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Research Article

Calcium fertilization strategy on mango physiological characteristics and yield[1]

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ABSTRACT

Calcium (Ca) is a nutrient responsible for maintaining plant quality and fruit yield. The production of new Ca sources, such as micronized (CaM) and complexed Ca (CaC), and their supplementation provide a better yield in mango cultivation. This study aimed to evaluate the effect of Ca sources (micronized and complexed with *Ascophyllum nodosum*) and application methods on mango cultivation, in semi-arid Brazil. The experimental design was randomized blocks, in a 6 x 6 factorial scheme. The Ca supplementation strategies (control; 1 L ha^{-1} of CaM; 2 L ha^{-1} of CaM; 2 L ha^{-1} of CaC with *A. nodosum* extract; 2 L ha^{-1} of CaC with *A. nodosum* extract + application of 2.5 L ha^{-1} via CaC fertigation; and 2.5 L ha^{-1} via CaC fertigation) were evaluated on six dates regarding nutritional aspects. For biochemical and production aspects, the six supplementation strategies with Ca were evaluated. The Ca concentration in leaves and fruits significantly affected the interaction among the factors. The fertilization strategy with 2.5 L ha^{-1} of complexed calcium via fertigation was fundamental to provide increases in the nitrogen and Ca concentration of the fruits from 65 days after full flowering, and had positive effects on fruiting and production of mangoes cv. Kent.

KEYWORDS: *Mangifera indica* L., *Ascophyllum nodosum*, fertigation, micronized and complexed calcium.

RESUMO

Estratégia de fertilização calcinada nas características fisiológicas e produtividade de manga

O cálcio (Ca) é um nutriente responsável por manter a qualidade de plantas e o rendimento de frutas. A produção de novas fontes de Ca, como o Ca micronizado (CaM) e o Ca complexado (CaC), e sua suplementação proporcionam um melhor rendimento no cultivo de mangueiras. Avaliou-se o efeito de fontes de Ca (micronizado e complexado com *Ascophyllum nodosum*) e métodos de aplicação no cultivo de mangueiras, no semiárido brasileiro. O delineamento experimental foi em blocos ao acaso, em esquema fatorial 6 x 6. As estratégias de suplementação de Ca (controle; 1 L ha^{-1} de CaM; 2 L ha^{-1} de CaM; 2 L ha^{-1} de CaC com extrato de *A. nodosum*; 2 L ha^{-1} de CaC com extrato de *A. nodosum* + aplicação de 2,5 L ha^{-1} via fertirrigação de CaC; e 2,5 L ha^{-1} via fertirrigação de CaC) foram avaliadas em seis datas, quanto aos aspectos nutricionais. Para aspectos bioquímicos e de produção, as seis estratégias de suplementação com Ca foram avaliadas. A concentração de Ca nas folhas e frutos afetou significativamente a interação entre os fatores. A estratégia de fertilização com 2,5 L ha^{-1} de cálcio complexado via fertirrigação foi fundamental para proporcionar aumentos na concentração de nitrogênio e Ca nos frutos a partir de 65 dias após a floração completa e teve efeitos positivos na frutificação e produção de mangas cv. Kent.

PALAVRAS-CHAVE: *Mangifera indica* L., *Ascophyllum nodosum*, fertirrigação, cálcio micronizado e complexado.

INTRODUCTION

Calcium (Ca) is an essential nutrient in mango production (*Mangifera indica* L.) (Wainwright & Burbage 1989). Although it is not a limiting factor in most soils, this nutrient has low levels in leaves and fruits (Almeida et al. 2014, Lobo et al. 2019). This characteristic can be attributed to the plants insufficient capacity to absorb and translocate sufficient amounts of Ca and to the increasing demand from tissues with vigorous growth, especially during fruit growth and development (Hocking et al. 2016).

Foliar applications of nutrients are an option in production, as they have direct contact with leaves

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and fruits to increase the accumulation inside the leaves and transport to other parts of the plant (Bibi et al. 2019). However, some factors can compromise the application success, such as the application time and the chemical form of the nutrient in the solution (Wojcik & Borowik 2013).

For a successful mango production, 20-30 % of the Ca required by the crop should be supplied in the fruit development phase, performing foliar application after full flowering (Torres et al. 2017), as the fruits are small and their less developed cuticle favors the Ca penetration inside the fruit (Wilsdorf et al. 2012). In this case, the most commonly used calcified foliar fertilizers are calcium nitrate [$Ca(NO_3)_2$], calcium chloride ($CaCl_2$) and some chelated forms (Lurie 2018).

Concerning root ion contact, Ca is usually supplied via soil, where sufficient conditions are required for its better absorption rate, especially by young roots (White & Broadley 2003). In turn, attention must be paid to all nutrients, since they can be lost or immobilized in the soil, and adsorption and leaching phenomena may occur (Siedt et al. 2021).

Wilsdorf et al. (2012) evaluated the contributions of Ca ($CaCl_2$) applications via soil and foliar treatment in increasing Ca concentrations in apple fruits. They found that foliar Ca applications were more effective than soil applications in increasing the Ca in the fruit. However, a calcium-based foliar product does not always increase the yields in most fruit trees, regarding absorption and transport efficiency within the tissues (Hocking et al. 2016, Bibi et al. 2019). Thus, there is a market demand to produce new calcium sources, allowing a more efficient application in crop yield via soil or foliar application, such as micronized and complexed Ca.

The micronization process is characterized by the reduction in particle size, promoting changes in its structures, surface area and functional properties, being applied to different materials such as metallic salts and organic components (Priamo et al. 2013). Manganaris et al. (2005) reported that micronized calcium sources are alternatives to standard foliar fertilization, as they have a high absorption capacity by plants (Sabir & Sabir 2019). Meanwhile, Unal et al. (2018) found that the weight, diameter and length of grape bunches were significantly increased by the foliar application of micronized Ca, thus improving fruit quality.

Regarding the use of complexed Ca in plants, the complexation of molecules is a practice that aims to enhance the processes of absorption, transport and redistribution of nutrients within tissues, in which the use of seaweed extracts favors the absorption of nutrients available in the solution (Halpern et al. 2015).

In a study with cherry trees cv. Skeena, Correia et al. (2019) observed that applying algae extract (*Ascophyllum nodosum*) and calcium favored an increase in total organic acids (malic, oxalic and shikimic acid). Meanwhile, Bonomelli et al. (2018) identified an increase in foliar Ca levels in avocado plants from the application of algae extract. Despite that, information on how micronized and complexed Ca behave physiologically in the plant still need to be elucidated. Therefore, this study aimed to evaluate the effect of Ca sources (micronized and complexed with *A. nodosum*) and application methods on mango cultivation, in semi-arid Brazil. To this end, the content of organic solutes, nitrogen and Ca in young and mature leaves, as well as yield, were quantified.

MATERIAL AND METHODS

The experiment was carried out from September to November 2018, in commercial orchards of mango cv. Kent located in the irrigated perimeter of Petrolina (9º23'08S, 40º42'00W and altitude of 465 m), Pernambuco state, Brazil.

The climate of this region is classified as BSh, which corresponds to a semi-arid region (Alvares et al. 2013). During the experiment, meteorological data were recorded by the automatic weather station of the Universidade Federal do Vale do São Francisco (Figure 1).

For the initial characterization of the area, samples of soil, leaves and fruits in the marble ball or "*chumbinho*" stage of mango cv. Kent were collected and analyzed for fertility and plant nutritional status as Ca and nitrogen concentration (g kg^{-1} of dry matter), total soluble carbohydrates and amino acids (µmol g^{-1} of fresh matter). Table 1 contains the results of the soil analysis at the initial stage of fruit development ("*chumbinho*").

The Kent mango trees used in this study were 3.5 years old in their first productive cycle, with spacing of 4 x 2.5 m. Irrigation was performed daily using a localized drip system, with water flow of 2.4 L h^{-1}. Floral induction was performed in four

Table 1. Soil chemical analysis in the experimental area cultivated with mango trees cv. Kent, in the fruit development phase.

Depths	pH	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	$H + Al^{3+}$	SB	CEC	V	Cu	Mn	Fe^{2+}	Zn
m	H_2O	mg dm^3				$cmol_c$ dm^3				%		mg dm^3		
0.0-0.2	7.26	57.03	0.35	0.05	4.01	0.76	0.71	5.1	5.9	87	1.47	3.72	12.83	1.83
0.2-0.4	7.60	49.27	0.21	0.04	0.91	0.34	1.43	1.5	2.9	51	0.44	0.98	11.43	0.27

Extraction methods: P, K, Na, Cu, Fe, Mn and Zn: Mehlich-1 (HCl + H_2SO_4); Ca, Mg and Al: KCl 1 mol L^{-1}. SB: sum of bases; CEC: cation exchange capacity; V: base saturation.

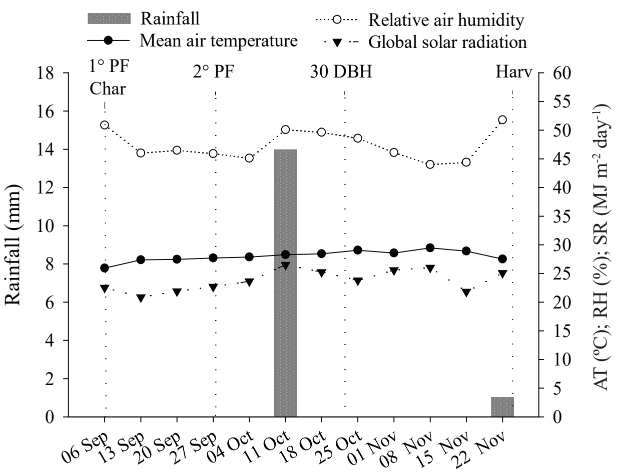


Figure 1. Climate data recorded during the experiment. Char: initial characterization; 1º PF: first physiological fruit fall; 2º PF: second physiological fruit fall; 30 DBH: 30 days before harvest; Harv: fruit harvest. AT: average air temperature; RH: relative air humidity; SR: solar radiation.

steps, with decreasing application of calcium nitrate (5, 4, 2 and 1.5 %, respectively).

Crop practices related to pruning, controlling invasive plants and combating pests and diseases followed the integrated production techniques proposed by Lopes et al. (2003), and nutritional management was performed by fertigation after analyzing the soil, leaves and crop requirements (Cavalcante et al. 2018).

The experiment was set up in a randomized block design, with four replications and 5 plants per plot. The treatments were distributed using a 6 x 6 factorial scheme, corresponding to Ca supplementation strategies and evaluation dates, respectively.

The Ca supplementation strategies were: control (without Ca application); foliar application of 1 L ha^{-1} of micronized Ca; foliar application of 2 L ha^{-1} of micronized Ca; foliar application of 2 L ha^{-1} of complexed Ca with *Ascophyllum nodosum* extract; foliar application of 2 L ha^{-1} of complexed Ca with *A. nodosum* extract + application via fertigation of 2.5 L ha^{-1} of complexed Ca (*A. nodosum* extract, humic acids and amino acids); and application via fertigation of 2.5 L ha^{-1} of complexed Ca (*A. nodosum* extract, humic acids and amino acids). The evaluation dates were 37, 62, 63, 64, 65 and 94 days after full blooming. The application of supplementation strategies was carried out in the fruit growth phase, providing 30 % of the recommended dose of Ca in three stages: after the first physiological fall, after the second physiological fall and at 32 days before harvest (Winston 2007). The foliar Ca was supplied with a dorsal sprayer. The solution was applied per plant following the irrigation line in the fertigation supply. Both strategies were determined according to the manufacturer's recommendations for mango cultivation, with the spray volume based on the supply strategy recommended by the number of plants per hectare. Figure 2 displays the activities timeline of supplementations and analyses.

The concentrations of total soluble carbohydrates and total free amino acids in the leaves were determined at harvest from samples composed of twelve mature leaves from the last vegetative flow at the median canopy height (Malavolta et al. 1997). The method described by Dubois et al. (1956) was used to quantify carbohydrates, and that described by Yemm & Cocking (1955) to quantify amino acids. The N and Ca extraction methods were, respectively, Kjeldahl and atomic absorption spectrophotometry.

The determination of nutritional concentration in leaves and fruits followed the recommendation of Malavolta et al. (1997). Collections to quantify the total Ca were performed moments before each supplementation (half an hour before), while collections for the quantification of total nitrogen occurred only at harvest (Figure 2). The samples were washed with distilled water and then dried in an oven with forced air circulation at 60 ºC, until constant mass. Subsequently, they were ground in a stainless-steel knife mill (Willey type).

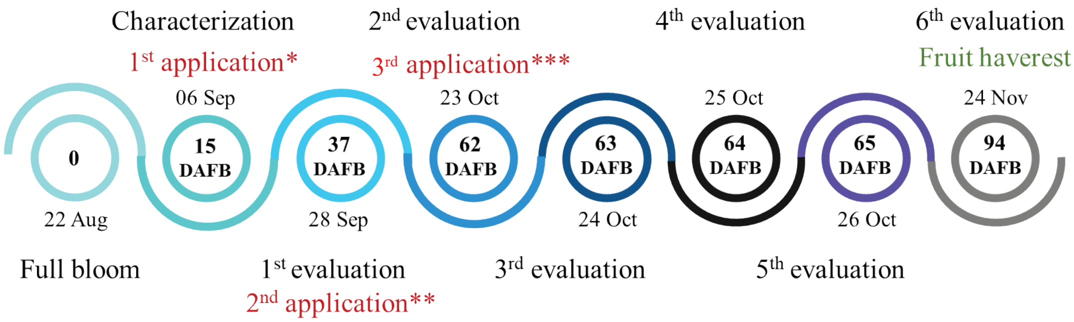


Figure 2. Application schedule of calcium supplementation strategies and plant material collection dates in a commercial mango orchard cv. Kent. * First physiological fruit drop; ** second physiological fruit drop; *** 32 days before fruit harvest. DAFB: days after full bloom.

The fruit harvest was carried out when the fruits were in the stage 2 of maturation (yellowish-cream pulp color) (Filgueiras 2000). These were counted and weighed to obtain the fruit yield (t h^{-1}). The fruit pulps were dried in an oven at 60 ºC, until constant mass, to determine the dry mass.

The data were submitted to analysis of variance, to evaluate significant effects, using the "F" test, and the treatments compared using the Tukey test ($p < 0.05$). The treatments were submitted to factorial analysis by the Tukey test ($p < 0.05$), to evaluate the effect of Ca absorption in leaves and fruits. All analyses were performed using the R statiscal software, version 3.5.2, and the graphs prepared with the Sigma Plot, version 14.0.

RESULTS AND DISCUSSION

The nutritional concentration of Ca in young leaves, mature leaves and fruits significantly affected the evaluation dates and the interaction between Ca supplementation strategies and evaluation dates (Table 2). When contrasting the Ca concentration in mature leaves in the characterization and soon after the first application of the respective Ca supplementation strategies, a generalized increase was observed, even when Ca was not applied (control) (Figure 3A).

Table 2. Synthesis of analysis of variance between calcium supplementation strategies (CSS) and collection dates on calcium concentration in leaves and fruits of mango cv. Kent.

Sources of variation	Young leaves	Mature leaves	Fruits
	Ca (g kg^{-1})		
CSS	1.29^{ns}	1.94^{ns}	0.93^{ns}
Dates	16.76*	52.36*	57.07*
CSS x dates	1.86*	2.05*	2.49*
CV (%)	29.17	20.97	30.70

* Significant ($p < 0.05$); ^{ns} not significant. CV: coefficient of variation.

For the control group, foliar application of 2 L ha^{-1} of micronized Ca and fertigation treatment of 2.5 L ha^{-1} of complexed Ca, the following values were recorded for the Ca concentration: 57.72, 47.95 and 64.02 g kg^{-1}, respectively.

The data highlighted that the mature leaves showed significant reductions (between 50 and 72 %) in the Ca concentration after the second physiological fall, differing only for the previous harvest. In the control group, for example, this decrease had a percentage change of about 58 %, decreasing to 23.90 g kg^{-1} of Ca. For the foliar application of 2 L ha^{-1} of micronized Ca and the fertigation treatment of 2.5 L ha^{-1} of complexed Ca, the decrease was around 50 %, reducing to 23.69 g kg^{-1}, and from approximately 72 %, reducing to 17.33 g kg^{-1} of Ca, respectively.

Although Ca is not mobile, the characteristic decrease observed between stages, especially in mature leaves, shows that, regardless of the treatment, this happens for phenological reasons, probably due to the translocation of calcium to the developing fruit and subsequent physiological fall of some fruits, causing nutritional loss (Rezende et al. 2023).

At 29 days after full bloom (20 Sep.), the foliar calcium results for mature leaves were within the sufficiency range established by Quaggio (1996) and Rezende et al. (2022), which were determined during full flowering.

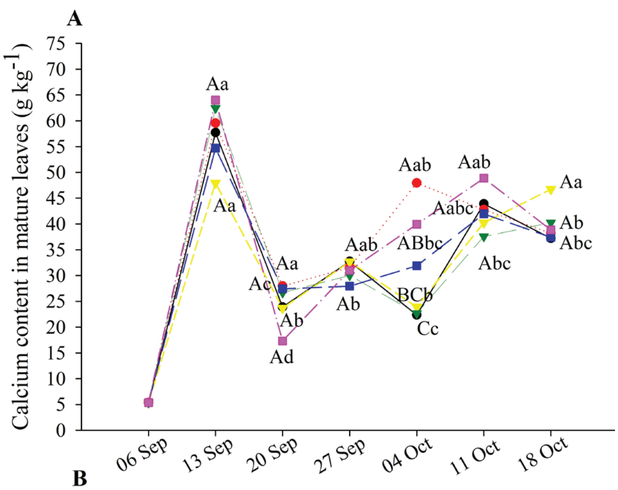
A more detailed consideration highlighted oscillations in the Ca concentration in mature leaves in all the evaluation dates (Figure 3). Except for the fourth evaluation date, the Ca concentration did not differ among the Ca supplementation strategies, but among the analysis dates. The fourth analysis displayed the lowest Ca values in the control group plants and in those plants that received the foliar application of 2 L ha^{-1} of Ca complexed with *A. nodosum* extract and foliar application of 2 L ha^{-1} of micronized Ca, displaying, respectively, 22.35, 22.68 and 23.92 g kg^{-1}.

It is also important to highlight that mature leaves with the highest Ca concentration values were recorded almost exclusively in the first evaluation date. For this variable, the control group displayed values very close to those recorded in the other Ca supplementation strategies, except for the fourth evaluation date.

Although the nutritional content is similar among the organs, especially on the developing fruits, it is necessary to consider the total amount produced by the plants, with a source and sink relationship being preponderant for their nutritional responses. Plants with more fruits (sinks) need more nutrients to distribute and enable adequate fruit growth (Rezende et al. 2022).

In young leaves, the Ca concentration showed a similar pattern to mature leaves, in terms of initial increment and fluctuations during the evaluation dates (Figure 3B); however, with much lower average values. The first evaluation date pointed out that plants that received the foliar application of 1 L ha^{-1} of micronized Ca and foliar application of 2 L ha^{-1} of complexed Ca with *A. nodosum* extract had the lowest Ca values (respectively, 7.62 and 9.37 g kg^{-1}), while the other plants showed a similar Ca concentration.

The third and fourth evaluation dates, corresponding to 1 and 2 days after the last application, highlighted a significant and generalized decrease, and then increased in the Ca concentration in these leaves. In comparison to the previous evaluation date, the reductions in the Ca concentration presented a percentage variation of about 58 % in the plants that received the foliar application of 2 L ha^{-1} of



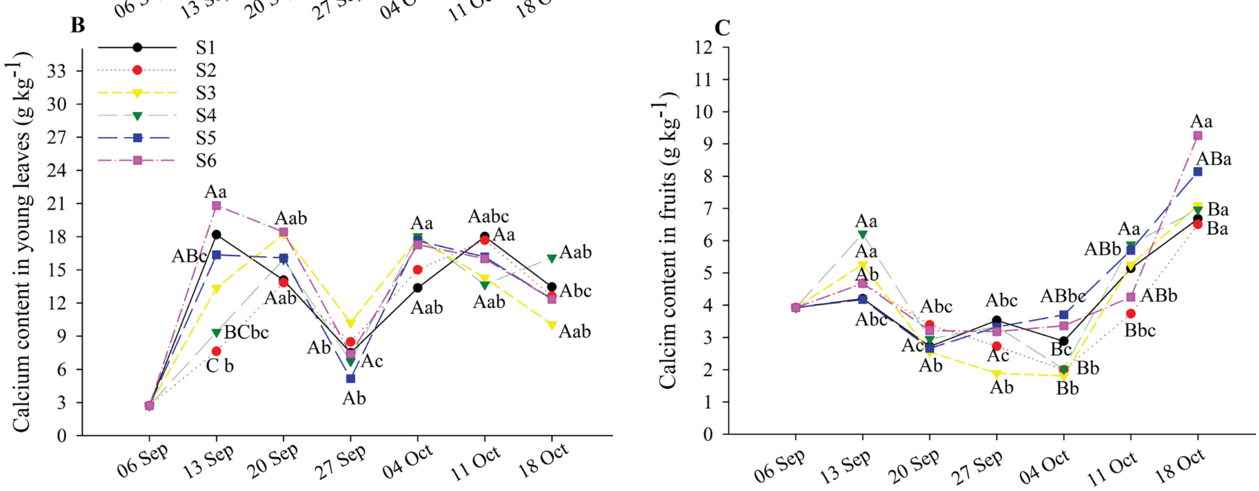


Figure 3. Total calcium concentration in mature leaves (A), young leaves (B) and fruits (C) of mango cv. Kent, as a function of calcium supplementation strategies and collection dates. S1: control; S2: foliar application of 1 L ha^{-1} of micronized Ca; S3: foliar application of 2 L ha^{-1} of micronized Ca; S4: foliar application of 2 L ha^{-1} of complexed Ca with *Ascophyllum nodosum* extract; S5: foliar application of 2 L ha^{-1} of complexed Ca with *A. nodosum* extract + application via fertigation of 2.5 L ha^{-1} of complexed Ca (*A. nodosum* extract, humic acids and amino acids); S6: application via fertigation of 2.5 L ha^{-1} of complexed Ca (*A. nodosum* extract, humic acids and amino acids). Similar capital letters (evaluation dates) and similar lowercase letters (calcium supplementation strategies) do not differ by the Tukey test at the level of 5 %.

complexed Ca with *A. nodosum*, of 60 % in the plants treated via fertigation with 2.5 L ha^{-1} of complexed Ca with humic acids, amino acids and *A. nodosum*, and of 67 % in those that received the foliar application of 2 L ha^{-1} of complexed Ca with *A. nodosum* + fertigation of 2.5 L ha^{-1} of complexed Ca. The remaining plants displayed a reduction percentage equal to or below 46 %.

These results (Figure 3) show that the strategies did not have effects on the calcium content of young leaves, because the first application was performed when the young leaves were growing, combined with low Ca mobility and fruit development. These conditions generated competition for drains, with the leaves being neglected, when compared to the fruits, which require higher calcium concentrations to structure the cell wall and middle lamella (Martins et al. 2018).

The last evaluation date, which coincided with the harvest, highlighted that the plants supplemented with Ca via fertigation of 2.5 L ha^{-1} of complexed Ca showed a significant reduction in the Ca concentration, when compared to the first evaluation date. The young leaves of plants that received the foliar application of 2 L ha^{-1} of complexed Ca with *A. nodosum* extract exhibited a Ca concentration increase of approximately 72 %. It is essential to highlight that the control group plants also displayed a Ca concentration similar to those that received Ca supplementation via foliar or via fertigation within the evaluation dates.

This initial generalized peak and then a generalized decrease in the leaves may suggest a natural demand for Ca by the plants at the beginning of fruit growth or that the more intense flowering probably led to a dilution of this nutrient (Hocking et al. 2016), since this period is critical for the Ca absorption (Almeida et al. 2014). Probably other factors besides the transpiration flow and fruit drain intensity increased the Ca concentration by the roots or leaves, also regulating the partition of nutrients to the leaves (White & Broadley 2003, Hocking et al. 2016).

The Ca concentration in the fruits (Figure 3C) also presented oscillations in the average values within the evaluation dates and were much lower than those observed in mature and young leaves (Figures 3A and 3B). When comparing all the evaluation dates, it was noticed that there was an almost generalized decrease in the Ca concentration among the supplementation strategies, including the control group, and that new significant increases were registered only in the sixth evaluation date.

The control group fruits exhibited a Ca concentration similar to one or all strategies of supplementation with Ca via foliar and fertigation in all the evaluation dates, except for the last one, where the fertigation supplementation of 2.5 L ha^{-1} of complexed Ca provided a significant increase in the Ca concentration. The fruits of plants supplemented via foliar with 2 L ha^{-1} of complexed Ca + 2.5 L ha^{-1} of complexed Ca via fertigation also displayed a considerable increase; however, not noteworthy, when compared to the others. Comparing both forms of supplementation in the first and last evaluation dates, an increase was observed in the percentage (98 and 95 %, respectively).

It is likely that the peaks in Ca concentration are related to the role of this nutrient in cell division processes, besides the stabilization of membranes and cell wall interactions. As an immobile nutrient in the phloem, Ca depends mainly on the transpiration water flow to accumulate in the fruits (Almeida et al. 2014).

Among the variables analyzed at harvest, carbohydrates, total N in mature leaves and fruits, and yield differed among the supplementation strategies (Table 3).

When analyzing the carbohydrates levels among the supplementation strategies, it was found that the leaves supplemented with 2 L ha^{-1} of foliar complexed Ca + 2.5 L ha^{-1} of complexed

Table 3. Synthesis of the analysis of variance for the means of nitrogen in young and mature leaves and fruits, amino acids, carbohydrates, fruit dry mass and fruit yield of mango cv. Kent, as a function of calcium supplementation strategies (CSS).

Sources of variation	Amino acids	Carbohydrates	Nitrogen			Fruit	
	Young leaves		Young leaves	Mature leaves	Fruits	Fruit dry mass	Fruit yield
	μmol g^{-1} of FM		g kg^{-1}			%	t ha^{-1}
CSS	1.32^{ns}	46.10*	2.08^{ns}	3.23*	1.68*	1.31^{ns}	11.55*
CV (%)	12.03	6.83	10.05	6.21	12.33	21.85	25.36

* Significant ($p < 0.05$); ^{ns} not significant. CV: coefficient of variation; FM: fresh mass; FDM: fruit dry mass; FY: fruit yield.

Ca via fertigation exhibited the lowest value, being accompanied by the plants supplemented with 2 L ha^{-1} of complexed Ca with *A. nodosum* extract. However, there was a similarity among the values recorded in the other forms of supplementation, including the control group (Figure 4A).

Soluble carbohydrates are vital sources of energy and carbon skeletons for organic compounds; they can exert a trivial function as signaling molecules, similarly to phytohormones, besides affecting plant immunity (Martínez-Lüscher & Kurtural 2021). Non-structural carbohydrates status may also play a role in photosynthetic acclimatization to fruits on mango trees (Ngao et al. 2021).

The intensive mango crop management prioritizes carbohydrates accumulation during specific phases, usually resulting from chlorophyll biosynthesis and photosynthetic activity, especially for high-energy-demand phases such as floral induction and fruit development (Silva et al. 2021, Carreiro et al. 2022).

According to Stino et al. (2011), Ca is necessary for sugar synthesis and accumulation, and, in small amounts, it can compromise fruit harvest and yield. The reduced soluble carbohydrate concentration in plants supplemented with complexed Ca (2 L ha^{-1}) and Ca via fertigation + complexed Ca may have occurred due to the high demand by the fruit due to these supplements, as this variable was analyzed at the harvest time, when fruits display their capability of mobilizing photoassimilates.

Similar results were reported by Cavalcante et al. (2018), Lopes et al. (2021), Silva et al. (2021) and Cunha et al. (2022). Although these studies were performed under different management strategies, the carbohydrate synthesis in leaves and accumulation in branches is preponderant for mango development.

It is essential to infer that the carbohydrate demand varies throughout the crop cycle. For instance, Silva et al. (2020) evaluated maturation strategies of mango branches cv. Tommy Atkins, as a function of biostimulant, under similar environmental conditions, and reported a tendency of soluble carbohydrates accumulation during the branch maturation phase, a desired effect for later energy demand that tends to increase. Combined with this, the mango foliar nutrition presented levels similar to those of the present study (30.50-35.97 g kg^{-1}).

Figure 4B presents the total N amount in young and mature leaves and fruits. By analyzing the figure, it can be pointed out that supplementations with 2.5 L ha^{-1} of complexed Ca via fertigation were essential and significant for N accumulation in mature leaves, with an average of 14.61 g kg^{-1}. On the other hand, the other supplementation strategies presented values similar to each other and

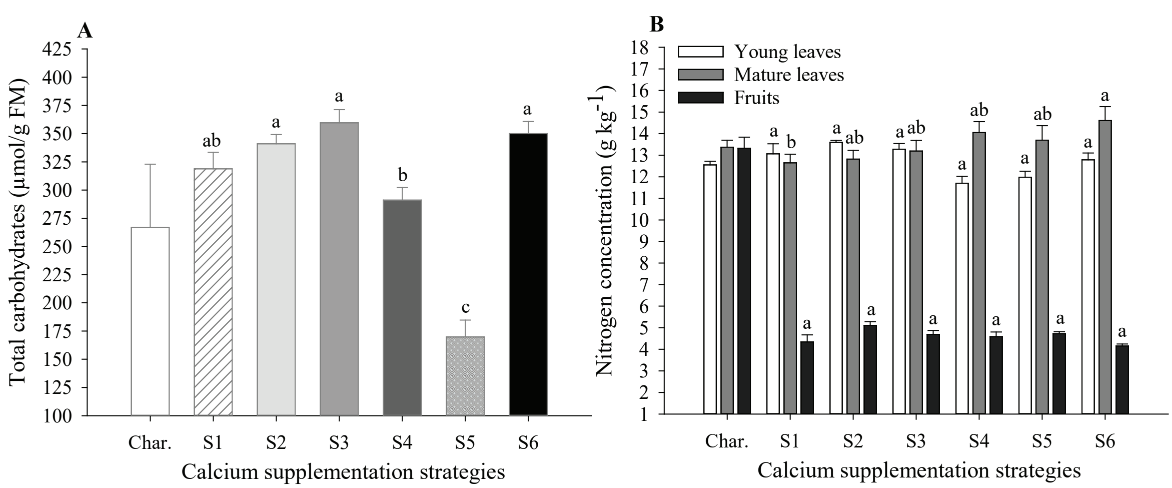


Figure 4. Total soluble carbohydrates in leaves (A) and total nitrogen concentration in young and mature leaves and fruits (B) of mango cv. Kent, due to calcium supplementation strategies. Bars with the same letter do not differ by the Tukey test ($p < 0.05$). Char: initial characterization; S1: control; S2: foliar application of 1 L ha^{-1} of micronized Ca; S3: foliar application of 2 L ha^{-1} of micronized Ca; S4: foliar application of 2 L ha^{-1} of complexed Ca with *Ascophyllum nodosum* extract; S5: foliar application of 2 L ha^{-1} of complexed Ca with *A. nodosum* extract + application via fertigation of 2.5 L ha^{-1} of complexed Ca (*A. nodosum* extract, humic acids and amino acids); S6: application via fertigation of 2.5 L ha^{-1} of complexed Ca (*A. nodosum* extract, humic acids and amino acids). FM: fresh mass.

close to those obtained by the plants of the control group, ranging from 12.65 g kg^{-1} (control group) to 14.05 g kg^{-1} (foliar application of 2 L ha^{-1} of complexed Ca with *A. nodosum* extract).

The appropriate foliar N concentration in the fruiting phase has not yet been fully elucidated due to the variation in fruit growth (fast/slow). This classification is based on the levels found in the complete flowering phase.

Thus, some authors disagree on the proper N concentration in mango leaves. For example, Quaggio (1996) considers that adequate N levels are between 12 and 14 g kg^{-1}, while Rezende et al. (2022) consider 13.4-16.7 g kg^{-1} suitable by the DRIS method. Therefore, the results obtained in this experiment are adequate according to the supply range described by Quaggio (1996), with S1 (control), S2 and S3 (micronized Ca); but, on the other hand, considering the sufficient range of Rezende et al. (2022), only S4, S5 and S6 (complexed Ca) are adequately supplied.

The foliar Ca application does not guarantee that there will be increases in specific characteristics or analyzed variables, such as total N concentration in mature leaves, as observed by Bibi et al. (2019) in mango, also supplemented with foliar Ca. Several factors in the soil-plant-atmosphere system may interfere with this balance (White & Broadley 2003).

Figure 5 summarizes the mean values of fruit yield. The Ca supplementation strategies were crucial in increasing fruit yield.

The plants supplemented via fertigation with 2.5 L ha^{-1} of complexed Ca and 2 L ha^{-1} of complexed Ca via foliar + 2.5 L ha^{-1} of complexed Ca via fertigation showed much higher fruit yield values. Comparing these two supplementation forms with the control, there were increases of about 417 and 290 %, respectively.

Fruit yield displayed an expressive increase, when compared to the control, especially when the plants were supplemented with 2.5 L ha^{-1} of complexed Ca. Perhaps this behavior is related to the more significant accumulation of total N in mature leaves also observed in these same plants (Figure 4B). Nitrogen is one of the macronutrients most required by plants. Like other macronutrients, it can drastically change their physiological behavior, acting on photosynthetic capacity parameters or even decreasing electron transport rates (Ngao et al. 2021). Therefore, its biochemical cycling, in addition to

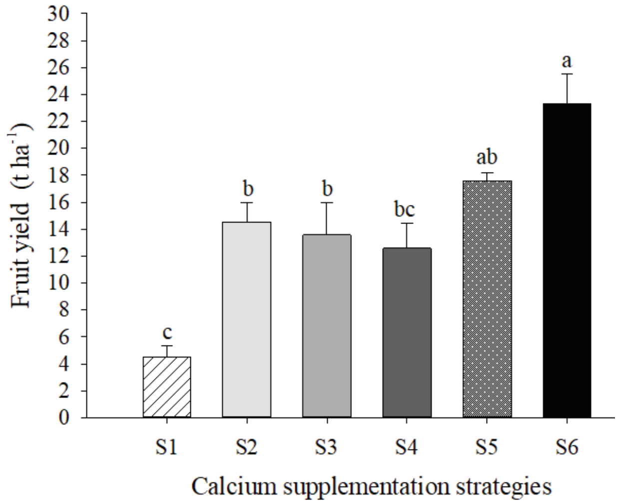


Figure 5. Fruit yield of mango cv. Kent, as a function of calcium supplementation strategies. Bars with the same letter do not differ by the Tukey test ($p < 0.05$). S1: control; S2: foliar application of 1 L ha^{-1} of micronized Ca; S3: foliar application of 2 L ha^{-1} of micronized Ca; S4: foliar application of 2 L ha^{-1} of complexed Ca with *Ascophyllum nodosum* extract; S5: foliar application of 2 L ha^{-1} of complexed Ca with *A. nodosum* extract + application via fertigation of 2.5 L ha^{-1} of complexed Ca (*A. nodosum* extract, humic acids and amino acids); S6: application via fertigation of 2.5 L ha^{-1} of complexed Ca (*A. nodosum* extract, humic acids and amino acids).

the cycling of other nutrients, is essential for mango cultivation (Almeida et al. 2014).

The control group plants (not supplemented with Ca) reached a yield of 4.51 t ha^{-1}, much lower than expected, because, even without treatment, their fruit yield was expected to be close to the national average of 30.8 t ha^{-1} (IBGE 2022). However, the foliar application of 2 L ha^{-1} of complexed Ca + application via fertigation of 2.5 L ha^{-1} of complexed Ca and the application via fertigation of 2.5 L ha^{-1} of complexed Ca were higher than the national average, demonstrating a positive effect of the Ca application on the fruit.

The results obtained for the number of fruits and fruit yield can be attributed to the fruit set rate caused by the supply of Ca soon after the first physiological fall, since Ca plays a role in the synthesis and accumulation of sugars, which are energy sources for growth and fruit development (Stino et al. 2011), reflecting on the fruit set rate and fruit yield.

The low fruit yield observed in plants not supplemented with Ca may also be associated with their age: they were young and, in their first production cycle, unable to express their full productive potential, as in more mature orchards. Lobo et al. (2019) may confirm this hypothesis. The authors applied biostimulants to an eight-year-old mango orchard cv. Kent in the São Francisco Valley region, and observed a lower yield of 22 t ha^{-1} in the 2016 crop and about 52 t ha^{-1} in the 2017 crop.

Therefore, it is essential that mango producers in the Brazilian northeastern semi-arid region evaluate the plant nutrition also by leaf analysis, in addition to soil analysis, so that the best supplementary fertilization strategy can be achieved during the development phase of the plants, in order to increase the Ca concentration in the leaves and, consequently, in the fruit set and production.

CONCLUSION

The fertilization strategy of 2.5 L ha^{-1} of complexed calcium via fertigation is fundamental to increase the Ca concentration of fruits from 65 days after full flowering and positively affects the setting and production of mango fruits cv. Kent.

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