcium, and consequently promote bitter pit and other physiological disorders in apples postharvest (Jemric *et al.*, 2016), with a reduction in flesh firmness (Casero *et al.*, 2010).

Thus, the aim of the study was to determine the effect of applications with calcium, nitrogen, potassium, magnesium, sulfur and NAA, as well as the harvest date on size and firmness of 'Golden Smoothie' apples cultivated in Chihuahua, Mexico.

MATERIALS AND METHODS

Plant material. The study was conducted in 2018 and 2019, in a commercial apple orchard (cv. Golden Smoothie on MM-111 rootstock) in Cuauhtémoc, Chihuahua, Mexico (28° 34' N, 106° 54' W; 1995 masl). Trees were 35 years-old and the tree density was 775 trees·Ha^{-1}.

Treatments. Groups of five trees were selected to monitor the effect of each of the treatments showed in the table 1. Stopit™ was used as the calcium chloride source (160 g·L^{-1} Ca^{2+} w/w, Phosyn Needs plc. UK) and always was added with Solubor™ (Sodium borate 20.5% B, 20 mule team Borax™) at 1 g·L^{-1}. Fruitone N™ was used as the source of naphthaleneacetic acid (3.5% NAA, AMVAC, Mexico).

Table 1. Treatments applied on 'Golden Smoothie' apple trees. 2018 and 2019.

Treatment	Product	Dosis	Applications[y]	
			Soil	Foliar
T1	Calcium chloride (12)[z]	1.6 g $Ca^{+2}\cdot L^{-1}$		12
T2	Urea Potassium sulfate Magnesium sulfate Wettable sulfur	100 g/tree 100 g/tree 51 g/tree 300 g/tree	10 10 10 10	
T3	Calcium sulfate NAA	300 g/tree 0.1 $g\cdot L^{-1}$	10	5
T4	Calcium chloride (6)	5.8 g $Ca^{+2}\cdot L^{-1}$		6
T5	Calcium sulfate NAA Calcium chloride (6)	300 g/tree 0.1 $g\cdot L^{-1}$ 5.8 g $Ca^{+2}\cdot L^{-1}$	10	5 6
T6	Control	***	***	***

z.- Numbers in parentheses indicate the sprays in the year.
y.- Foliar and soil fertilizations were applied at intervals of 8 days.

Foliar and soil samplings. Due to the lack of financing in 2018, and to observe the residual effect of two years of treatments, in July 2019 soil and leaf samples were collected in triplicate for the chemical measurements. One kilogram of soil (5-20 cm depth) was taken up from both control trees and trees treated at soil (treatments 2, 3, 5 and 6), 1 and 4 treatments were not sampled since they did not receive application at soil. Per triplicate, forty leaves were taken from all experimental trees.

Harvest date. In 2018, two harvest dates were included, the commercial harvest (141 days after full bloom, DAFB) and the late harvest (171 DAFB), whereas only a mid-late date (161 DAFB) was considered in 2019. On each harvest date, 12 fruits from each experimental group (treatment) were randomly selected to be analyzed for weight, flesh firmness, total soluble solids, starch index, skin color and calcium content. From each treatment and harvest date, approximately 20 kg of fruit were stored at 0 °C. Three (2018) and two (2019) samplings of 12 fruits each were carried out during storage, which were evaluated for flesh firmness. The storage periods were 179 and 135 d in 2018 and 2019, respectively.

Physicochemical measurements. The mineral content of soil, leaves and fruits were determined in the Laboratory of the Regional Association of Fruit Growers (UNIFRUT) in Chihuahua. Nitrogen was determined by the micro-kjeldhal method (Bremner & Mulvaney, 1982). To quantify K, Ca and Mg, samples were subjected to an acid digestion (Cottenie, 1994), and their concentrations were obtained by atomic absorption spectrophotometry (Perkin Elmer, AAnalyst 100). The pH and electrical conductivity of the soil samples were measured according to the procedures described by SAMLA (2004) and Hoskins (1997), respectively. Aforementioned analyses were carried out at the end of the two evaluation years. Fruit size was determined using a vernier caliper and the weight with a digital balance (Ohaus, USA). A Universal Texture Analyzer TA-XT2i (Texture technologies Corp. USA) was used to evaluate the fruit flesh firmness, recording the maximum force to penetrate 10 mm depth with a cylinder probe (Ø=11 mm) at 10 mm·sec^{-1} in two opposite sides of each fruit. Total soluble solids content (TSS) was determined in fruit juice with a digital refractometer PAL-1 pocket (ATAGO, Japan). Skin color was evaluated on two opposed sites of each fruit with a CR-300 Chroma Meter (Minolta, Japan). Starch index was determined by immersing fruit slices in an iodine-potassium iodide solution. The incidence of physiological disorders such as bitter pit was evaluated at the same time as the rest of quality parameters, counting fruits with symptoms.

Data analysis. Each harvest date and sampling time from storage were analyzed separately, using a completely randomized design with twelve replicates (fruits) for each treatment. Data were subjected to analysis of variance (ANOVA) and means were separated by Tukey test (p=0.05) using the SAS system for Windows version 9.0 (SAS Institute Inc., Cary, NC, 2012).

RESULTS AND DISCUSSION

Harvest date. In 2018, the delayed harvest (171 DAFB) caused an increase in fruit weight of 14.9%, representing an increase in yield of ~5.8 Ton·ha^{-1} compared to the commercial harvest date (141 DAFB); however, lately harvested fruit was 12.6 N less firm (Table 2). An average fruit firmness of 60.4 N was obtained with a mid-late harvest (161 DAFB) in 2019, similar to that observed with the late harvest in 2018 (61.0 N). According to our results, Hall *et al.* (2001) found that 'Golden Delicious' apples continue growing after reaching the physiological stage required for commercial harvest (150-160 DAFB). This growing rate can be of up to 1 g per day. Our study evidenced that fruits grew at a rate of 0.74 g per day after the commercial harvest date, whereas its firmness decreased 0.42 N per day. Similar rates of fruit growing and softening were reported by Johnston *et al.* (2002). Some studies have demonstrated that delayed harvest of fruit compromise fruit quality attributes as firmness, color, starch hydrolysis, shelf life, and increase the difficulty for controlling the negative effects of ethylene biosynthesis on fruit preservation (Ornelas-Paz *et al.*, 2018).

On the other hand, the Official Mexican Standard (NMX-FF-061-SCFI-2003) establishes a minimal firmness of 44.5 N for 'Golden Delicious' apples to be marketed fresh. In this experiment, the fruits harvested on a commercial date reached this value at 103 days of storage, whereas those lately harvested did so at 60 days, which means a 58% less storability of the fruit. In terms of fruit firmness, the nutrition treatments evaluated did not influence the storage capacity of the apples (Figure 1).

Chemical treatments. $CaCl_2$ sprays effectively increased the calcium content in leaves and fruits; however, fruit quality at harvest and during storage was not influenced by these treatments (Tables 2-4, Figure 1). Moreover, 6 sprays of $CaCl_2$ at high doses (5.8 g·L^{-1}) increased the calcium content in leaves more effectively than 12 sprays at low doses (1.6 g·L^{-1}). The lowest values of calcium content in the fruit were observed for control fruit (Table 4); however, symptoms of Ca^{2+} deficiency were not observed in this fruit both at harvest and during storage. According to our results, in other assays, eight $CaCl_2$ sprays not shown beneficial effects on fruit firmness, soluble solids, ethylene production, starch index,

Table 2. Effect of the chemical treatments on the fruit quality of 'Golden Smoothie' apples at commercial and late harvests. 2018.

Treatment	Product	Weight (g)	Flesh firmness (N)	TSS (°Brix)	Starch index (1-6)	Skin color (Hue)
	Commercial harvest (141 DAFB)					
T1	Calcium chloride (12)[y]	119.6ns[z]	75.0ns	12.7 ab	4.0 a	116.5 ab
T2	Urea Potassium sulfate Magnesium sulfate Wettable sulfur	134.0	72.0	12.7 ab	2.9 b	116.7 a
T3	Calcium sulfate NAA	126.3	72.7	12.4 b	4.0 a	115.2 bc
T4	Calcium chloride (6)	130.3	75.5	13.2 a	4.0 a	114.6 c
T5	Calcium sulfate NAA Calcium chloride (6)	128.4	71.4	12.3 b	4.4 a	115.6 abc
T6	Control	123.7	75.0	12.7 ab	3.9 a	115.5 abc
	Late harvest (171 DAFB)					
T1	Calcium chloride (12)	145.1 ab	57.4ns	14.3 ab	6.0ns	108.1ns
T2	Urea Potassium sulfate Magnesium sulfate Wettable sulfur	167.1 a	59.7	13.7 abc	6.0	109.5
T3	Calcium sulfate NAA	136.6 b	64.7	14.6 a	5.9	111.8
T4	Calcium chloride (6)	147.0 ab	59.8	13.2 abc	5.9	109.6
T5	Calcium sulfate NAA Calcium chloride (6)	144.4 ab	63.4	12.6 c	6.0	111.6
T6	Control	156.0 ab	60.8	13.0 bc	5.9	108.7

z.- Mean separation by Tukey's test ($p \leq 0.05$). Means followed by different letters within the same column and time of harvest are significantly different. DAFB: days after full bloom, ns: not significant.
y.- Numbers in parentheses indicate the sprays in the year.

and peel color, however the incidence of bitter pit in postharvest was reduced (Hoying & Cheng, 2013). Ornelas-Paz *et al.* (2018) demonstrated that the changes of Ca^{2+} content in 'Golden Delicious' apples did not correlate with fruit firmness. However, other studies have shown variable effects, year to year, of the calcium treatments on the fruit quality (Casero *et al.*, 2010); even some researchers suggest that soil applied calcium can replace the foliar application traditionally used in apple orchards (Danner *et al.*, 2015). Sometimes, calcium sprays do not increase the fruit firmness at harvest, however, the softening in storage is delayed, probably due to a reduction in the respiration rate and senescence of fruit (Xu *et al.*, 2022). The efficacy of the calcium sprays can be related with the weather conditions, since in years with low precipitation and high air temperature the calcium effect could be useless or adverse (Moor *et al.*, 2006). Moreover, Danner *et al.* (2015) found ineffective the sprays with calcium in an apple orchard located at 26° 34' S, similar latitude to those of our experimental condition (28° 29' N).

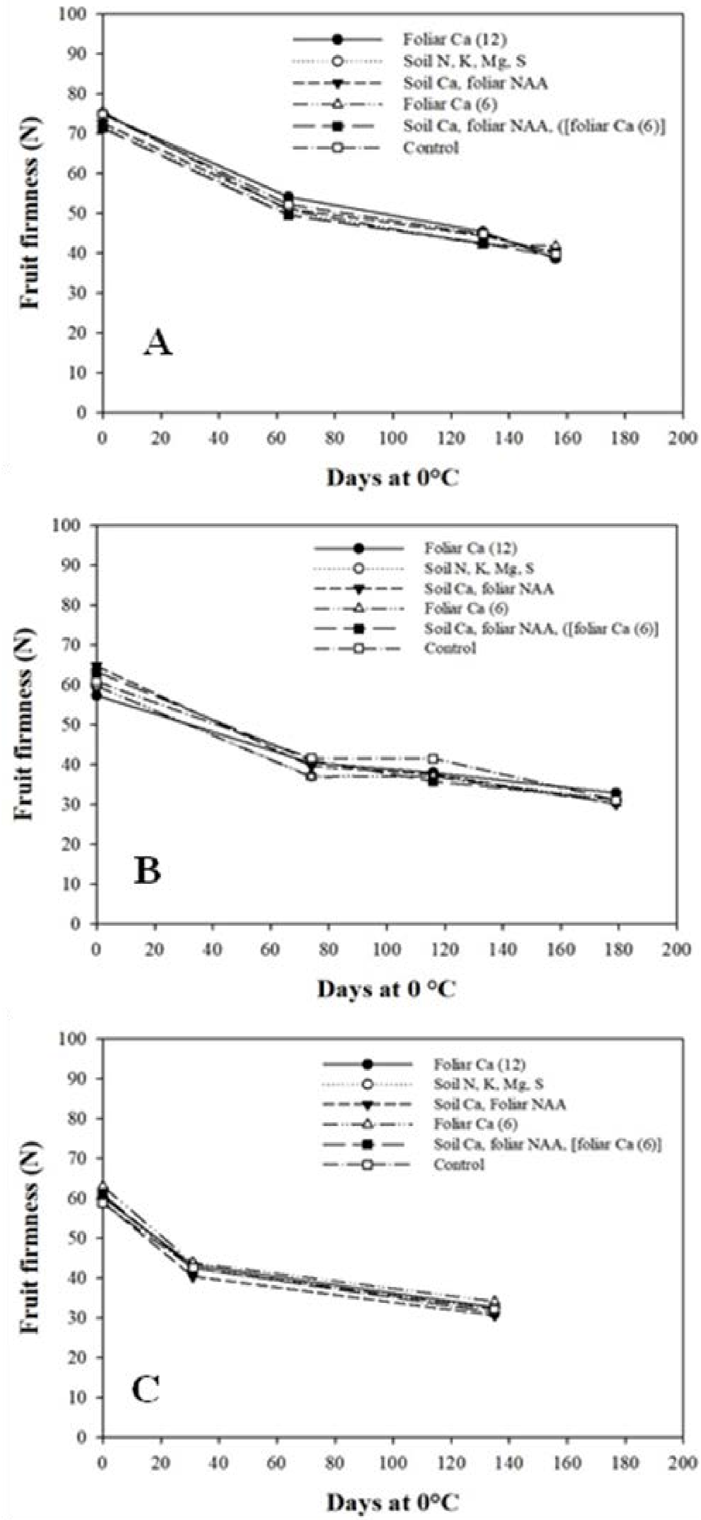

Figure 1. Flesh firmness of fruits 'Golden Smoothie' during the storage at 0° harvested at: A) 141 DAFB (commercial date), B) 171 DAFB (late date) in 2018; and C) 161 DAFB (mid-late) in 2019.

Table 3. Effect of calcium application on the fruit quality of 'Golden Smoothie' apples at mid-late harvest. 2019.

Treatment	Product	Weight (g)	Flesh firmness (N)	TSS (°Brix)	Starch index (1-6)	Skin color (Hue)
	Mid-late harvest (161 DAFB)					
T1	Calcium chloride (12)[y]	122.7ns[z]	60.2ns	12.4 ab	5.7ns	112.6ns
T2	Urea Potassium sulfate Magnesium sulfate Wettable sulfur	125.7	60.5	12.2 ab	5.9	113.3
T3	Calcium sulfate NAA	127.3	59.1	13.1 a	5.7	113.4
T4	Calcium chloride (6)	116.5	62.9	12.0 b	5.9	113.2
T5	Calcium sulfate NAA Calcium chloride (6)	125.8	60.8	12.3 ab	5.8	111.6
T6	Control	121.5	58.9	12.1 b	5.8	114.3

z.- Mean separation by Tukey's test ($p \leq 0.05$). Means followed by different letters within the same column and time of harvest are significantly different. DAFB: days after full bloom, ns: not significant.
y.- Numbers in parentheses indicate the sprays in the year.

Table 4. Effect of the treatments on the calcium content in 'Golden Smoothie' apple trees. 2019.

Treatment	Product	Ca (%)	
		Foliar	Fruit
T1	Calcium chloride (12)[y]	2.1 abc[z]	0.92 a[z]
T2	Urea Potassium sulfate Magnesium sulfate Wettable sulfur	1.8 bc	0.77 a
T3	Calcium sulfate NAA	1.9 bc	0.88 a
T4	Calcium chloride (6)	2.3 ab	0.96 a
T5	Calcium sulfate NAA Calcium chloride (6)	2.6 a	0.98 a
T6	Control	1.5 c	0.49 b

z.- Mean separation by Tukey's test ($p \leq 0.05$). Means followed by different letters within the same column are significantly different.
y.- Numbers in parentheses indicate the sprays in the year.

In this experiment, the inefficacy of calcium sprays to improve the fruit quality, especially on firmness, could be attributed to the calcium supplied via xylem previous seasons and stored in wood and bark, preventing the visualization of the effects of the treatments. Besides that, control fruit, without calcium applied, even so did not show symptoms of disorders as bitter pit. On the other hand, Hocking *et al.* (2016) found that the calcium absorbed by the roots moves very slowly through the tree to the fruit, with this process taking up to years.

In our study, NAA did not influence the fruit quality and calcium content, being that it has demonstrated that NAA decreases photosynthesis, promotes dark respiration, inhibits the transport of photosynthates to fruits, and consequently vegetative growth is decreased, promoting the calcium availability for fruits (Amarante *et al.*, 2020).

The treatment with a mixture of nutrients at soil decreased it's pH from 7.6 to 6.4, effect largely caused by the sulfur added. However, an effect on the Ca^{2+} content in fruits, leaves or bitter pit development, were not observed, as has been suggested by Cheng (2015). Moreover, this mixture increased the electrical conductivity of soil to 4.5 $ds \cdot m^{-1}$ as well as its content of NO_3^-, P, K^+ and Mg^{2+} (Table 5). Although studies have demonstrated that an overfertilization on apple trees with N, K^+ or Mg^{2+} can induce a calcium deficiency in fruits (Jemric *et al.*, 2016), the fertilization in our experiment with N, K^+, Mg^{2+}, S and Ca^{2+} did not influence the calcium content in leaves or fruits as well as the fruit quality.

CONCLUSIONS

Foliar and soil applications with calcium in the apple orchard increased the content of this mineral in leaves and fruit but did not influence fruit quality in both years evaluated, including firmness. Delayed harvest of fruit favored fruit size but compromised fruit firmness. The storability of the fruit lately harvested was 43 d less than that of fruit harvested at the commercial date. Even in the control fruits, both seasons, the stored fruits do not show some physiological disorder as bitter pit.

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Table 5. Effect of the treatments applied to soil over the mineral content and chemical properties of the soil. 2019.

Treatment	Ground treatment	Nitrates ($Kg \cdot Ha^{-1}$)	K (ppm)	Ca (ppm)	Mg (ppm)	pH	EC (ds/m)
T2	Urea Potassium sulfate Magnesium sulfate Wettable sulfur	371.8 a^z	1,683.0 a	$5,178^{ns}$	448 a	6.4 c	4.5 a
T3	Calcium sulfate	57.6 b	1,024.2 b	5,266	396 b	7.4 b	2.0 b
T6	Control	47.8 b	1,189.3 b	4,942	434 a	7.6 a	1.4 b

z.- Means followed by different letters within the same column are significantly different according to Tukey's test ($p \leq 0.05$). ns, not significant.

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