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Original article

Control of fruit cracking in Clementino mandarin plants

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ABSTRACT

One of the widest spread physical defects limiting citrus production is the cracking of the skin and splitting of detached fruits. The objective of this work was to evaluate different doses of calcium nitrate and calcium and magnesium carbonate to control the splitting fruits, the production, nutrition and quality 'Clementine' mandarin fruits. The following treatments was to evaluate: T1: control, T2: 225 g $Ca(NO_3)_2$, T3: 450 g $Ca(NO_3)_2$, T4: 720 g $Ca(NO_3)_2$ and T5: 720 g of $CaMg(CO_3)_2$ plant^{-1}.They was applied in March (50 %) and September (50 %), spring budding period, during three consecutive seasons. Complete randomized blocks, design with four replicates were done. All seasons, in March, foliar samples were, for each treatment taken, for determining concentrations of nitrogen, phosphorus, potassium, calcium and magnesium. During February and March, detached fruit under the crown of each plant was between February and March recorded. At harvest time, 30 fruits were in the experimental plot sampled and equatorial diameter, bark thickness, percentage of juice, acidity, content of total soluble solids and maturity index were measured. The contribution of calcium had a positive effect on the production, significantly increasing the number of fruits per plant and the fewer number of fruits that fell due to cracking of the bark. T3 and T4 with calcium in the form of calcium nitrate and T5 with calcium and magnesium in the form of dolomite presented higher contents of leaf calcium with respect to T1, which only received NPK and Mg contribution through fertilization with 15- 6-15-6.

Key words: quality, *Citrus*, nutrition, production

INTRODUCTION

Argentina ranks eighth as a producer of fresh citrus fruits (1). In the northeast region of the country, the production of oranges and mandarins stands out. The 'Clementina' mandarin (*Citrus reticulata* Blanco) is a cultivar highly appreciated for its flavor and earliness. It presents a small to medium-sized fruit with a thin, spherical-shaped skin that is flat on the sides (2,3). The cracking of the fruit is a factor that conditions the production of mandarins in this region. It begins in February and reaches its maximum incidence in March, which coincides with the expansion stage of the pulp and the minimum thickness of the rind (2).

The cracking of the fruit or splitting consists of the cracking of the bark that occurs in the fruits when they are on the tree, generally before reaching maturity. The splitting begins generally, by the style zone and can evolve until the equatorial zone and reach the peduncular zone, but sometimes the rupture of the crust begins by the equatorial zone of the fruit. This physiological disorder causes fruit to be of up to 30 % of production discarded, but in periods of high rainfall, it can represent up to 45 % of the fruit that has fallen due to cracking (2). The market demands healthy fruit, especially when it is intended for fresh consumption and export. Cracked fruits are rejected or economically depreciated, since cracking favors the appearance of fungi and bacteria (2,3).

In English, *'cracking'* is called the cracking that is limited to the epidermis and *'splitting'* the cracking that penetrates the pulp. This alteration has been detected in all citrus areas and especially in 'Navelina' orange, 'Tangor', 'Ortanique' and 'Nova' mandarin (2). In citrus fruits these two types of physiological conditions occur, both being equally harmful to production and the commercial chain (3).

This physiological disorder is attributed to different causes that can be divided into two groups: 1) those that affect the quality of the fruit membranes and 2) those that generate drastic changes in the water potential of the fruit, producing a deep crack that penetrates to the interior of the pulp (3). The factor most mentioned by the authors is the water supply to the plant, which can cause fluctuations in the water potential of the fruit (4). Other researchers suggest that the cracking is due to the reduced availability of calcium, potassium and boron. However, it should be taken into account that soil moisture also influences the absorption of elements by the plant (2,4).

Calcium (Ca) forms an important part of the constitution of the cell membrane and accumulates between the cell wall and the middle lamina, where it interacts with pectic acid to form calcium pectate [5], which confers stability and maintains the integrity of these. This nutrient acts as a cementing agent for cells, it is closely to meristematic activity related, and has an influence on the regulation of enzyme systems, phytohormone activity and increases tissue resistance to pathogens, increasing postharvest shelf life and nutritional quality [6]. The symptoms of the deficiency appear in leaves without reaching their final size (stage 1:15 according to the BBCH scale [5]), the plants in general lose vigor and the fruits show cracking of the bark or splitting [3].

A constant supply of Ca absorbed by the root and transferred to the fruit is crucial for healthy fruit development. The long-distance transport of Ca is carried out through xylem/apoplast pathways from the root to the upper parts [7,8], and in the case of the absorption of Ca by the fruit, the expansion of the It is also a determinant for the inflow of sap that delivers Ca to the fruit [9–11].

In plant cells, magnesium (Mg) plays a specific role as an activator of enzymes included in respiration, photosynthesis, and DNA and RNA synthesis. It is also part of the chlorophyll molecule. Mg is attributed participation in the development of fruits, contributing to the work of fructose 1.6 diphosphatase, which regulates the synthesis of starch, a factor that can be a determining factor in the level of sugars and the quality of the fruits. The lack of this mineral element is by a yellowing of the leaf manifested, which does not reach the entire surface, leaving a green filled V, with its vertex pointing towards the apex of the leaf. Given the mobility of this element in the plant, the affected leaves are the oldest. It is common to find it in autumn and winter, when the fruit has already matured and/or after its collection, in varieties such as ′Navelina′, ′Satsuma′ and ′Salustiana′, while it is difficult to detect it in ′Clementina′. Its origin may be due to antagonism with Ca, and especially with K, high doses of nitrogen fertilizers, which cause a greater absorption of K and an accumulation of P in the soil [3].

The Mg deficiency causes premature defoliation, reduced root development, reduced harvest, smaller fruits, with thin and fine rind, producing a higher frequency of cracking in fruits [2,3]. The use of potassium and calcium has been studied to reduce fruit cracking of orange and mandarin cultivars [3,12].

Due to the above, this work aims to evaluate different doses of calcium nitrates and calcium and magnesium carbonate to control the cracking of Clementine mandarin fruits.

MATERIALS AND METHODS

Lot characteristics

The study was carried out during three consecutive campaigns 2011-2012, 2012-2013 and 2013-2014, in the Trébol Pampa Establishment (28º03'40 " South Latitude and 58º 15 '08' 'West Longitude), Department of Mburucuyá, Corrientes, Argentina. Mandarin plants (*Citrus reticulata* Blanco) cv. 'Clementino' grafted on *Poncirus trifoliata* L. Raf., with eight years of implantation on a soil *Udipsament alphic*, sandy, red yellow podsolic, their chemical characteristics are displayed in Table 1. The planting density was 555 plants per hectare in a 6 x 3 meter frame.

Table 1. Soil chemical characteristics of the experimental lot in Mburucuyá (28º03’40 ’’ South Latitude and 58º 15 ’08’ ’West Longitude), Corrientes, Argentina

OM (g kg^{-1})	N (g kg^{-1})	P (mg kg^{-1})	K (cmol$_c$ kg^{-1})	Ca (cmol$_c$ kg^{-1})	Mg (cmol$_c$ kg^{-1})	pH
0.34	0.035	5	1.4	1.17	0.76	5.5

The quantitative determination of the OM of the soil was carried out by the Walkey and Black method, that of P by the Bray Kurtz I method, K by flame photometry, Ca and Mg by EDTA complexometry. Soil pH was measured potentiometrically in a 1: 2½ solid: liquid mixture (pH was determined in water).

The climate of the place is classified, according to the Köppen-Geiger system, as Cfa: Subtropical without dry season (hot summer). The mean annual temperature is 21.7 ºC; the average annual rainfall is 1289 millimeters (mm) [(13)].

Experimental design

An experimental design of complete random blocks with four replications was carried out, using an experimental plot of four plants, evaluating the two plants.

In Table 2 the experiment applied were described in this work.

Table 2. Name of the treatments, details of the sources and dose of fertilizer

Treatments	Sources and doses	Number of nutritional units per plant
T1	1.5 kg pta^{-1} F1	N= 340 g; P_2O_5= 90 g; K_2O= 225 g; MgO= 90 g
T2	1.5 kg pta^{-1} F1 + 0.225 kg pta^{-1} F2	N= 340 g; P_2O_5= 90 g; K_2O= 225 g; MgO= 90 g; CaO= 58.5 g
T3	1.5 kg pta^{-1} F1 + 0.450 kg pta^{-1} F2	N= 340 g; P_2O_5= 90 g; K_2O= 225 g; MgO= 90 g; CaO= 117 g
T4	1.5 kg pta^{-1} F1 + 0.720 kg pta^{-1} F2	N= 340 g; P_2O_5= 90 g; K_2O= 225 g; MgO= 90 g; CaO= 187.2 g
T5	1.5 kg pta^{-1} F1 + 0.720 kg pta^{-1} F3	N= 340 g; P_2O_5= 90 g; K_2O= 225 g; MgO= 147.6 g; CaO= 180 g

F1: Fertilizer, which contributes in percentage of N: 15, P_2O_5: 6, K_2O: 15 and MgO: 6. F2: Ca $(NO_3)_2$, which contributes in percentage of N: 16 and CaO: 26; F3: CaMg $(CO_3)_2$ that contributes in percentage, MgO: 8 and CaO: 25

In treatments T1, T2, T3 and T5, urea, CO $(NH_2)_2$ was added, which contributes in percentage N: 46, in order to correct the doses of N in order to evaluate the effect of the application of Ca and Mg.

In the three campaigns mentioned above, the application of the treatments was carried out in two moments, in March (50 % of the dose of each treatment) and in September (completing the remaining 50 % of the dose per treatment), months that coincide with the fruit growth and development and spring budding and flowering respectively.

Variables analyzed

To evaluate the total number of fruits affected by cracking (TFA), in all years, the number of fallen fruits under the canopy of each plant was at two times counted, the first in February and the second in the month of March.

In order to evaluate the nutritional status of the plants, samples of 8-month-old leaves were taken in fruiting branches, coming from spring budding, and the contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg).

At harvest time, 30 random fruits were taken per experimental plot to determine the quality characters of the fruits. The following variables were determined: equatorial diameter (ED) in millimeters by digital caliper, bark thickness (BTH) in millimeters with digital caliper, juice percentage (JU) = juice mass/fruit weight x 100, titratable acidity (TA) by neutralization volumetry (expressed in % of citric acid), content of total soluble solids (TSS) expressed in ºBrix and maturity index (MI) = SST/TA.

At the time of harvest, the total production (Pr) in kilograms per plant (kg plant^{-1}) was also evaluated and the total number of fruits per plant (NFP) was counted.

The harvests were carried out on the following dates, March 31, 2012, March 14, 2013 and April 25, 2014.

Statistical analysis

To evaluate differences between treatments, analysis of variance (ANOVA) was performed. A statistical model was considered with the factors Block, Year, Treatment and the interaction Year*Treatment. Duncan's test ($\alpha \leq 0.05$) was performed for the treatments averaging the years as the interaction was not significant (P-value: 0.8093). Prior to ANOVA, the data were subjected to normality tests, with the modified Shapiro-Wilks statistic ($\alpha \leq 0.05$).

Then a principal component analysis (PCA) was carried out to determine the behavior of the treatments with respect to the variables studied, considering the treatments as classificatory variables. Artificial axes were constructed that allowed obtaining Biplot graphs with optimal properties to interpret and identify associations between observations (treatments) and variables in the same space. All analyzes were performed using the Infostat software [(14)].

RESULTS AND DISCUSSION

Table 3 shows the mean values of the variables: total affected fruits, total production per plant and total number of fruits per plant. Treatments T5: 1.5 kg pta^{-1} F1 + 0.720 kg pta^{-1} F3 and T3: 1.5 kg pta^{-1} F1 + 0.450 kg pta^{-1} F2 presented significantly lower values of fruits affected by cracking and achieved production and total number of fruits per plant significantly higher with respect to treatment T1: 1.5 kg pta^{-1} F1. However, treatment T4: 1.5 kg pta^{-1} F1 + 0.720 kg pta^{-1} F2 significantly exceeded the rest of the treatments in the variables total production and number of fruits per plant, despite presenting total affected fruits similar to treatment T1: 1.5 kg pta^{-1} F1. F1 acted as a fertilizer, which contributes in percentage of N: 15, P_2O_5: 6, K_2O: 15 and MgO: 6; F2: Ca $(NO_3)_2$. The latter contributes in percentage of N: 16 and CaO: 26 and F3: CaMg $(CO_3)_2$ that contributes in percentage, MgO: 8 and CaO: 25.

Table 3. Influence of fertilization on the number of fruits affected by cracking (TFA), total production (PR) and the number of fruits per plant (NFP) in mandarin trees ′Clementino′

Treataments	TFA	PR (kg $plant^{-1}$)	NFP
T1: 1.5 kg pta^{-1} F1	92.54 c	48.67 a	352.83 a
T2: 1.5 kg pta^{-1} F1 + 0.225 kg pta^{-1} F2	73.38 bc	63.17 b	459.67 ab
T3: 1.5 kg pta^{-1} F1 + 0.450 kg pta^{-1} F2	62.42 ab	65.97 b	477.25 b
T4: 1.5 kg pta^{-1} F1 + 0.720 kg pta^{-1} F2	66.38 bc	83.33 c	606.67 c
T5: 1.5 kg pta^{-1} F1 + 0.720 kg pta^{-1} F3	45.67 a	63.63 b	512 bc
Standard Error (E.E.)	8.22	6.09	43.12

Means with the same letter in a column do not differ statistically according to Duncan's multiple range test ($p \leq 0.05$). F1: Fertilizer, which contributes in percentage of N: 15, P_2O_5: 6, K_2O: 15 and MgO: 6. F2: Ca $(NO_3)_2$, which contributes in percentage of N: 16 and CaO: 26; F3: CaMg $(CO_3)_2$ that contributes in percentage, MgO: 8 and CaO: 25

The calcium contribution had a positive impact on production, significantly increasing the number of fruits per plant, shown by the lower number of fallen fruits due to cracking of the bark. Treatment T5 obtained the lowest value of affected fruits and intermediate values of production and number of fruits per plant. Treatment T1 had more affected fruits, lower production and number of fruits per plant, differing significantly from the rest of the treatments.

These results reveal that the contribution of Ca improves production and increases the number of fruits per plant in 'Clementino' mandarin, with fewer fruits affected by cracking, results that coincide with other studies (4,15).

It was found that the effect of calcium applied in the form of sprays before the harvest in 'Schattenmorelle' cherry decreased the number of cracked fruits (15). Similarly, in another study it was found that calcium nitrate (4 %) and boric acid (1.5 %) were effective in reducing the cracking of the pomegranate fruit (*Punica granatum* L.), increasing the mass and the size of the fruit (diameter and length) in comparison with the fruit of the control plants (16).

In addition, it was found that the contribution of Ca decreases the incidence of fruit cracking in 'Nova' mandarin (12). Likewise, in lychee plants of the cultivar Mauritius treated with calcium in doses of 50 and 200 mmol L^{-1}, no fruits affected by cracking were observed (5).

In Figure 1, the main components PC 1 and PC 2 are observed, noting that PC 1 explains 81.5 % of the total variability. An association between the variables number of fruits and total production per plant with treatments T3, T4 and T5 is visualized, while the total of fruits affected by cracking was associated with treatments T1 and T2.

Similar results were obtained in *Murcott tangor*, where foliar supplementation with N, P and K significantly improved productivity (17). Likewise, the results of this work are similar to those found in Nova mandarin, where the plants received a contribution of Ca-B and K. The sprays with Ca-B at 0.4 and 0.6 % showed an abscission significant reduction of fruits and at the same time higher production (12).

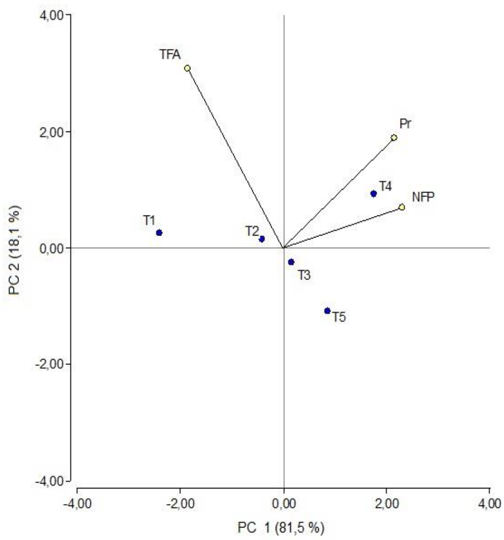

Figure 1. Biplot graph of the variables total of affected fruits (TFA), production (Pr) and number of fruits per plant (NFP), in 'Clementino ' mandarin for the five treatments evaluated

Table 4 shows the results of the average foliar concentrations of the macronutrients. The values obtained from the foliar analyzes were compared with those proposed by citrus nutrition researchers [(18)]. In general, the foliar levels of N exceeded these values, while the rest of the macronutrients were found below the ranges presented [(18)]. The effect of the treatments was only reflected in the foliar calcium content while the rest of the nutrients evaluated did not show significant differences between applications. Treatments T3 and T4 with calcium nitrate [Ca $(NO_3)_2$] and treatment T5 with calcium and magnesium dolomite [CaMg $(CO_3)_2$] contained higher calcium content in leaves. Regarding the T1 treatment, which only received NPK and Mg by fertilization with 15-6-15-6.

Similar results were obtained in *Carica papaya* plants fertilized by foliar applications with three different sources of Ca:calcium chloride [$CaCl_2$], calcium nitrate [Ca $(NO_3)_2$] and calcium propionate [Ca $(C_2H_5COO)_2$]. This was applied using four concentrations (0, 60, 120 and 180 mg L^{-1}), finding that the higher the concentration of Ca applied to the leaves, the accumulation of Ca in the plant improved [(19)].

Table 4. Concentrations of macronutrients in leaves of mandarin trees ′Clementino′ by treatment

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
T1: 1.5 kg pta^{-1} F1	2.96 ab	0.11	0.75	2.31 a	0.23
T2: 1.5 kg pta^{-1} F1 + 0.225 kg pta^{-1} F2	2.92 a	0.12	0.88	2.68 ab	0.25
T3: 1.5 kg pta^{-1} F1 + 0.450 kg pta^{-1} F2	3.01 ab	0.11	0.88	3.14 b	0.27
T4: 1.5 kg pta^{-1} F1 + 0.720 kg pta^{-1} F2	3.33 b	0.11	0.86	3.15 b	0.24
T5: 1.5 kg pta^{-1} F1 + 0.720 kg pta^{-1} F3	3.15 ab	0.11	0.91	2.92 b	0.27
Standard Error (S.E.)	0.224	0.012	0.11	0.20	0.25
		NS	NS		NS

Means with the same letter in a column do not differ statistically according to Duncan's multiple range test ($p \leq 0.05$), NS: Not significant. F1: Fertilizer, which contributes in percentage of N: 15, P_2O_5: 6, K_2O: 15 and MgO: 6. F2: Ca $(NO_3)_2$, which contributes in percentage of N: 16 and CaO: 26; F3: CaMg $(CO_3)_2$ that contributes in percentage, MgO: 8 and CaO: 25

Table 5 shows the fruit quality variables, where only significant differences were found in the percentage of juice with the highest value for the T1 treatment and the lowest in T3.

Similar results were found by the authors who studied the effect of calcium sprays applied before harvest in the 'Schattenmorelle' cherry [(15)], determining that neither the total soluble solids, nor the total acidity of the fruit at harvest was affected, as thus they also verified that the fruits contained more calcium than in the control plants.

The results of this work coincide in the values of the variables equatorial diameter, ºBrix, acidity and maturity index (MI) without significant differences between treatments [(12)].

Regarding the thickness of the bark, the contribution of Ca and K promoted greater thickness, which could affect the susceptibility to cracking of the fruits [12].

Table 5. Average values of the physical and chemical characteristics of the fruits in mandarin 'Clementino'

Treatments	ED (mm)	BTH (mm)	JU (%)	TSS(º BRIX)	TA	MI
T1: 1.5 kg pta^{-1} F1	56.04	2.87	51.1 b	11.58	1.25	9.63
T2: 1.5 kg pta^{-1} F1 + 0.225 kg pta^{-1} F2	55.80	3.01	47.85 ab	11.35	1.46	8.15
T3: 1.5 kg pta^{-1} F1 + 0.450 kg pta^{-1} F2	55.18	2.88	46.18 a	11.52	1.29	9.28
T4: 1.5 kg pta^{-1} F1 + 0.720 kg pta^{-1} F2	55.62	3.08	47.7 ab	11.23	1.25	9.30
T5: 1.5 kg pta^{-1} F1 + 0.720 kg pta^{-1} F3	53.98	2.97	47.19 ab	11.02	1.33	8.59
Standard error (S.E.)	5.46	0.13	1.21	0.25	0.09	0.48
	NS	NS		NS	NS	NS

Means with the same letter in a column do not differ statistically according to Duncan's multiple range test ($p \leq 0.05$). NS: Not significant. Equatorial diameter (ED), bark thickness (BTH), juice percentage (JU), total soluble solids (TSS), titratable acidity (TA) and maturity index (MI)

In light of these results, the higher application dose of calcium nitrate achieved higher production and number of fruits per plant, despite presenting intermediate values of fruits affected by cracking. However, the intermediate dose of calcium nitrate had a similar behavior to the treatment with dolomite contribution in the total of affected fruits, production and number of fruits per plant.

CONCLUSIONS

- The contribution of calcium in the form of calcium nitrate and dolomite decreased the amount of fruits affected by cracking with intermediate production values and number of fruits per plant.
- Production increases with the addition of calcium in the form of nitrate, in doses of 750 g $plant^{-1}$.
- The fruit quality variables do not show differences between treatments except in the percentage of juice where it is observed that with the contribution of calcium in the form of calcium nitrate [$Ca(NO_3)_2$] it increases significantly compared to the control.

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