Research Group 'Fruit Production in São Francisco Valley'
Petrolina, Brazil

Field management strategies to enhance mango fruit dry mass

- Final report of research project -

Dr. Ítalo Herbert Lucena Cavalcante
Federal University of São Francisco Valley, Petrolina, Brazil
National Council for Scientific and Technological Development (CNPq)
Leader of the Research Group 'Fruit Production in São Francisco Valley' (FRUTVASF)
italo.cavalcante@univasf.edu.br / https://frutvasf.univasf.edu.br/

December 2023

Abstract: Fruit dry mass has been considered one of the most important fruit quality parameter for mangoes. Some field researches have been developed to better understand and maybe increase mango fruit dry mass with some success but no clear results are found in the scientific literature. Mango fruit dry mass may be related to the nutritional management of the orchard, especially for calcium. Thus, a research project was developed with the objective to increase fruit dry mass of 'Kent' and 'Ataulfo' mango cultivars through a field management for water deficit and calcium fertilizing. The experiments (mango trees cv. Ataulfo and Kent) were arranged in randomized blocks, following a 2 × 4 factorial design, with four repetitions and three plants per plot. The factors involved the suspension of water supply fifteen days before harvest (without and with) and calcium sources [no calcium (control), calcium chloride – CaCl2, calcium complexed with organic acids – Ca-OA, and calcium complexed with amino acids – Ca-AA]. The analyzed variables included fruit yield (t ha^{-1}), leaf nutrient concentrations during pruning, flowering induction, and fruit harvest; and fruits (pulp and skin separately) at pre-flowering and harvest stages, calcium bound to the cell wall, and post-harvest fruit quality. The use of chelated calcium sources (with organic acids or amino acids), in conjunction with water deficit during 15 days before fruit harvest, enhances the fruit yield and post-harvest quality of mangoes in the 'Ataulfo' and 'Kent' varieties. The application of chelated calcium with amino acids increases the Ca bound to the cell wall content in the pulp of 'Ataulfo' mangoes, while chelated calcium with organic acids, associated with water deficit before harvest, raises the bound Ca content in 'Kent' mangoes. However, the application of chelated calcium with amino acids produces fruits of higher quality suitable for export in both cultivars. For the 'Ataulfo' cultivar, it is recommended to suspend irrigation before fruit harvest and use a chelated calcium with amino acids. For the 'Kent' cultivar, it is not recommended to suspend irrigation before harvest, and the recommended calcium source is also one chelated with amino acids.

Keywords: *Mangifera indica* L., nutritional status, calcium fertilizing, fruit post-harvest, fruit production

1. Introduction

Fruit dry mass has been considered one of the most important fruit quality variable for mangoes because it mainly consists of carbohydrates, 60% of which are sugars and acids (Ueda et al., 2000). Indeed, the dry mass content of mango at harvest, along with other characteristics, serves as the most reliable harvest index, indicative of fruit quality (Freitas et al., 2022).

Some field research have been developed to better understand and maybe increase mango fruit dry mass (Simmons et al., 1998; Anderson et al., 2017; Sena et al., 2023), with some success but no clear results are found in the scientific literature.

Field experiments that correlate fertilizing management, irrigation strategy, biostimulation and abiotic stress alleviation for elevated temperature and low air humidity periods are particular important to reach higher fruit dry mass. One of the nutrients crucial for maintaining post-harvest quality in mango is calcium (Freitas et al., 2016; Tenreiro et al., 2023). Calcium, in addition to participating in plant metabolic processes such as protein synthesis, nitrogen assimilation, enzymatic activation, carbohydrate and amino acid transport (Genú and Pinto, 2002; Hocking et al., 2016; Thor, 2019), plays a role in fruit growth and the reduction of physiological disorders, as reported Assis et al. (2004).

Despite the nutritional significance of calcium for mango trees, given that it is one of the most absorbed nutrient by the plant (Rezende et al., 2022) and the third most exported to the fruits (Maldonado-Celis et al., 2019), this element exhibits low mobility in plant phloem, with transport occurring through the xylem (Thor, 2019). When calcium supply is insufficient or transportation is inefficient, localized deficiencies occur, directly influencing the post-harvest fruit quality (Freitas et al., 2022).

In mango orchards Ca is supplied by liming usually soon after harvesting to meet the demand for growth flow. In soil, Ca2+ is adsorbed to the negative charges of mineral and organic colloids through electrostatic bonds being in equilibrium with the soil solution. In order for Ca2+ to be absorbed by plants, it is necessary to transport it through mass flow, and as such, it is subject to leaching losses, especially in sandy soils. In soil, Ca2+ can be lost by leaching, absorption by plants and erosion. Thus, there is a demand for Ca to supply the high demand of this nutrient, especially during the fruit development phase (Silva et al., 2002). Despite having a high rate of nutrient use by the plant and fast responses, leaf fertilization may not be efficient, and it could affect also fruit dry mass.

The traditionally sources used in mango cultivation include calcium chloride, limestone, gypsum, and calcium nitrate, although new complexed Ca sources may assist in the availability process and, consequently, enhance plant absorption. Among the most used calcium complexing agents are humic substances, complex organic compounds, extracts from seaweed, chitin, chitosan derivatives, antitranspirants, and free amino acids (Du Jardin, 2012). In the cultivation of fruit species, the use of humic substances and organic acids have increased aimed at improving fruit yield and quality (Hidayatullah et al., 2018), as well as the addition of amino acids and suspended organic acids for the optimized utilization of nutrients applied during fertilization (Mouco et al., 2009; Hidayatullah et al., 2018).

Another practice that may impact fruit dry mass and has become quite common among mango producers is the suspension of irrigation few days before the fruit harvest with the aim of increasing soluble solids content and advancing the harvest with fruits of better quality (Castro Neto and Reinhart, 2003). However, the results are still controversial regarding the effect and substantiation of this practice in improving mango production and fruit quality. Among the findings supporting this practice, Castro Neto and Reinhart (2003) concluded that the application of water deficit before harvest reduces the accumulation of dry mass in 'Haden' mango fruits, indicating that it may not be an advantageous practice for the producer. Meanwhile, in 'Tommy Atkins' mango trees, Santos et al. (2016a) and Santos et al. (2016b) found that controlled water deficit applied during the fruit maturation phase maintains fruit yield and increases water use efficiency. Bally and Harris (2000) observed that water stress in the pre-flowering stage increased the potential for fruiting in 'Kensington' mango trees.

Thus, a research project was developed with the objective to increase fruit dry mass of ‘Kent’ and ‘Ataulfo’ mango cultivars through a field management for water deficit and calcium fertilizing.

2. Material and Methods

2.1 Characterization of the climate and soil of the experimental orchards

The experiments with 'Ataulfo' and 'Kent' mango trees were conducted at Casa Nova and Nogueira Farms between 2021 and 2022. Casa Nova, Bahia, Brazil is georeferenced at coordinates 9°19'40.5"S 41°07'55.9"W, with an altitude of 400 m above sea level; while Petrolina, Pernambuco, Brazil is georeferenced at coordinates 9°21'42.7"S 40°38'01.4"W, with an altitude of 395 m above sea level.

The climate in the region where the experiments were conducted was classified as BSwh, according to Köppen, indicating a hot semi-arid climate (Alvares et al., 2013). Monthly data on rainfall, temperature, and relative humidity were monitored during the experiment, recorded by automatic weather stations near the experimental areas (Figure 1).

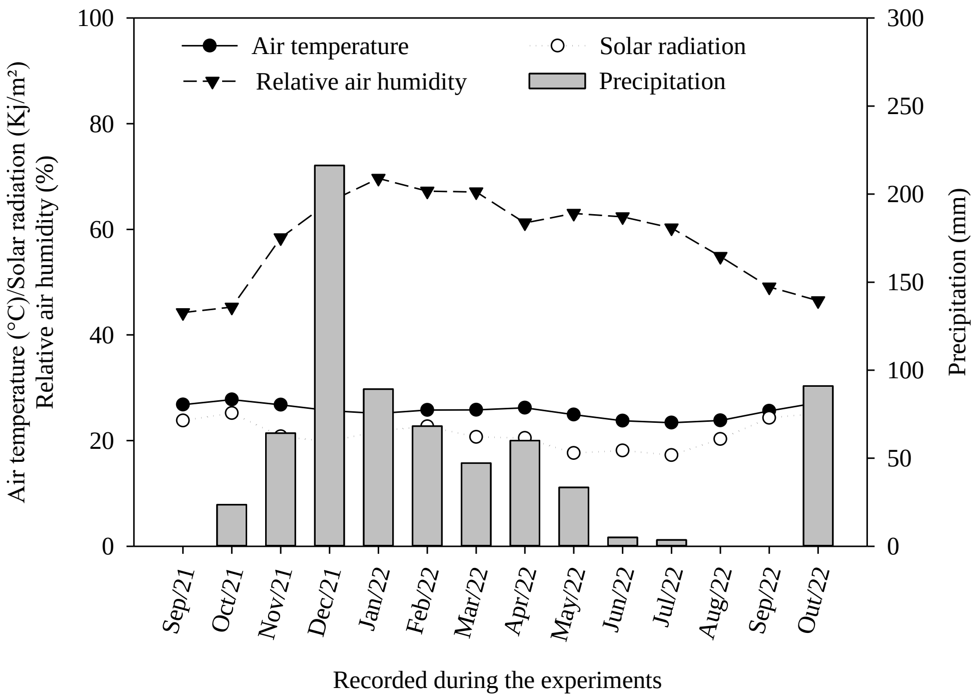

Figure 1. Air temperature, solar radiation, relative air humidity, and precipitation recorded during the experiments.

Before the experiments were set up, soil samples were collected at a depth of 0 to 30 cm, and leaves were collected for nutrient analysis in each experimental area (Tables 1 and 2).

Table 1. Soil chemical analysis of the experimental areas before the application of treatments.

Cultivar	Soil depth	pH	M.O	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	$(H^+ + Al^{3+})$	SB	V	Sat. Ca
	cm	H_2O	g $100g^{-1}$	mg dm^{-3}			--------------- $cmol_c$ dm^{-3} ------------------					%	%
Ataulfo	0-30	6.21	17.1	34.3	0.12	0.06	3.40	0.95	0.00	0.45	4.53	90.90	68.2
Kent	0-30	6.81	19.4	11	0.27	0.03	2.39	0.54	0.00	0.76	3.23	80.95	59.9

SB: sum of bases; Sat.: saturation. Extractors: P, K e Na: Resin (HCl + H_2SO_4); Ca, Mg e Al: KCl 1 M.

Table 2. Nutritional analysis of 'Ataulfo' and 'Kent' mango leaves before the application of treatments.

Cultivar	N	P	K^+	Ca^{2+}	Mg^{2+}	S	B	Cu^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}
	———— g kg^{-1} ————						———— mg kg^{-1} ————				
Ataulfo	14.8	1.3	4.5	27.4	1.8	2.1	57.1	10.1	111.4	150.9	15.4
Kent	13.7	1.2	3.8	29.0	2.7	1.6	115.2	7.2	130.8	646.9	29.9

2.2 Experimental procedure and study material

The experiments (mango trees cv. Ataulfo and Kent) were arranged in randomized blocks, following a 2 × 4 factorial design, with four repetitions and three plants per plot. The factors included the suspension of water supply fifteen days before harvest (without and with) and calcium sources [no calcium (control), calcium chloride – CaCl2, calcium complexed with organic acids – Ca-OA, and calcium complexed with amino acids – Ca-AA].

The 'Ataulfo' mango trees in the orchard were five years old at the start of the experiment and spaced 10 m × 10 m (population density = 100 plants ha^{-1}), irrigated daily by micro-sprinkler irrigation system with sprinklers flowing at 60 L h^{-1} and operating at a service pressure of 0.2 MPa. The 'Kent' mango trees in the orchard were four years old and spaced 3.5 m × 2.0 m (1428 plants ha^{-1}), irrigated daily by a drip irrigation system with dual tape emitters, with four emitters per plant and a flow rate of 2.4 L h^{-1}.

At the beginning of the experiments, calculations were realized to increase calcium saturation to 75% (Ataulfo) and 70% (Kent), planned in two stages:

i) During the pre-pruning phase, based on soil chemical attributes following the soil base saturation equilibrium methodology described by Albrecht (1975). In the 'Ataulfo' mango orchard, soil calcium saturation was raised from 68.2% (Table 1) to 70%, and in the 'Kent' mango orchard, it was increased from 59.9% (Table 1) to 65%. In both orchards, calcium correction for saturations was carried out by applying a fertilizer containing *Lithothamnium*, marine calcium (Algen®), composed of 32% Ca and 2% Mg, at doses of 14.60 kg/hectare for 'Ataulfo' (Figure 2A) and 109.95 kg/hectare for 'Kent' (Figure 2B).

Figure 2. Illustration of the application of marine calcium (*Lithothamnium*) to raise the initial soil calcium saturation before the application of calcium sources in the experimental areas of 'Ataulfo' (A) and 'Kent' mangoes (B).

ii) After the initial elevation of soil calcium levels, calcium sources were applied to raise soil Ca2+ to 75% in the 'Ataulfo' mango area and in the 'Kent' mango area to 70%. Calcium chloride, containing 24% Ca, was applied at a rate of 78 kg per hectare, and calcium complexed with organic acids (Codasal®, containing 8.7% Ca, 6.0% N, and 14.7% lignosulfonate complexing agents) and calcium complexed with amino acids (Hendosar®, containing 9.0% N, 6.0% K2O, 7.15% Ca, 1.2% Mg, and additives with amino acids) were applied at lower doses due to their higher efficiency, as demonstrated by Tenreiro (2020).

The determined doses of the respective calcium sources were applied according to the nutritional requirements for mango cultivation, divided into 50% of the recommended dose applied right after pruning (split into two fortnightly applications of 25%), 20% of the recommended dose applied at panicle emergence, and 30% of the recommended dose applied during fruit growth (split into two fortnightly applications of 15%). The fractional application of calcium sources considered the nutritional requirement of Ca at each stage of mango cultivation (Winston, 2007), as shown in Figure 3.

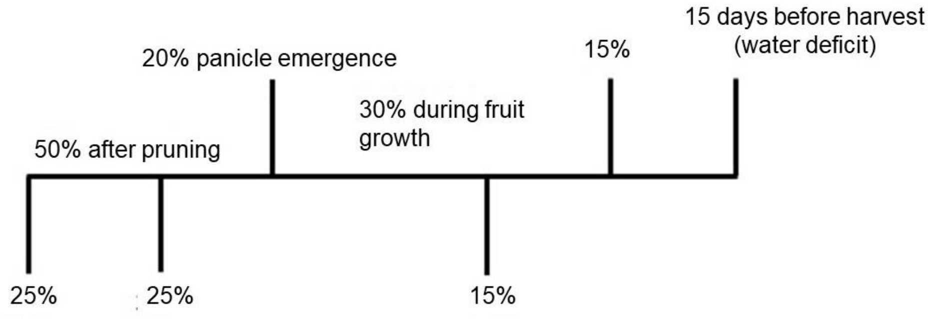

Figure 3. Diagram of calcium source applications (% of calcium recommendation) and water supply deficit during 15 days before fruit harvest for 'Ataulfo' and 'Kent' mango trees.

Both experiments underwent fertilization practices (excluding calcium), cultural management, weed, pest, and disease control, and floral induction, following the instructions of Genú and Pinto (2002), Cavalcante et al. (2018), and Torres (2019). Fifteen days before fruit harvest, water supply restriction was applied to plants under water deficit conditions to increase dry mass and improve mango fruit quality (Castro Neto and Reinhart, 2003).

2.3 Analyzed variables

To diagnose the nutritional status of the leaves, samples were collected at 178 days after production pruning in the pre-flowering phase and at 284 days and 250 days after production pruning in 'Ataulfo' and 'Kent' mango trees, respectively. Samples were collected and stored in paper bags, then sent to the Plant Soil Laboratories® for soil and leaf analysis. Leaf collection criteria followed the recommendations of Malavolta et al. (1997). After washing with distilled water, the leaves were placed in a paper bag for drying in a forced-air oven at 60°C until constant mass, ground in a stainless-steel knife mill (Willey type) and stored in a hermetically sealed container. The samples were analyzed for N (g kg^{-1}), P (g kg^{-1}), K (g kg^{-1}), Ca (g kg^{-1}), Mg (g kg^{-1}), S (g kg^{-1}), B (mg kg^{-1}), Fe (mg kg^{-1}), Cu (mg kg^{-1}), Mn (mg kg^{-1}), and Zn (mg kg^{-1}) according to the methodology proposed by Tedesco et al. (1995).

Fruit harvesting was carried out on September, 2022, and October, 2022, for 'Ataulfo' and 'Kent' mango trees, respectively, when the fruits were at stage 2, characterized by a cream-yellow pulp color (Filgueiras et al., 2000). For yield estimation (t ha^{-1}), the number of fruits was counted, weighed, and multiplied by the planting density of 100 plants/hectare for 'Ataulfo' and 1,428 plants/hectare for 'Kent' to obtain fruit yield in tons per hectare.

For post-harvest analysis of the fruits, four fruits per plot were selected, totaling 12 fruits per treatment, taken to the laboratory, and stored in a B.O.D (Biochemical Oxygen Demand) incubator for 15 days at 10 °C and 7 days at 25 °C to simulate the maritime transport period for major importing markets and shelf life, respectively (United States and European Union) (Figure 4). Additionally, ten fruits per treatment were selected, forming one sample per treatment, for the determination of calcium bound to the cell wall of the fruit pulp, following the methodology described in Bonomelli et al. (2018).

Figure 4. Mango fruits 'Ataulfo' (A) and 'Kent' (B) in a B.O.D (Biochemical Oxygen Demand) under controlled conditions for air temperature simulating maritime transport and shelf life of the fruits.

The physical-chemical variables analyzed were: fruit mass (MF) with a semi-analytical balance (precision = 0.01g) and expressed in g; length (CF) and width (LF) of the fruits with the aid of a digital caliper brand Starret® (0.01 mm – 300 mm) and expressed in mm; pulp firmness (FP) with a digital penetrometer with an 8 mm tip, taking measurements on two opposite sides of the equatorial region of the fruit where the epidermis was removed, expressed in kgf cm^{-2}; soluble solids (SS) were determined by direct reading on an ABBE® refractometer and expressed in °Brix; titratable acidity (AT) determined by titration with 0.1N NaOH solution and phenolphthalein indicator and expressed in % and the SS/AT ratio obtained by the direct relationship between soluble solids and titratable acidity; vitamin C (Vit C) was quantified by titration using a DFI solution (2,6 dichloro-phenolindophenol), using 1 mL of diluted juice in 50 mL of 0.5% oxalic acid (Zenebon et al., 2008). Figure 5 visually shows the performance of these analyses.

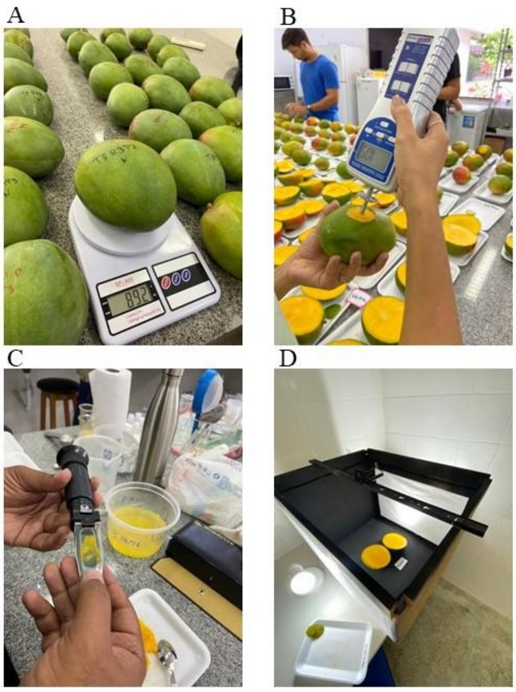

Figure 5. Illustration of the physical-chemical analysis of 'Ataulfo' and 'Kent' mango fruits, referring to fruit mass (A), firmness (B), soluble solids (C), and photographs of the fruits (D) performed in the Agroindustry Laboratory at Univasf/Petrolina-PE.

2.4 Statistical analysis

Before statistical analysis, the data were subjected to normality (Shapiro-Wilk) and homogeneity analysis. Subsequently, the data from each experiment were individually subjected to analysis of variance using the 'F' test ($p \leq 0.05$). The means related to water restriction and calcium sources were compared using the Tukey test at a 5% probability level. The statistical analysis was performed using the Sisvar software version 5.6.

3. Results and Discussion

3.1 Nutritional status in macronutrients and micronutrients of 'Ataulfo' and 'Kent' mangoes in the pre-flowering phase

As can be seen in Table 3, leaf N concentrations in both mango cultivars were not affected by the Ca sources, which may be justified by the low nutrient levels in some of the evaluated sources, as well as the nitrogen fertilization management of the orchards that prioritizes the sprouting phase (Cavalcante et al., 2018), not the pre-flowering phase when the evaluation was conducted. According to the sufficiency range for N defined by Rezende et al. (2022), the concentrations in 'Ataulfo' and 'Kent' mango trees for all treatments are within the optimal range from 14.2 g kg^{-1} to 16.9 g kg^{-1}, which is relevant considering that excess N can affect mango flowering (Santos et al., 2021). This result is also important because sources containing amino acids (Basile et al., 2021) and organic acids (Torres, 2019) can influence the N availability to plants, as also reported by Colla et al. (2014) and Liu et al. (2008).

Table 3. Synthesis of variance analysis for foliar macronutrient contents in the pre-flowering phase of 'Ataulfo' and 'Kent' mango trees under fertigation with calcium sources.

FV	N (g kg^{-1})		P (g kg^{-1})		K (g kg^{-1})		Ca (g kg^{-1})		Mg (g kg^{-1})		S (g kg^{-1})	
	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent
Calcium source ('F Value)	1.78^{ns}	0.36^{ns}	3.81*	6.39**	4.93**	3.33**	2.29^{ns}	3.32*	0.34^{ns}	19.08**	0.76^{ns}	3.85*
Control	16.26a	14.61a	1.22b	1.44b	10.07a	8.81a	21.23a	28.95b	2.49a	3.13c	2.32a	1.43b
CaCl2	16.24a	14.87a	1.28ab	1.46ab	9.29ab	8.80a	24.36a	31.48ab	2.53a	3.99ab	2.29a	1.57ab
Ca-OA	15.31a	14.75a	1.30ab	1.37b	8.42ab	8.08a	22.84a	32.07ab	2.38a	3.74b	1.90a	1.67a
Ca-AA	16.48a	14.47a	1.36a	1.58a	7.85b	7.62b	24.98a	32.31a	2.43a	4.50a	2.05a	1.48b
Average	16.07	14.67	1.29	1.46	8.90	8.32	23.45	31.20	2.45	3.84	2.14	1.53
CV (%)	6.85	5.52	6.56	6.65	13.91	10.82	10.84	7.65	12.30	9.53	16.71	10.11

FV – Source of variation; CV – Coefficient of variation; CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids; *, **, ns – significant at 5%, 1% and not significant, respectively by the F test. Means with equal lowercase letters do not differ from each other by the F test ($p \leq 0.05$)

Calcium sources affected P leaf concentrations in the studied cultivars (Table 3), with higher levels obtained with Ca-AA application in both cultivars. Phosphorus nutritional management is crucial for assisting in root system development, influencing water and nutrient absorption, and resulting in better vegetative growth, flowering, and fruiting development (Rezende et al., 2023). Applications of sources containing amino acids can chelate macro and micronutrients, forming complexes with nutrients and making them available to the plant, as also occurs for phosphorus (Lambais, 2011).

For the nutrient K, calcium sources influenced both cultivars, and higher K leaf values in plants that did not receive calcium sources (control) (Table 3). The decreases in leaf Ca2+ and Mg2+ concentrations in the control treatment may have occurred due to competitive effects resulting from increased K availability, as also reported by Lima et al. (2019). In some cases, the K availability may increase more than that of Ca and Mg, due to K's lower attraction to soil negative charges (Barber & Humbert, 1963).

As can be seen in Table 3, Ca concentrations were influenced by calcium sources in 'Kent' mango trees with the Ca-AA treatment. This cultivar presented higher Ca leaf levels when Ca-AA was applied, indicating efficiency in nutrient absorption and translocation. The Ca leaf concentrations in 'Kent' mango trees were within the range of 30.9 g kg^{-1} to 36.9 g kg^{-1}, except for the control treatment, while in all treatments for the 'Ataulfo' cultivar, they were below the recommended range. Calcium is essential in mango cultivation, participating in plant and fruit cell development and influencing quality, as well as reducing internal breakdown in the pulp (Silva et al., 2004; Krishna et al., 2020).

Leaf Mg concentrations were affected by calcium sources for the 'Kent' cultivar, with the Ca-AA application providing a higher average nutrient level in the leaf. Magnesium is crucial in the pre-flowering phase of mangoes, being an integral part of chlorophyll molecules and an activator of enzymes (Silva et al., 2004).

Sulfur leaf concentrations in the 'Kent' cultivar depended on calcium sources (Table 3), showing higher S leaf levels when Ca-OA was supplied. Organic acids directly influence S levels in the soil and leaf for the studied cultivars (Torres, 2019). However, it is important to note that soils with low clay content, such as those with low organic matter content, may have low sulfur availability, limiting crop fruit yield (Rheinheimer et al., 2005). Sources of organic acids can increase sulfur levels, as observed in this study.

In general, fertilizers containing amino acids as complexing agents can increase the efficiency of nutrient availability, as highlighted by Mógor (2015). Positive results were found when Ca-AA was applied, promoting higher leaf levels of N, P, and S in 'Ataulfo' mango trees and higher levels of P, Ca, and Mg in 'Kent' mangoes (Table 3).

Nitrogen is a structural component of amino acids, forming part of proteins, enzymes, coenzymes, nucleic acids, and chlorophyll (Mahmud et al., 2020). The differences in leaf concentrations compared to those defined by Rezende et al. (2022) may also be influenced by rootstock, cultivar, region, and management; however, these values can enhance mango crop fruit yield.

As shown in Table 3, higher K values were recorded in treatments without calcium in the studied cultivars. Regarding Ca concentrations, the opposite occurred. This is related to the fact that nutrients in higher concentrations tend to reduce or inhibit the absorption of those in lower concentrations. High K concentration would induce lower calcium and magnesium levels (Lieten, 2006). The use of amino acids in agriculture has been increasing due to the benefits provided to plants, resulting in higher yields and better quality in various crops (Brandão, 2007). Albuquerque et al. (2008) reported significant growth of plants after several applications of products containing free amino acids in their formulation.

Assis et al. (2004) emphasizes the importance of the calcium-nitrogen relationship in the occurrence of physiological disorders in fruits, highlighting the physiological role these elements play and their speed of absorption and translocation within plants. Calcium plays a crucial role in preserving the integrity of cell membrane walls, and calcium deficiency in fruits is often associated with increased permeability and cell disintegration (Aghdam et al., 2012). Thus, maintaining calcium within the sufficiency range is fundamental.

According to Table 4, calcium sources influenced leaf copper (Cu) concentrations in 'Ataulfo' mango trees during the pre-flowering phase, with higher levels in plants that received Ca-OA. Organic acids increased the nutrient's availability of insoluble forms of various plant nutrients, according to Canellas et al. (2015). Organic acids possess functional radicals that make them capable of forming organic complexes with Fe, Al, Ca, and Mg (Pearson, 1966). Micronutrient management is important, although the mango's requirement for Cu levels is small (Silva et al., 2004). All treatments promoted Cu levels above the reference values defined by Rezende et al. (2022), ranging from 6.6

mg kg^{-1} to 14.5 mg kg^{-1}. In contrast to the Cu leaf levels found in this study, Faria (2014) reported leaf nutrient levels in 'Tommy Atkins' mango trees during the flowering stage ranging from 2.70 to 3.29 mg kg^{-1}, thus below the reference values of Rezende et al. (2022).

Table 4. Synthesis of analysis of variance for leaf micronutrient levels in the pre-flowering stage of 'Ataulfo' and 'Kent' mango trees under fertigation with calcium sources.

FV	B (mg kg^{-1})		Cu (mg kg^{-1})		Fe (mg kg^{-1})		Mn (mg kg^{-1})		Zn (mg kg^{-1})	
	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent
Calcium source (‘F Value)	1.60^{ns}	1.61^{ns}	5.01**	0.84^{ns}	2.26^{ns}	7.35**	5.40**	0.85^{ns}	2.43^{ns}	1.83^{ns}
Control	70.40a	118.53a	19.67ab	9.35a	55.55a	70.87b	120.59b	576.35a	25.11a	19.88a
CaCl2	68.51a	127.15a	34.24ab	14.36a	46.04a	86.02ab	179.26a	585.80a	14.72a	18.09a
Ca-OA	69.83a	146.66a	35.02a	20.08a	48.26a	90.34a	129.18b	540.86a	16.59a	20.82a
Ca-AA	80.48a	133.94a	13.50b	15.54a	43.08a	103.14a	146.00ab	667.45a	14.42a	16.47a
Average	72.30	131.57	25.60	14.83	48.23	87.59	143.75	590.36	17.71	18.81
CV (%)	17	20.1	52.88	91.51	20.72	15.85	21.93	27.59	51.40	21.43

FV – Source of variation; CV – Coefficient of variation; CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids; *, **, ns – significant at 5%, 1% and not significant, respectively by the F test. Means with equal lowercase letters do not differ from each other by the F test ($p \leq 0.05$).

The highest leaf Fe in 'Kent' mango trees were quoted in treatments with Ca-AA, with a superiority of 19.90% over plants that received CaCl2 (Table 4). According to Costa (2009), amino acid-based products in plants are indisputable as they are involved in a significant portion of both primary and secondary metabolism, complexing with elements, and primarily contributing to the synthesis of various compounds that influence fruit production and quality.

There was an influence of calcium sources on leaf Mn levels in the pre-flowering stage of 'Ataulfo' mango trees (Table 4), with higher values obtained in plants that received CaCl2. Due to this treatment having lower levels of other cations, it resulted in higher Mn levels. It is essential to highlight that Mn must be in balance with other cations, such as iron, calcium, and magnesium (Silva et al., 2022a; Silva et al., 2022b;). However, Mn is the most demanded micronutrient in mango cultivation and is an essential component in chlorophyll formation and the formation, multiplication, and functioning of chloroplasts (Silva et al., 2004). The higher presence of this nutrient in vegetative parts demonstrates its importance in photosynthesis, especially in water photolysis (Taiz et al., 2017).

Micronutrients are of similar importance to other nutrients for plant development. They can be distinguished from macronutrients by the quantity absorbed, being required in smaller amounts. However, their deficiency compromises plant growth, development, and fruit yield (Cremonesi et al., 2019). The nutritional requirements of crops increase according to the increasing levels of fruit yield achieved over the years (Oliveira et al., 2019). According to Silva et al. (2022), iron and manganese are the micronutrients with the highest accumulation in mango cultivation. Taiz et al. (2017) reported that some plant tissues, such as mesophyll, contain almost as much Mn or Fe as Mg and S.

The high leaf Cu amounts found in this study may be related to pesticides applied to the area during crop management. According to Silva et al. (2014), in some cases, elevated Cu leaf concentrations can be a consequence of applying fungicides and sprays based on the element, used to control diseases. These products can accumulate in the soil, increasing the nutrient's availability to the plant.

3.2 Nutritional status in macronutrients of 'Ataulfo' and 'Kent' mango trees in the post-harvest phase

According to Table 5, there was an interaction between water deficit and calcium sources in the leaf nutritional status of 'Ataulfo' cultivar (N) and 'Kent' cultivar (K, Ca, and Mg).

Table 5. Synthesis of analysis of variance for leaf macronutrient levels (N, K, Ca, and Mg) in the post-harvest phase of 'Ataulfo' and 'Kent' mangoes as a function of water deficit before fruit harvest and fertigation with calcium sources.

FV	N ($g\ kg^{-1}$)		K ($g\ kg^{-1}$)		Ca ($g\ kg^{-1}$)		Mg ($g\ kg^{-1}$)	
	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent
Water deficit WD ('F' value)	11.93^{**}	5.79^{*}	6.33^{*}	0.18^{ns}	1.78^{ns}	16.82^{**}	0.03^{ns}	2.73^{ns}
Without	14.95b	12.75b	6.56b	7.18a	21.54a	21.87b	1.96a	3.18a
With	15.65a	13.25a	7.25a	7.31a	23.16a	25.87a	1.98a	3.37a
Calcium sources Ca ('F' value)	2.04^{ns}	3.62^{*}	2.28^{ns}	4.42^{*}	2.87^{ns}	6.93^{**}	0.85^{ns}	15.37^{**}
Control	15.07a	13.50a	6.88a	8.00a	23.07a	20.50b	1.86a	2.87c
CaCl2	15.08a	13.12ab	6.35a	7.50ab	21.36a	23.62ab	2.08a	3.00ab
Ca-OA	15.37a	12.62b	7.33a	6.75b	20.12a	26.62a	2.00a	3.37b
Ca-AA	15.68^{a}	12.75ab	7.06aa	6.75b	24.85a	24.75a	1.96a	3.87a
WD x Ca	3.36^{*}	1.20^{ns}	1.99^{ns}	5.09^{**}	2.23^{ns}	5.75^{**}	0.62^{ns}	3.55^{*}
CV (%)	3.76	4.52	11.29	11.36	15.37	11.55	14.39	9.77

FV – Source of variation; CV – Coefficient of variation; CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids; *, **, ns – significant at 5%, 1% and not significant, respectively by the F test. Means with equal lowercase letters do not differ from each other by the F test ($p \leq 0.05$).P

For leaf N content in the 'Ataulfo' cultivar, the interaction between water blade and calcium sources indicates the superiority of Ca-AA compared to the control, with higher average values when water deficit was applied, except for the control treatment (Figure 6A).

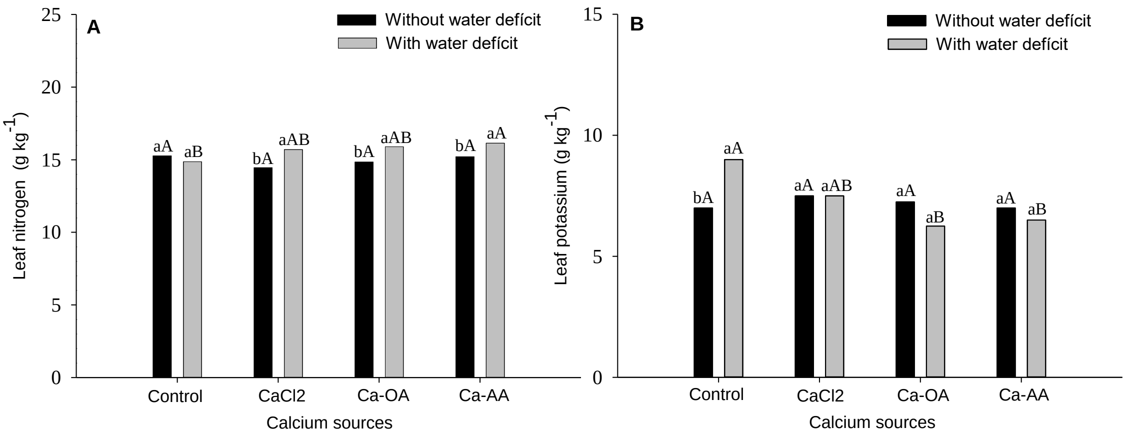

Figure 6. Leaf nitrogen content in 'Ataulfo' mango (A) and potassium in 'Kent' mango (B) before the fruit harvest phase as a function of water deficit and calcium sources. Bars with the same lowercase letters do not differ significantly from each other for each water deficit according to the Tukey test at a 5% probability level. Bars with the same uppercase letters do not differ significantly from each other for calcium sources within each water deficit according to the Tukey test at a 5% probability level. CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids.

Also, when considered individually (Table 5), leaf N levels were lower in plants treated with calcium sources containing organic acids (Ca-OA) and amino acids (Ca-AA) in the 'Kent' mango tree, an important result for the mango tree due to the negative effects of this nutrient on fruit quality. In this regard, a high N level and a low Ca level are related to the cause of mango jelly seed, worsening, and influencing the quality and appearance of fruits (Ma et al., 2022).

Potassium leaf levels in the 'Kent' cultivar depended on the interaction between water blade and calcium sources, indicating the superiority of the control (without calcium). Higher average values were also observed when water blade deficit was performed (Figure 6B). As can be seen in Table 3 during the pre-flowering phase, K was higher in leaf levels of the control treatment in both the pre-flowering and harvest phases. This may be related to the application of Ca in the treated treatments, compromising K absorption. These cations compete for the same absorption channel, reducing the absorption of those in lower concentration in the soil solution, affecting K-Mg and K-Ca relationships. When Mg and Ca values are higher in the soil, K availability decreases (Raij, 2011).

Water deficit increased leaf N levels when associated with calcium application, with increments of 8.57% with CaCl2, 7.07% with Ca-OA, and 6.11% with Ca-AA (Figure 6A). K levels were also elevated with water blade suspension, with higher leaf K levels observed when no calcium was applied, with a 38.46% increase compared to the Ca-AA treatment (Figure 6B). This result is related to potassium absorption, which can be affected by calcium (Ca) and magnesium (Mg) concentrations due to competitive inhibition, as these elements compete for the same binding site in the plant (Marschner, 2012).

As shown in Figure 6A, there was no difference between calcium sources for leaf N content in the 'Ataulfo' mango tree without water deficit. However, the application of complexed calcium associated with amino acids with water deficit before fruit harvest promoted the highest leaf N values, with a superiority of 8.60% compared to the control treatment. Through these results, Ca-AA increased N leaf levels, consequently related to the increase in chlorophyll content. The amino acids in the product formulation influenced this absorption and assimilation of N, as glutamic acid, present in higher concentration in the product formulation, which is directly involved in N absorption and metabolism by plants (Taiz et al., 2017).

In Figure 6B, there is noticeable competition between cations. K can negatively interfere with the absorption of other cations, as similar valence and hydrated ionic radius can cause competition for the same sites in the soil or the same cellular mechanisms (Marschner, 2012). However, K is essential for any crop, and environments with low K concentration show a decrease in photosynthesis, reducing growth, such as leaf area, and mobilizing K from older leaves to younger leaves (Hu et al., 2020).

For leaf Ca and Mg levels in the 'Kent' cultivar, the interaction between water blade and calcium sources indicates the superiority of complexed sources (Ca-AA and Ca-OA) compared to the control. Higher average values were also observed when water deficit was performed, except for the control treatment (Figure 7).

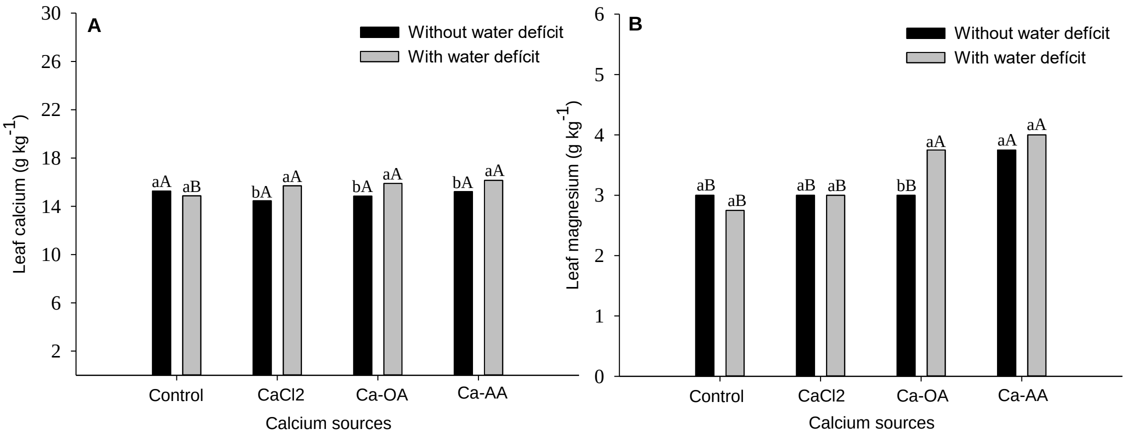

Figure 7. Leaf levels of calcium (A) and magnesium (B) in 'Kent' mango at the fruit harvest phase as a function of water deficit and calcium sources. Bars with lowercase letters do not differ for each water deficit by Tukey test at 5% probability. Bars with uppercase letters do not differ for calcium sources within each water deficit by Tukey test at 5% probability. CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids.

In Table 5, leaf Ca levels were higher in plants treated with calcium sources containing organic acids (Ca-OA) and amino acids (Ca-AA) in 'Kent' mango trees, and the same result was recorded for Mg leaf levels. This result is important for increasing the Ca:Mg ratio and thus preventing disorders in fruits, such as jelly seed (Assis et al., 2004). However, both nutrients were absorbed without competition as they were balanced; excess calcium in relation to Mg in the soil solution impairs the uptake of the latter, and excess Mg also impairs calcium uptake (Lange et al., 2021).

These results suggest that fertilizer management for these cultivars provided nutritional balance and may have positively impacted the fruit yield and quality of 'Kent' mango orchards. Rezende et al. (2022) report that the high fruit yield of the Kent cultivar is significantly associated with the nutritional status of the plants. High fruit yield requires efficient nutritional management, as commercial crops with high fruit yield have a high nutritional demand (Rezende et al., 2022). Rezende et al. (2023) emphasize that leaf sampling and diagnosis during this phase become more advantageous, reducing problems in more developed tissues and being fundamental for management correction.

For the post-harvest phase, there are no literature-reported ranges considered ideal for mango cultivation, making nutritional diagnosis challenging and constituting a gap in knowledge, even in the present day. Higher leaf levels of Ca (Figure 7A) and Mg (Figure 7B) in the post-harvest phase of 'Kent' mango trees were observed when receiving calcium-complexed sources subjected to water deficit. When receiving Ca-AA sources with water deficit, Ca leaf was 8.60% higher when compared to the control treatment (Figure 7A), a result similar to leaf Mg, which obtained 45.45% more with Ca-AA compared to the control. Studies conducted by Yan et al. (2022) show that higher levels of Ca2+ in the plant can inhibit the rupture of cell walls through pectolytic enzymes secreted by the pathogen during penetration, due to better plant structure.

Understanding the functions and requirements of each nutrient for the crop provides a better view of the quality and fruit yield index of the products to be commercialized, preparing the production system for better performance (Oldoni et al., 2021).

3.3 Fruit yield of 'Ataulfo' and 'Kent' mangoes

There was a significant effect between the water blade and calcium source factors for the fruit yield of 'Ataulfo' and 'Kent' mangoes (Table 6).

Table 6. Synthesis of variance analysis for the fruit yield of 'Ataulfo' and 'Kent' mango trees as a function of water deficit before fruit harvest and fertigation with calcium sources.

FV	Ataulfo	Kent
Water deficit WD (‘F’ value)	9.02**	13.15**
Without	4.69b	14.03b
With	5.43a	19.10a
Calcium sources Ca (‘F’ value)	16.63**	6.89**
Control	5.10a	12.66b
CaCl2	3.52b	16.14ab
Ca-OA	6.04a	15.93b
Ca-AA	5.55a	21.53a
WD x Ca	10.30**	4.01*
CV (%)	13.85	23.89

FV – Source of variation; CV – Coefficient of variation; CaCl2 - Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids; *, **, ns – significant at 5%, 1%, and not significant, respectively, by the F-test. Means with equal lowercase letters do not differ from each other by the F-test ($p \leq 0.05$).

The water deficit before harvest affected fruit yield of the 'Ataulfo' mango tree only when associated with the application of calcium complexed with amino acids (Ca-AA), resulting in an increase of 3.07 tons compared to plants without water suspension in the same treatment (Figure 8A). Related results were reported by Mouco et al. (2009) who used amino acid-based products in Tommy Atkins mango trees to reduce thermal stress, and observed higher number of fruits per plant. Amino acids play a crucial role in the plant's primary and secondary metabolism, synthesizing compounds important for fruit quality and production. The balance of phenolic compounds is particularly important for fruit composition, such as mangoes (Mouco et al., 2009).

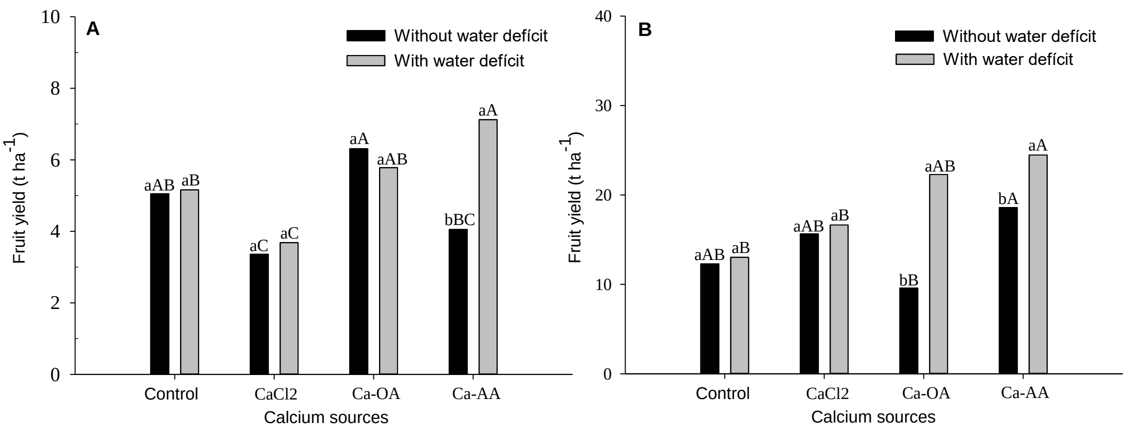

Figure 8. Fruit yield (t ha^{-1}) of 'Ataulfo' (A) and 'Kent' (B) mango cultivars as a function of water deficit before fruit harvest and calcium sources. WD – Water deficit. Bars with equal lowercase letters do not differ from each other for each water deficit by Tukey's test at 5% probability. Bars with equal uppercase letters do not differ from each other for calcium sources within each water deficit by Tukey's test at 5% probability. CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids.

According to Figure 8B, the water deficit before harvest increased fruit yield in the 'Kent' mango tree only when associated with complexed calcium sources, with gains of 12.71 tons in the source complexed with organic acids and 5.86 tons in the complexed with amino acids. Regardless of the application or absence of water deficit, complexed calcium sources promoted the highest fruit yields in the 'Kent' mango tree, with superiority over the control treatment (without calcium).

The superiority in fruit yield of the 'Kent' mango tree with calcium applications, especially complexed sources, is noteworthy. Calcium is an essential nutrient associated with mango tree fruit yield as it acts on fruit setting and fruit growth (cell elongation). Due to its low mobility in the phloem, the application of complexed sources facilitates this mobility and transfer from the plant to the fruits. According to Stino et al. (2011), calcium plays a role in the synthesis and accumulation of sugars, which are energy sources for fruit growth and development, particularly in the fruit setting rate. Tenreiro et al. (2023), applying water-soluble calcium + amino acids via fertigation during the flowering phase in 'Tommy Atkins' mango trees, observed fruit yield ranging from 15.37 t ha^{-1}, a value lower than that found in the present study. Deficit irrigation management has shown promising results in increasing mango tree fruit yield, but it depends on mango cultivar. According to Fonseca et al. (2018), reducing irrigation by up to 50% for four months before flowering promotes higher production than full irrigation levels in 'Ubá' mango trees.

Strategic calcium source applications can reduce physiological fruit drop in mango trees, increasing fruit yield. Calcium is also responsible for greater development of the root system in fruit-bearing plants (Prado and Natale, 2004). Larger root systems allow the plant to explore soil resources more effectively, absorbing higher quantities of other nutrients, contributing to increased fruit production (Almeida, 2012). Results found by Bitange et al. (2019) show that calcium applications in 'Van Dyke' mango trees increased the number and mass of fruits per plant while reducing fruit abortion. Njuguna et al. (2016) reported higher crop yields with calcium application.

Faria et al. (2016) on Tommy Atkins mango trees under water deficit for floral induction observed a significant effect on the number of fruits per plant. Water deficit during floral induction, with a reduction in irrigation by up to 60% of ETc, can be used in 'Kent' mango cultivation to increase fruit mass and fruit yield (Gomes, 2019). However, it is essential to consider that the results mentioned above refer to a reduction in water irrigation during the pre-flowering period, not for fruit harvest, which is a different phenological phase than that studied in the present work.

3.4 Post-harvest fruit quality

Calcium sources complexed with minor substances promote greater calcium mobility in the xylem to the drains, mainly because calcium is a low-mobility element in the plant (Drazeta et al., 2004; Thor, 2019). Mahajan et al. (2011) emphasize that products composed of nanoparticles have specific characteristics, such as higher nutrient absorption efficiency, facilitating greater element absorption.

According to the result of the analysis of variance (Table 7), there was no significant effect of the interaction between water deficit × calcium sources on the physical characteristics of 'Ataulfo' mango fruits ($p \leq 0.05$). However, in 'Kent' mango trees, fruit length was the only physical variable that responded to the interaction between water deficit × calcium sources.

Table 7. Summary of analysis of variance for physical fruit evaluations of 'Ataulfo' and 'Kent' mangoes as a function of water deficit before fruit harvest and fertigation with calcium sources.

FV	Fruit mass (g)		Fruit length (mm)		Fruit width (mm)		Fruit firmness (N)		Fruit dry mass (%)	
	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent
Water deficit WD (‘F’ value)	3.21^{ns}	0.13^{ns}	2.51^{ns}	0.04^{ns}	1.62^{ns}	0.15^{ns}	0.28^{ns}	2.32^{ns}	27.41^{**}	0.92^{ns}
Without	202.04a	543.51a	107.89^{a}	116.54a	64.92a	98.39a	4.52a	4.28a	24.91b	23.24a
With	212.60a	551.56a	109.69^{a}	116.17a	65.73a	98.87a	4.59a	4.49a	28.59a	23.86a
Calcium sources Ca (‘F’ value)	4.71^{*}	1.84^{ns}	4.76^{*}	2.98^{ns}	4.96^{**}	1.86^{ns}	0.99^{ns}	0.47^{ns}	3.27^{*}	2.9^{ns}
Control	219.25a	532.77a	110.55a	116.55a	66.04a	97.49a	4.53a	4.30a	24.91b	21.94a
CaCl2	190.53b	543.03a	105.53b	112.87a	63.21b	99.81a	4.63a	4.31a	27.02ab	23.76a
Ca-OA	204.52ab	524.25a	108.18ab	115.94a	65.86a	96.95a	4.39a	4.44a	27.26ab	24.17a
Ca-AA	215.00a	590.09a	110.60a	120.06a	66.17a	100.25a	4.68a	4.49a	27.83a	24.31a
WD x Ca	2.24^{ns}	0.64^{ns}	2.74^{ns}	3.19^{*}	1.64^{ns}	0.24^{ns}	0.37^{ns}	1.79^{ns}	0.84^{ns}	0.05^{ns}
CV (%)	8.04	11.18	2.96	4.15	2.74	3.46	7.81	8.78	7.44	7.7

FV – Source of variation; CV – Coefficient of variation; CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids; *, **, ns – significant at 5%, 1% and not significant, respectively by the F test. Means with equal lowercase letters do not differ from each other by the F test ($p \leq 0.05$).

The mass of 'Ataulfo' fruits was not affected by the imposition of water restriction before harvest, but calcium sources had a significant effect, with inferiority recorded for fruits produced in plants fertilized with CaCl2, while the other sources did not differ from each other, including the control treatment. The similarity of the control to other calcium sources is justified by the lower fruit yield of this treatment (Table 6) since the source-to-sink ratio, specifically for mangoes, plays a crucial role in fruit size (Boudon et al., 2020). Plants fertilized with Ca-AA provided fruits with mass within the export requirements (215 g), i.e., fruits between 170 g and 230 g, specifically for the 'Ataulfo' cv.

In 'Kent' mangoes, the fruit mass was not affected by any treatments, with an overall average fruit mass of 547.52 g. Higher fruit mass values were obtained by Silva et al. (2009) in a study cataloging quality components of various mangoes at the harvest point, with the 'Kent' mango averaging 704.4 g, serving as a reference value. Comparable results for 'Kent' mangoes were found by Lobo et al. (2019), with a fruit mass of 543 g.

The fruit length of 'Ataulfo' was not affected by water restriction before harvest; however, calcium sources had a significant effect, with inferiority recorded for plants fertilized with CaCl2, and the other sources did not differ from each other, including the control. In 'Kent' mangoes, there was an interaction between water restriction and calcium sources for fruit length (Figure 9), with higher values with the application of Ca-AA, recording 120.06 mm.

From the information presented in Figure 9, plants that where not submitted to water deficit before harvest, no statistical difference between calcium sources for fruit length was recorded. However, under water suspension before harvest, 'Kent' mango fruits fertilized with calcium sources complexed with organic acids and amino acids, respectively, exhibit greater length, with advantages of 9.13% and 12.09%, for instance, compared to plants fertilized with calcium chloride.

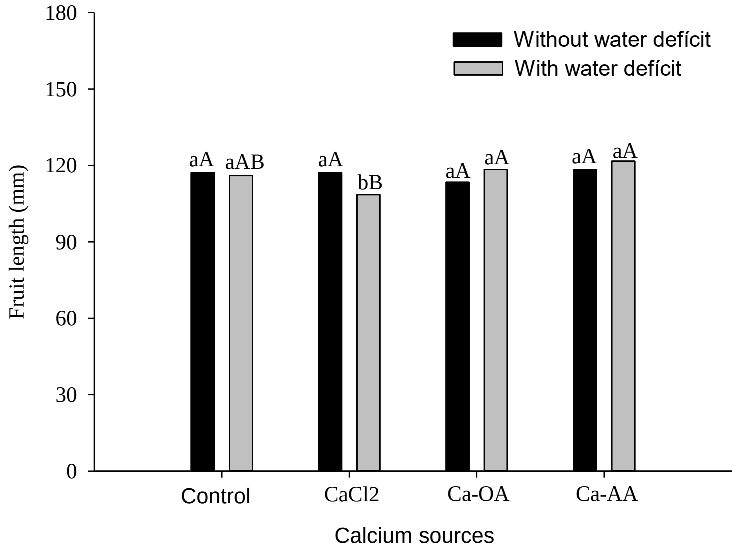

Figure 9. Fruit length of 'Kent' mango fruits as a function of water deficit before fruit harvest and calcium sources. Bars with lowercase letters do not differ within each calcium source for water deficit by the Tukey test at a 5% probability. Bars with uppercase letters do not differ within each water deficit for calcium sources by the Tukey test at a 5% probability. CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids.

The application of water restriction did not have a significant effect on fruit length for treatments without calcium, calcium complexed with organic acids, and calcium complexed with amino acids. However, in CaCl2 application, water suspension reduced fruit length by 12.09%. Working with the same calcium source, Chitarra and Chitarra (2000) observed a reduction in the quality of 'Tommy Atkins' mango fruits treated with calcium chloride during storage for 35 days. Silva and Menezes (2001) reported that treatment with CaCl2 in pre-harvest of 'Tommy Atkins' mango did not prove to be efficient for calcium absorption by the fruit.

For fruit width in 'Ataulfo,' values ranged from 63.21 mm to 66.27 mm, and in 'Kent,' values ranged from 97.49 mm to 100.26 mm, with the highest values for treatments without calcium and with Ca-AA, respectively, showing no significant variation between them (Table 7). Superior results for fruit width (110.34 mm) were reported by Lobo et al. (2019) using a biostimulant containing soluble nutrients in 'Kent' mangoes.

Fruit mass, length, and width were higher in treatments without calcium and in calcium sources complexed with organic acids and amino acids, which did not differ significantly between them, and the lowest values for these variables were found in fruits from plants that received CaCl2. Although there was no statistical difference, numerically, the fruits of 'Kent' mangoes under water deficit before harvest and with the application of calcium complexed with amino acids showed the highest values for physical characteristics (Table 7).

For fruit firmness in 'Ataulfo,' there was no isolated effect and no response to treatment application, with an average value of 4.55 N and higher numerical value in fruits from plants with water restriction before harvest (4.59 N) and calcium complexed with amino acids (4.68 N). No difference was observed between treatments in 'Kent' for fruit firmness, with an average value of 4.38 N and higher numerical values in fruits from plants with water restriction before harvest (4.49 N) and those fertilized with calcium complexed with amino acids (4.49 N). Firmness is considered one of the important attributes in fruit quality (Jeronimo et al., 2007), important for longer shelf life, as reducing fruit firmness will decrease the time the fruit can withstand until deterioration (Table 7).

The fruits from the control treatment (without calcium) exhibited statistically similar averages to the Ca-AA supplementation strategy for not all variables for both cultivars. In fact, nitrogen and potassium nutrition for the entire area may have influenced the control treatment along with Ca-AA in some physical variables, as the presence of nitrogen directly influences vegetative growth, as well as cell division and expansion (Taiz et al., 2017).

Amino acid-based fertilizers directly influence fruit quality and composition due to their connection to primary and secondary metabolism (Taiz et al., 2017), especially when associated with calcium, as it positively influences fruit setting, increasing fruit yield. Marschner (2012) argued that plant growth zones, as well as fruit setting and growth, require higher amounts of Ca.

According to Table 7, the application of water deficit 15 days before harvest increased the dry mass of 'Ataulfo' mango fruits by 14.77% compared to plants without water restriction, and in 'Kent' mangoes, the increase was 2.66%. The practice of water restriction before mango harvest is common among farmers in the Vale do São Francisco region (Castro Neto and Reinhart, 2003).

According to Table 7, calcium complexed with amino acids was superior to other calcium sources for increasing the dry mass of fruits in both studied cultivars. Compared to the control treatment (without calcium), Ca-AA showed increases in the dry mass of 'Ataulfo' mango fruits by 9.43%. The use of organic acids and amino acids increases the efficiency of nutrient absorption as nutrient complexing agents can enhance their assimilation and transport inside plants and fruits, resulting in increased fruit yield and fruit quality (Mouco et al., 2009; El-Kosary et al., 2011).

For the pulp dry mass in 'Kent' mangoes, no statistical difference was observed among the evaluated treatments. However, when comparing the treatment without calcium, which obtained the lowest dry mass value (21.94%), and the treatment with the highest dry mass (Ca-AA = 24.31%), this is due to the presence of compounds in the fruit due to the presence of calcium. Indeed, Anderson et al. (2017) concluded that water denial for periods as short as 2 weeks before harvest resulted in increased fruit dry mass (17.6 cf. 16.5% in control). It is important to infer that dry mass consists of starch, sugars, organic acids, minerals, pectins, and other compounds (Nassur, 2013).

Among the important aspects in mango value differentiation, the most relevant points are the higher soluble solids content and dry mass, which consequently are sold at higher values (Câmara, 2017). Considering that a variation in dry mass accumulation from 18% to 29% in mangoes is appropriate at the ripening stage for harvest (National Mango Board, 2011), the values obtained in this experiment are in line with the required standards. This value is more expressive since 'Ataulfo' mango fruits show a strong correlation between dry mass and soluble solids at the full ripening stage (Nassur, 2013).

Fruit growth is linked to early development, and especially in this phase, considerable amounts of Ca2+ are required (Montanaro et al., 2012). Sources of this nutrient complexed with easily mobile substances can accelerate absorption and transport to the fruit, contributing to increased size. This statement is confirmed by Conn et al. (2011), who describe that the availability of Ca2+ within the apoplast has a direct impact on cell wall strength and expansion, reflecting on fruit size.

The water suspension × calcium sources interaction influenced ($p \leq 0.05$) soluble solids and the SS/TA ratio in 'Ataulfo' mango fruits (Table 8). Titratable acidity and vitamin C content did not respond to treatments and showed average values of 0.58% and 7.63 g 100 mL^{-1}.

For the chemical attributes, the water suspension × calcium sources interaction significantly influenced ($p \leq 0.05$) soluble solids and the SS/TA ratio in 'Ataulfo' mango fruits, and titratable acidity and the SS/TA ratio in 'Kent' mango fruits (Table 8). In 'Ataulfo' mangoes, titratable acidity and vitamin C content did not respond to treatments and presented average values of 0.58% and 7.63 mg/100 g of pulp, respectively. Meanwhile, water deficit before harvest in 'Kent' mangoes affected the soluble solids and the SS/TA ratio, with increases of 6.64% and 19.83%, respectively. Water deficit before harvest can influence the increase in soluble solids content, as it reduces the water content in the fruit, increasing the concentration of dry mass, which is specially composed by soluble sugars (Spreer et al., 2007).

Table 8. Summary of analysis of variance for physical-chemical analyses for titratable acidity (TA), soluble solids (SS), SS/TA ratio, and vitamin C (Vit, C) in fruits of 'Ataulfo' and 'Kent' mangoes as a function of water deficit before fruit harvest and fertigation with calcium sources.

FV	AT (%)		SS (%)		Ratio SS/AT		Vit. C (mg/100 g pulp)	
	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent	Ataulfo	Kent
Water deficit WD (‘F’ value)	0.03^{ns}	4.73^{*}	347.34^{**}	8.83^{**}	9.99^{*}	17.26^{**}	0.03^{ns}	14.06^{**}
Without	0.57a	0.72a	17.31b	15.66b	33.76b	22.51b	7.66a	4.79b
With	0.58a	0.64b	20.80a	16.70a	41.50a	28.32a	7.60a	5.74a
Calcium sources Ca (‘F’ value)	0.08^{ns}	3.64^{*}	37.31^{**}	3.89^{*}	0.39^{ns}	5.88^{**}	1.01^{ns}	1.71^{ns}
Control	0.59a	0.76a	17.53c	15.46b	36.10a	21.67b	7.66a	4.66a
CaCl2	0.59a	0.67b	18.84b	16.05ab	37.11a	25.27a	7.84a	5.34a
Ca-OA	0.56a	0.68b	19.82a	16.51ab	39.75a	25.34a	7.82a	5.62a
Ca-AA	0.57a	0.62b	20.04a	16.70a	37.56a	29.24a	7.20a	5.43a
WD x Ca	2.36^{ns}	4.83^{*}	33.34^{**}	2.38^{ns}	3.53^{*}	5.33^{**}	0.06^{ns}	0.68^{ns}
CV (%)	24.48	12.74	2.78	6.26	18.41	14.76	10.96	14.63

FV – Source of variation; CV – Coefficient of variation; CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids; *, **, ns – significant at 5%, 1% and not significant, respectively by the F test. Means with equal lowercase letters do not differ from each other by the F test ($p \leq 0.05$).

As observed in Figure 10A, the soluble solids in the pulp of 'Ataulfo' mango, except in the calcium-free soil, were higher when subjected to pre-harvest water deficit. This water suppression led to increases of 15.29%, 26.20%, and 26.54%, respectively, in treatments with potassium chloride, calcium complexed in organic acids, and calcium complexed in amino acids. Thus, the application of complexed calcium and water deficit promotes greater increases in soluble solids in 'Ataulfo' mango.

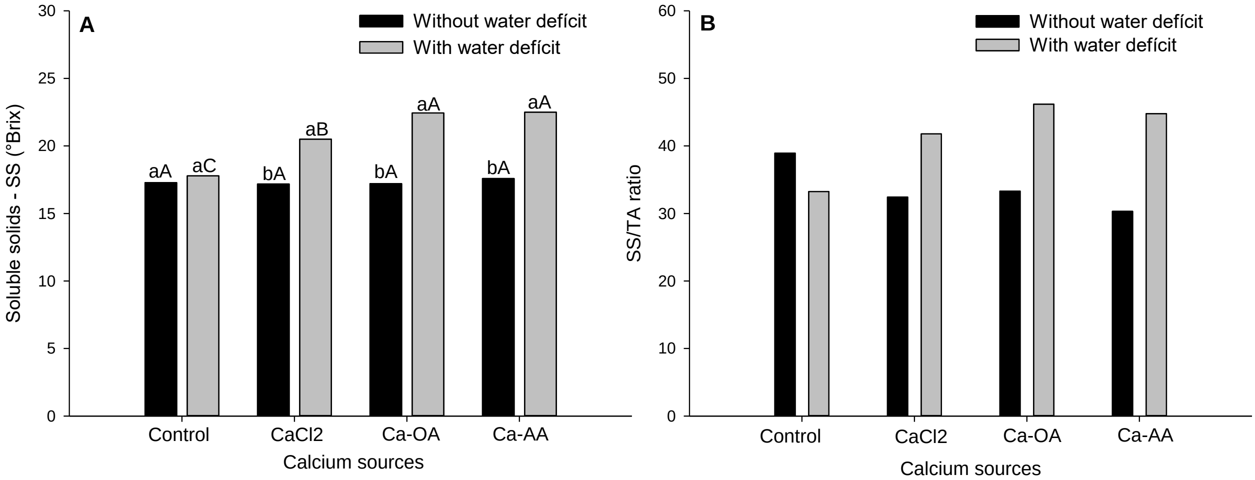

Figure 10. Soluble solids - SS (A) and SS/TA ratio (B) of 'Ataulfo' mangoes as a function of water deficit before fruit harvest and calcium sources. Bars with lowercase letters are not significantly different from each other for water deficit within each calcium source by Tukey's test at 5% probability. Bars with uppercase letters are not significantly different from each other for calcium sources within each water deficit by Tukey's test at 5% probability. CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids.

Compatible results for soluble solids in ‘Haden’ mango were quoted by Reis et al. (2013) and Wei et al. (2017), who also reported higher soluble solids in mangoes with reduced irrigation during the cycle. Studies confirm that reduced water availability contributes to an increase in the concentration of soluble sugars in fruits (Simões et al., 2021). In this study, higher results for soluble solids were reported when compared to the results of Lobo et al. (2019), in 'Kent' mango, obtaining 16.4 ºBrix, while this study obtained 22.50 ºBrix.

Only in the complexed calcium sources, the pre-harvest water deficit promoted higher values of the SS/TA ratio in 'Ataulfo' mango fruits, with an increase of 38.62% and 47.67%, respectively, for Ca-OA and Ca-AA compared to plants without water deficit (Figure 10B). Close results were found by Tenreiro et al. (2023), who found higher SS/TA values in Tommy Atkins mangoes when applying calcium complexed in organic acids and water-soluble calcium + L-α-amino acids via foliar. The increase in soluble solids (Figure 10A) and the reduction in titratable acidity, consequently, the increase in the SS/TA ratio, are associated with the breakdown of complex carbohydrates (cellulose, pectins, and hemicellulose) into monosaccharides such as glucose and fructose (Tharanathan et al., 2006), favoring sweeter fruits. This ratio has a significant representation of the isolated measurement of sugars or acidity, indicating a balance between components, especially the taste of the fruits (Chitarra and Chitarra, 2005).

Among the tested calcium sources, Ca-AA promoted the highest levels of soluble solids in 'Kent' mango fruits, followed by Ca-OA and CaCl2 (Table 8). According to Teixeira (2017), the application of amino acids in mango trees during the productive phase benefits the photosynthetic rate and increases plant tolerance to biotic and abiotic factors, acting as an anti-stress component. For comparative effects, Ca-AA promoted increases of 8% compared to fruits from non-calcium fertilized plants.

The values obtained in this research are within the range considered adequate and reported by Dick et al. (2009) (14.2 to 20 °Brix) for 'Kent' mango fruits. Carneiro et al. (2018) obtained values of 13.6 °Brix in harvested fruits of cv. Tommy Atkins.

According to Table 8, the vitamin C content was higher in treatments with irrigation deficit (5.74 mg/100 g of pulp) compared to those without irrigation deficit (4.79 mg/100 g of pulp), increased nearly 20%. According to Helyes et al. (2012), the dilution of vitamin C decreases based on the reduction of water levels, and based on this, the accumulation of assimilates promoted better quality parameters. Lower vitamin C values were found by Oliveira et al. (2011) when analyzing 'Tommy Atkins' mango, obtaining 1.75 mg/100 g of pulp, while compatible results were quoted by Carneiro et al. (2018). The vitamin C content is one of the main nutritional indicators, and fruits with higher levels of this component are desirable since part of it is lost during post-harvest transport, storage, and processing (Chitarra and Chitarra, 2005).

'Kent' mango fruits with higher titratable acidity were those from plants that were not fertilized with calcium and subjected to pre-harvest water suspension (0.82%) and with the application of Ca-OA without water deficit (0.76%), as seen in Figure 11A. Higher values were recorded by Lobo et al. (2019) in 'Kent' mango fruits under the application of a biostimulant, obtaining 0.98 g of citric acid/100 g of pulp, presenting more acidic fruits.

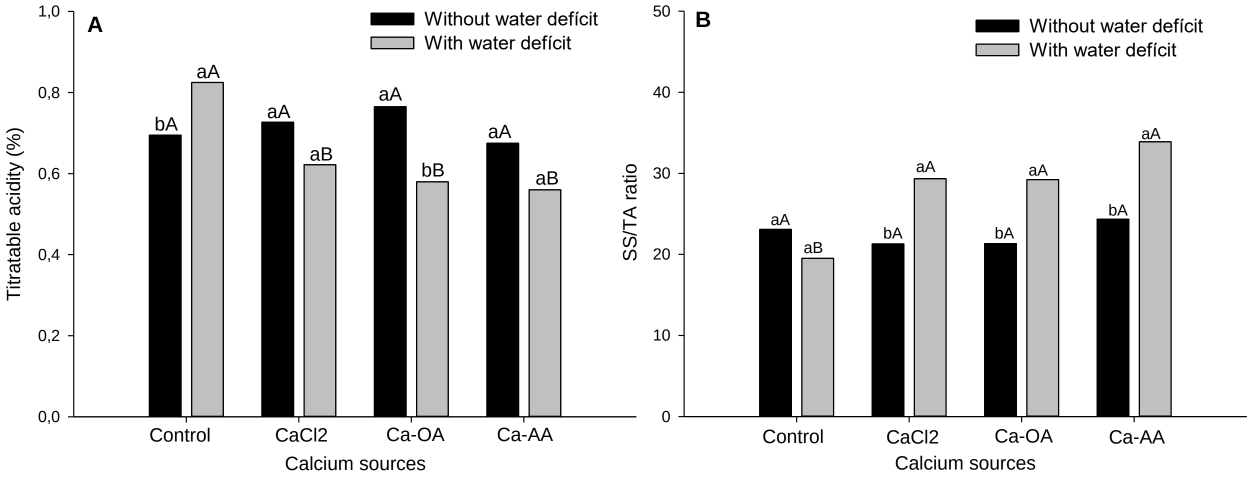

Figure 11. Titratable acidity values - TA (A) and SS/TA ratio (B) in 'Kent' mango fruits as a function of water deficit before fruit harvest and calcium sources. Bars with lowercase letters are not significantly different from each other for water deficit within each calcium source by Tukey's test at 5% probability. Bars with uppercase letters are not significantly different from each other for calcium sources within each water deficit by Tukey's test at 5% probability. CaCl2- Calcium chloride; Ca-OA – Calcium complexed with organic acids; Ca-AA – Calcium complexed with amino acids.

Regarding calcium sources within each water deficit situation, there was no difference in the SS/TA ratio of the fruits between Ca sources when there was no pre-harvest water deficit (Figure 11B). While the application of Ca2+, regardless of the source used, promotes a higher SS/TA ratio in 'Kent' mango fruits under water deficit before fruit harvest. In the scientific literature, some authors report that irrigation management impact on the mango cycle positively influences fruit quality (Motilva et al., 2000; Pickering et al., 2002).

According to Figure 11, calcium complexed in organic acids was the source that contributed more directly to the increase in titratable acidity of 'Kent' mango fruits when water deficit was applied (0.76%), being superior by 10.14%, 5.55%, and 13.43%, respectively, to the fruit levels obtained in treatments without calcium, CaCl2, or Ca-AA.

In 'Kent' mango with water deficit before harvest, mango fruits had higher TA in plants that did not receive calcium application (0.82%), with a superiority of 32.25%, 41.37%, and 46.42%, respectively, compared to fruits from plants fertilized with CaCl2, Ca-OA, and Ca-AA. According to Simões et al. (2021), the reduction of irrigation in the 'Kent' mango cycle can increase the titratable acidity of fruits by 1.45%.

Except for treatments without calcium, the application of water deficit promoted increases in the SS/TA ratio of 'Kent' mango fruits, with increases of 50.43% in CaCl2 application, 49.82% with Ca-OA, and 73.80% with Ca-AA (Figure 11B). The association between water deficit and the application of calcium complexed with amino acids promotes higher results in the SS/TA ratio.

In mango, the increase in the fruit SS/TA ratio is associated with the degradation of complex carbohydrates such as cellulose, pectins, and hemicellulose, to monosaccharides such as glucose and fructose (Tharanathan et al., 2006). Siller-Cepeda et al. (2009) found that 'Kent' mango fruits 12 days after harvest had an SS/TA ratio of 23.6. According to Benevides et al. (2008), the SS/TA ratio indicates the degree of balance between the two components (soluble solids and titratable acidity) and is related to taste, being an important parameter for fruit selection.

The highest values of calcium bound to the cell wall in the pulp of 'Ataulfo' mango fruits were in treatments with Ca-AA and Ca-OA, respectively, with and without pre-harvest water deficit (Figure 12A). According to Gao et al. (2021), the formulation containing amino acids can form a stable complex with calcium and thus increase its availability, facilitating calcium absorption by plant tissues. In addition, the calcium concentration in the fruit affects the cell wall and, consequently, promotes longer shelf life (Yamamoto et al., 2011).

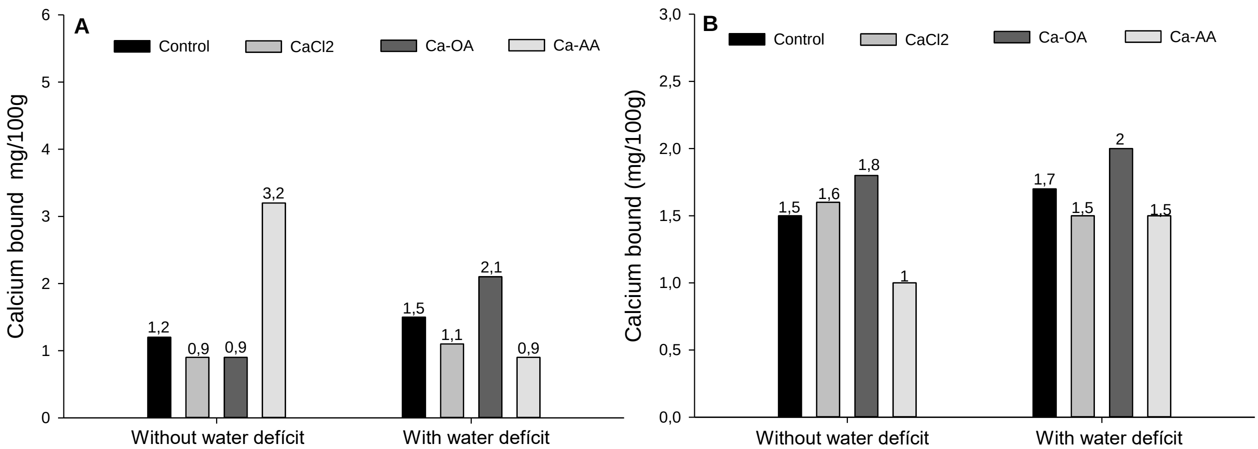

Figure 12. Calcium bound to the cell wall in the pulp of 'Ataulfo' (A) and 'Kent' (B) mango fruits as a function of water deficit before fruit harvest and calcium sources. Ca-OA – Calcium complexed to organic acids; Ca-AA – Calcium complexed to amino acids; WH – Water deficit.

As shown in Figure 12B, calcium complexed in organic acids promoted the highest levels of bound calcium to the cell wall in 'Kent' mango fruits, regardless of pre-harvest water deficit application. Furthermore, it is noteworthy that with this calcium source and the application of pre-harvest water deficit, it was the treatment with the highest bound Ca value (2.0 mg/100 g of pulp), being superior, for example, by 33.3% to the fruits of plants that did not receive calcium and water deficit.

The application of calcium complexed in organic acids increased the presence of bound Ca in 'Kent' mango fruits, in both irrigation management, resulting in fruit with a longer shelf life and fewer anomalies. El-Kosary et al. (2011) emphasize that the application of nutrient complexes with organic substances not only increases pulp yield but also reduces malformation and internal collapse of 'Keitt' mango fruits. In mango trees, Rezende et al. (2022) highlight that nutritional imbalance influences the association of Ca with the pectin of the fruit cell wall. Especially the relationship between B and Ca nutrients, as B maximizes and assists the transport of Ca absorption into the plant, as well as acting in the balance between Ca and K (Muengkaew, 2017).

Low calcium values in fruits can be caused not only by low absorption but also by competition between plant and fruit growth points for available calcium. Calcium strengthens cell walls, making them less susceptible to anomalies, such as jelly seed. According to Kumar et al. (2014), mango fruit has a pectin value of approximately 18% in the skin, and a high content ensures good post-harvest resistance, as Ca is one of the main components of the cell wall (Freitas et al., 2016). Calcium plays a crucial role in plants, especially because about 60% of cellular Ca is present in the cell wall (Tobias et al., 1992).

Studies report that softening in the pulp may be the result of cellular modifications in different plant species, emphasizing that each one needs to be studied separately since observations made with a particular species cannot be extended to other species (Goulão and Oliveira, 2008). Excessive softening of fruits is the main factor responsible for shelf-life limitations, transportability, and storage, due to the increased occurrence of physical damage during handling and greater susceptibility to pests and diseases. Many consumers are increasingly using fruit firmness as a guide to ensure that fruits delivered to customers have the necessary texture characteristics throughout the year (Johnston et al., 2002). For this reason, the importance of higher calcium in the fruit, increasing firmness and consequently shelf life (Soares, 2020).

Despite the importance of determining bound Ca to the cell wall, there is still no literature range for sufficiency or considered desired values, especially considering the potential effects on fruit quality and its post-harvest viability.

4. Main results and recommendations

The results generated from the project's implementation indicate that mango varieties respond differently to calcium sources applied through fertigation, as well as to the suspension of water supply before harvest. The use of chelated calcium sources (with organic acids or amino acids) in combination with water deficit 15 days before fruit harvest increases the fruit yield and post-harvest quality of 'Ataulfo' and 'Kent' mango varieties. Water restriction before harvest, along with the application of chelated calcium in amino acids, has a positive impact on the physical attributes of 'Ataulfo' mangoes, especially in increasing the dry mass of the fruits, but does not affect 'Kent' mangoes. The application of chelated calcium in amino acids increases the Ca content bound to the cell wall in the pulp of 'Ataulfo' mangoes, while chelated calcium in organic acids, associated with water suspension before harvest, elevates the bound Ca content in 'Kent' mangoes. However, the application of chelated calcium in amino acids produces higher quality fruits suitable for export in both varieties.

Recommendations: For the 'Ataulfo' cultivar, it is recommended water deficit before fruit harvest, and during the production cycle, use a source of chelated calcium with amino acids. For the 'Kent' variety, it is not recommended to suspend irrigation before harvest, and the recommended calcium source is also the one chelated with amino acids.

5. Acknowledgements

The author recognizes the action of the National Mango Board on supporting the generation of scientific information for the mango industry, and thank both farms Casa Nova and Nogueira for the partnership to develop the field researches of the project.

6. References

Aghdam, M.S., Hassanpouraghdam, M.B., Paliyath, G., Farmani, B. The language of calcium in postharvest life of fruits, vegetables and flowers. Scientia Horticulturae, 144: 102-115, 2012. https://doi.org/10.1016/j.scienta.2012.07.007

Albrecht, W.A. The Albrecht Papers. Volume II – Soil Fertility and Animal Health, Edited by charles Walters, Acres USA, 192 p., 1975.

Albuquerque, T.C.S. Efeitos da Aplicação foliar de aminoácidos na qualidade de uvas Benitaka. Reunião Brasileira de Fertilidade do Solo, Rio de Janeiro. Abstracts... Rio de Janeiro SBCS p. 549-554, 2008.

Almeida, E.V. Mango tree response to lime applied during the production phase. Open Journal of Soil Science, 2(2): 155-161, 2012. http://dx.doi.org/10.4236/ojss.2012.22021

Anderson, N.T., Subedi, P.P., Walsh, K.B. Manipulation of mango fruit dry matter content to improve eating quality. Scientia Horticulturae, 226: 316-321, 2017. https://doi.org/10.1016/j.scienta.2017.09.001

Assis, J.S., Silva, D.J., Moraes, P.L.D. Equilíbrio nutricional e distúrbios fisiológicos em manga 'Tommy Atkins'. Revista Brasileira de Fruticultura, 26: 326- 329, 2004. https://doi.org/10.1590/S0100-29452004000200034

Bally, I.S.E., Harris, M., Whiley, A.W. Effect of water stress on flowering and yield of 'Kensington Pride'mango. Acta Horticulturae, 509: 277-281, 2000.

Barber, S.A., Humbert, R.P. Advances in knowledge of potassium relationship in the soil and plant. Fertilizer Technology and Uses. Madison: SSSA, p.231-268, 1963.

Basile, B., Brown, N., Valdes, J.M., Cardarelli, M., Scognamiglio, P., Mataffo, A., Rouphael, Y., Bonini, P., Colla, G. Plant-Based biostimulant as sustainable alternative to synthetic growth regulators in two sweet cherry cultivars. Plants, 10: 619, 2021. https://doi.org/10.3390/plants10040619

Benevides, S. D., Ramos, A. M., Stringheta, P. C., Castro, V. C. Qualidade da manga e polpa da manga Ubá. Food Science and Technology, 28: 571-578, 2008. https://doi.org/10.1590/S0101-20612008000300011

Bitange, N. M., Chemining'wa, G.N., Ambuko, J., Owino, W. O. Yield and tissue calcium concentration of mango (*Mangifera indica* L.) fruit as influenced by calcium source and time of application. International Journal of Plant & Soil Science, 28(4): p 1-12, 2019. 10.9734/ijpss/2019/v28i430112

Bonomelli, C., Arias, M.I., Villalobos, L. Adaptation and validation of a methodology for the measurement of calcium fractions in fruits. Communications in Soil Science and Plant Analysis, 49:6, 735-744, 2018. DOI: 10.1080/00103624.2018.1435681

Boudon, F., Persello, S., Jestin, A., Briand, A-S., Grechi, I., Fernique, P., Guédon, Y., Léchaudel, M., Lauri, P-É., Normand, F. V-Mango: a functional–structural model of mango tree growth, development and fruit production. Annals of Botany, 126(4): 745–763, 2020. https://doi.org/10.1093/aob/mcaa089

Brandão, R.P. Importância dos aminoácidos na agricultura sustentável. Informativo Bio Soja, 5: 6-8, 2007.

Canellas, L.P., Olivares, F.L., Aguiar, N.O., Jones, D.L., Nebbioso, A., Mazzei, P., Piccolo, A. Humic and fulvic acids as biostimulants in horticulture. Scientia Horticulturae, 196: 15-27, 2015. https://doi.org/10.1016/j.scienta.2015.09.013.

Carneiro, M.A., Lima, A.M.N., Cavalcante, Í.H.L., Sousa, K. dos S.M. de, Oldoni. F.C.A., Barbosa K. da S. Production and quality of mango fruits cv. Tommy atkins fertigated with potassium in semi-arid region. Revista Brasileira de Fruticultura, 40(5): e–034, 2018. https://doi.org/10.1590/0100-29452018034

Castro Neto, M.T., Reinhardt, D.H. Relações entre parâmetros de crescimento do fruto da manga cv. Haden. Revista Brasileira de Fruticultura, 25: 35-37, 2003.

Cavalcante, Í.H.L., Santos, G.N.F., Silva, M.A., Martins, R.S., Lima, A.M.N., Modesto, P.I.R., Alcobia, A. M., Silva, T.R.S., Amariz, R.A.E., Beckmann-Cavalcante, M.Z. A New Approach to induce mango shoot maturation in Brazilian semi-arid environment. Journal of Applied Botany and Food Quality, 91: 281-286, 2018. https://doi.org/10.5073/JABFQ.2018.091.036

Chitarra, M. I. F., Chitarra, A. B. Pós-colheita de frutos e hortaliças: fisiologia e manuseio, 2nd ed., Lavras: UFLA, Brasil, 2005.

Colla, G., Youssef, R. Canaguier, R., Svecova, E., Cardarelli, M.T. Biostimulant action of a plant-derived protein hydrolysate produced through enzymatic hydrolysis. Frontiers in Plant Science, 5: 1-6, 2014. https://doi.org/10.3389/fpls.2014.00448

Conn, S.J., Gilliham, M., Athman, A., Schreiber, A.W., Baumann, U., Moller, I., Cheng, N., Stancombe, M.A., Hirschi, K.D., Webb, A.A.R., Burton, R., Kaiser, B.N., Tyerman, S.D, Leigh, R.A. Cell-specific vacuolar calcium storage mediated by CAX1 regulates apoplastic calcium concentration, gas exchange, and plant productivity in Arabidopsis. Plant Cell, 23: 240–257, 2011. https://doi.org/10.1105/tpc.109.072769

Costa, A.R. Fertilizantes minerais e aminoácidos aplicados via foliar na produtividade, desenvolvimento vegetativo e nutrição do cafeeiro. M.Sc. Thesis, Federal University of Uberlândia, 2009.

Cremonesi, M.V., Ramalho, B., Golfetto, P., Krepki, L.S., Pauletti, V. Marcha de absorção, taxa de acúmulo e exportação de micronutrientes e alumínio pelo tabaco (*Nicotiana tabacum* L.). Revista de Ciências Agroveterinárias, 18(1): 13-23, 2019. https://doi.org/10.5965/223811711812019013

Dick, E., Adopo, A.N., Camara, B., Moudioh, E. Influence of maturity stage of mango at harvest on its ripening quality. Fruits, 64: 13-18, 2009. ttps://doi.org/10.1051/fruits/2008045

Drazeta, L., Lang, A., Hall, A.J., Volz, R.K., Jameson, P.E. Causes and effects of changes in xylem functionality in apple fruit. Annals of Botany, 93: 275–28, 2004. https://doi.org/10.1093/aob/mch040

Du Jardin, P. 2015. Plant biostimulants: definition, concept, main categories and regulation. Scientiae Horticulturae, 196: 3-14. https://doi.org/10.1016/j.scienta.2015.09.021

El-Kosary, S., El-Shenawy, I.E., Radwan, S.I. Effect of microelements, amino and humic acids on growth, flowering and fruiting of some mango cultivars. Journal of Horticultural Science & Ornamental Plants, 3(2): 152-161, 2011.

Faria, L.N. Manejo da irrigação na indução floral e na fase produtiva da mangueira Tommy Atkins em condições semiáridas. PhD thesis, Federal University of Viçosa, Brazil.

Faria, L.N., Soares, A.A., Donato, S.L.R., Santos, M.R., Castro, L.G. The effects of irrigation management on floral induction of 'Tommy Atkins' mango in Bahia semiarid. Revista Engenharia Agrícola, 36(3): 387-398, 2016. https://doi.org/10.1590/1809-4430-Eng.Agric.v36n3p387-398/2016

Faria, L.N., Soares, A.A., Donato, S.L.R., Santos, M.R., Castro, L.G. The effects of irrigation management on floral induction of 'Tommy Atkins' mango in Bahia Semiarid. Engenharia Agrícola, 36(3): 387-398, 2016. https://doi.org/10.1590/1809-4430-Eng.Agric.v36n3p387-398/2016

Filgueiras, H. A. C. Colheita e manuseio pós-colheita. Frutas do Brasil: Manga Pós-colheita. Fortaleza: Embrapa Agroindústria Tropical, p. 22-25, 2000.

Fonseca, N., Coelho, E.F., Vieira, R.S. Déficit hídrico na indução do florescimento e do aumento da produtividade da mangueira ‘Uba’ em cultivo orgânico na região da Chapada Diamantina, Bahia. Cruz das Almas: Embrapa Mandioca e Fruticultura, 2018.

Freitas, S.T., Amarante, C.V.T., Mitcham, E.J. Calcium deficiency disorders in plants. In: Sunil Pareek. (Org.). Postharvest ripening physiology of crops. 2ed. Boca Raton: CRC Press, 2016, p. 478-512.

Freitas, S.T., Guimarães, Í.T., Vilvert, J.C., Do Amaral, M.H.P., Brecht, J.K., Marques, A.T.B. Mango dry matter content at harvest to achieve high consumer quality of different cultivars in different growing seasons. Postharvest Biology and Technology, 189: 111917-8, 2022. https://doi.org/10.1016/j.postharvbio.2022.111917

Gao, X., Song, X., Liu, K., Li, T., Zheng, W., Wang, Y., Liu, Z., Zhang, M., Chen, Q., Li, Z., Li, R., Zheng, L., Liu, W., Miao, T. Mixture of controlled-release and conventional urea fertilizer application changed soil aggregate stability, humic acid molecular composition, and maize nitrogen uptake. Science of the Total Environment, 789: 147778, 2021. https://doi.org/10.1016/j.scitotenv.2021.147778.

Genú, P.J. de C., Pinto, A.C de A. A Cultura da Mangueira. 1.ed. Brasília: Embrapa Informação Tecnológica, 2002. 452 p.

Gomes, F.T. Manejo do déficit hídrico para indução floral da mangueira ‘Kent’ no Vale do submédio São Francisco. M.Sc Thesis, Federal University of São Francisco Valley, Brazil. 2019.

Goulão, L.F., Oliveira, C.M. Cell wall modifications during fruit ripening: when a fruit is not the fruit. Trends in Food Science & Technology, 19: 4-25, 2008. https://doi.org/10.1016/j.tifs.2007.07.002

Helyes, L., Lugasi, A., Pék, Z. Effect of irrigation on processing tomato yield and antioxidant components. Turkish Journal of Agriculture and Forestry, 36: 702–709, 2012. https://doi.org/10.3906/tar-1107-9

Hidayatullah, A.K., Mouladad, M., Nisar, A., Syed, A. S. Effect of humic acid on fruit yield attributes, yield and leaf nutrient accumulation of apple trees under calcareous soil. Indian Journal of Science and Technology, 11(15): 1-8, 2018. https://dx.doi.org/10.17485/ijst/2018/v11i15/119931

Hocking, B., Tyerman, S. D., Burton, R. A., Gilliham, M. Fruit Calcium: Transport and Physiology. Frontiers in Plant Science, 7: 569, 2016. https://doi.org/10.3389/fpls.2016.00569

Hu, W., Lu, Z., Meng, F., Li, X., Cong, R., Ren, T., Sharkey, T.D., Lu, J. The reduction in leaf area precedes that in photosynthesis under potassium deficiency: the importance of leaf anatomy. New Phytologist, 227: 1749-1763, 2020. https://doi.org/10.1111/nph.16644

Jeronimo, E.M., Brunini, M.A., Arruda, M.C., Cruz, J.C.S., Gava, G.J.C., Silva, M.A. Qualidade de mangas' Tommy Atkins' armazenadas sob atmosfera modificada. Ciência e Agrotecnologia, 31: 1122-1130, 2007. https://doi.org/10.1590/S1413-70542007000400027

Johnston, J.W., Hewett, E.W., Hertog, M.L. Post-harvest softening of apple (*Malus domestica*) fruit: a review. New Zealand Journal of Crop and Horticultural Science, 30: 145-160, 2002.

Krishna, K.R., Sharma, R.R., Srivastav, M. Physiological and biochemical attributes associated with jelly-seed disorder in mango (*Mangifera indica* L.). Acta Physiologiae Plantarum 42, 90 (2020). https://doi.org/10.1007/s11738-020-03079-z

Kumar, M., Ponnuswami, V., Jeya Kumar, P., Saraswathy, S. Influence of season affecting flowering and physiological parameters in mango. Scientific Research and Essays, 9(1): 1-6, 2014. 10.5897/SRE2013.5775

Lambais, G.R. Aminoácidos coadjuvantes da adubação foliar e do uso do glifosato na cultura da soja. M.Sc. Thesis. University of São Paulo, Brazil, 2011.

Lange, A., Cavalli, E., Pereira, C.S., Chapla, V.M., Freddi, O. da Silva. Relações cálcio:magnésio e características químicas do solo sob cultivo de soja e milho. Nativa, 3: 294-301, 2021. https://doi.org/10.31413/nativa.v9i3.11526

Lieten, P. Effect of K:Ca:Mg ratio on performance of 'Elsanta' strawberries grown on peat. Acta Horticulturae, 708: 397-400, 2006.

Lima, L.R., Arévalo-Hernández, O., Paiva, A.Q., Júnior, S.O., Gross, E. Nutrição de helicônia em função de doses de resíduos agroindustriais no solo. Agrotrópica, 1: 61 – 68, 2019. http://dx.doi.org/10.21757/0103-3816.2019v31n1p61-68

Liu, X. Q., Kim, K.S. Effect of amino acid fertilization on nitrate assimilation of leafy radish and soil chemical properties in high nitrate soil. Communications in Soil Science and Plant Analysis, 39: 269–281, 2008. https://doi.org/10.1080/00103620701759301

Lobo, J.T., de Sousa, K.d.S.M., de Paiva Neto, V.B., Pereira, R.N., dos Santos Silva, L., Cavalcante, Í.H.L. Biostimulants on fruit yield and quality of mango cv. Kent grown in semiarid. Journal of the American Pomological Society, 73: 152–160, 2019.

Ma, X., Wang, J., Su, M., Liu, B., Du, B., Zhang, Y., He, L., Wang, S., Wu, H. The link between mineral elements variation and internal flesh breakdown of 'Keitt' mango in a steep slope mountain area, Southwest China. Horticulturae, 8: 533, 2022. https://doi.org/10.3390/horticulturae8060533

Mahajan, P., Dhoke, S.K., Khanna, A.S. Effect of nano-ZnO particle suspension on growth of mung (Vigna radiata) and gram (*Cicer arietinum*) seedlings using plant agar method. Journal of Nanotechnology, 2: 1–7, 2011. https://doi.org/10.1155/2011/696535

Mahmud, K., Makaju, S., Ibrahim, R., Missaoui, A. Current progress in nitrogen fixing plants and microbiome research. Plants, 9: 97, 2020. https://doi.org/10.3390/plants9010097

Malavolta, E., Vitti, G.C., Oliveira, S.A. Avaliação do estado nutricional das plantas: princípios e aplicações. 2. ed. Piracicaba: POTAFOS, 319 p. 1997.

Maldonado-Celis, M.E., Yahia, E.M., Bedoya, R., Landázuri, P., Loango, N., Aguillón, J., Restrepo, B., Ospina, J.C.G. Chemical Composition of Mango (*Mangifera indica* L.) fruit: nutritional and phytochemical compounds. Frontiers in Plant Science, 10: 1073, 2019. https://doi.org/10.3389/fpls.2019.01073

Marschner, P. Mineral nutrition of higher plants. Elsevier Ltd. 3 ed. 651 p. 2012.

Mógor, A.F. Fertilizantes foliares complexados com aminoácidos ajudam a corrigir carências nutricionais em plantas. Agrolink, 2015.

Montanaro, G., Dichio, B., Xiloyannis, C. Fruit transpiration: mechanisms and significance for fruit nutrition and growth. In: Advances in selected plant physiology aspects. Montanaro, G., Dichio, B., Eds. Intechopen: London, United Kingdom, 2012, p. 233-250.

Motilva, M.J., Tovar, M.J., Romero, M.P., Alegre, S., Girona, J. Influence of regulated deficit irrigation strategies applied to olive trees (Arbequina cultivar) on oil yield and oil composition during the fruit ripening period. Journal of the Science of Food and Agriculture, 80: 2037–2043, 2000. https://doi.org/10.1002/1097-0010(200011)80:14<2037: AID-JSFA733>3.0.CO,2-0

Mouco, M.A.C., Lima, M.A.C., Silva, A.L., Santos, S., Rodrigues, F.M. Amino acids on mango yield and fruit quality at Submédio São Francisco Region, Brazil. Acta Horticulturae, 820: 437-442, 2009. https://doi.org/10.17660/ActaHortic.2009.820.54

Muengkaew, R., Chaiprasart, P., Wongsawad, P. Calcium-boron addition promotes pollen germination and fruit set of mango. International Journal of Fruit Science, 17(2): 147-158, 2017. https://doi.org/10.1080/15538362.2016.1259085

Nassur, R.C.M.R. Indicadores de qualidade em mangas durante o amadurecimento. PhD Thesis. Federal University of Lavras, Brazil. 2013.

National Mango Board. Manual de práticas para o melhor manejo pós-colheita da manga. National Mango Board, 2011.

Njuguna, J., Ambuko, J., Hutchinson, M., Owino, W. Incidence of jelly seed disorder in ‘Tommy Atkins’ and ‘Van Dyke’ mangoes as affected by agro-ecological conditions in Kenya. International Journal of Plant and Soil Science, 11(5): 1-9, 2016. http://dx.doi.org/10.9734/IJPSS/2016/26447

Oldoni, F.C.A., Bernardo, M.P., Oliveira Filho, J.G., Aguiar, A.C., Moreira, F.K.V., Mattoso, L.H.C., Colnago, L.A., Ferreira, M.D. Valorization of mangoes with internal breakdown through the production of edible films by continuous solution casting. LWT. 2021, 145, 111339. https://doi.org/10.1016/j.lwt.2021.111339

Oliveira, D.D.S., Aquino, P.P., Ribeiro, S.M.R., Proença, R.P.D.C., Pinheiro, S. H.M. Vitamina C, carotenoides, fenólicos totais e atividade antioxidante de goiaba, manga e mamão procedentes da Ceasa do Estado de Minas Gerais. Acta Scientiarum - Health Science, 33: 89–98, 2011. https://doi.org/10.4025/actascihealthsci.v33i1.8052

Oliveira, R.L.L., Prado, R.M., Felisberto, G., Checchio, M.V., Gratão, P.L. Silicon mitigates manganese deficiency stress by regulating the physiology and activity of antioxidant enzymes in sorghum plants. Journal of Soil Science and Plant Nutrition, 19: 524-34, 2019. https://doi.org/10.1007/s42729-019-00051-w

Pearson, G.A., Ayers, A.D., Eberhard, D.L. Relative salt tolerance of rice during germination and early seedling development. Soil Science, 102: 151-156, 1966.

Pickering, A.H., Behboudian, M.H., Mills, T.M. Stress physiology of the grapevine: an overview. In: Recent Research Developments in Plant Biology, Pandalai, S.G.,Ed., Research Signpost: Kerala, India, 2002, p. 303–320.

Prado, R.M., Natale, W. Calagem na nutrição de cálcio e no desenvolvimento do sistema radical da goiabeira. Pesquisa Agropecuária Brasileira, 39: 1007-1012, 2004.

Raij, B.V. Fertilidade do solo e manejo de nutrientes. Piracicaba: International Plant Nutrition Institute, p. 420, 2011.

Reis, J.B.R.S., Jesus, A.M., Dias, M.S.C., Castricini, A., Dias, J.R. Efeito de lâminas de irrigação e doses de PBZ na pós-colheita da mangueira cv. Haden no Norte de Minas Gerais. Revista Brasileira de Agricultura Irrigada, 5: 214-224, 2013. https://doi.org/10.7127/RBAI.V5N300059

Rezende, J.S., Freire, F.J., Silva, S.R.V., Musser, R.S., Cavalcante, Í.H.L., Saldanha, E.C.M., Santos, R.L., Cunha, J. C.C. Establishment of specific DRIS standards for mango cultivars Tommy

Atkins, Kent and Keitt compared to generic standards in the Sub-Middle São Francisco Valley. Journal of Plant Nutrition, 45: 2627-2654, 2022. https://doi.org/10.1080/01904167.2022.2064294

Rezende, J.S., Freire, F.J., Silva, S.R.V., Musser, R.S., Cavalcante, Í.H.L., Saldanha, E.C.M., Santos, R.L., Cunha, J.C. Nutritional diagnosis of mango plants post-harvest in anticipation of pre-flowering avoids nutritional stress. Revista Brasileira de Engenharia Agrícola e Ambiental, v. 27, p. 359-366, 2023. https://doi.org/10.1590/1807-1929/agriambi.v27n5p359-366

Rheinheimer, D.S. Resposta de culturas à aplicação de enxofre e a teores de sulfato num solo de textura arenosa sob plantio direto. Ciência Rural, 35(3): 562-569, 2005. https://doi.org/10.1590/S0103-84782005000300011

Santos, A.J.S., Paiva Neto, V.B., Sanches, L.G., Carreiro, D.A., Pereira, M.P.M., Borges, M.C.R. Z., Santos, S.E.R., Cavalcante, Í.H.L. Nitrate reductase activity in the different phenophases of 'palmer' mango cultivated in the semiarid. Journal of Applied Botany and Food Quality, v. 94, p. 192-198, 2021. http://dx.doi.org/10.5073/JABFQ.2021.094.023

Santos, M.R.D., Donato, S.L.R., Coelho, E.F., Cotrim Junior, P.R.F., Castro, I.N.D. Irrigation deficit strategies on physiological and productive parameters of 'Tommy Atkins' mango. Revista Caatinga, 29(1): 173–182, 2016b. https://doi.org/10.1590/1983-21252016v29n120rc

Santos, M.R.D., Donato, S.L.R., Faria, L.N., Coelho, E.F., Cotrim Junior, P.R.F. Irrigation strategies with water deficit in 'Tommy Atkins' mango tree. Engenharia Agrícola, 36(6):1096–109, 2016a. https://doi.org/10.1590/1809-4430-Eng.Agric.v36n6p1096-1109/2016

Sena, J.P., Silva, L.S., Oliveira, F.F., Silva Júnior, G.B., Cavalcante, Í.H.L. Calcium fertilization strategy on physiological characteristics and fruit yield of mango. Pesquisa Agropecuária Tropical, 2023. *In press*

Siller-Cepeda, J., Muy-Rangel, D., Báez-Sañudo, M., Araizalizarde, E., Ireta-Ojeda, A. Calidad poscosecha de cultivares de mango de maduración temprana, intermedia y tardía. Revista Fitotecnia Mexicana 32: 45-52, 2009.

Silva, A.C., Souza, A.P., Leonel, S., Souza, M.E., Ramos, D.P., Tanaka, A. A. Growth and flowering of five mango cultivar under subtropics conditions of Brazil. American Journal of Plant Sciences, 5(3): 393-402, 2014. http://www.scirp.org/journal/PaperInformation.aspx?PaperID=42759

Silva, A.V.C., Menezes, J.B. Caracterização físico-química da manga 'Tommy Atkins' submetida a aplicação de cloreto de cálcio pré-colheita e armazenamento refrigerado. Scientia Agricola, 58: 67-72, 2001. https://doi.org/10.1590/S0103-90162001000100012

Silva, D.F.P., Siqueira, D.L., Pereira, C.S., Salomão, L.C.C., Struiving, T.B. Caracterização de frutos de 15 cultivares de mangueira na Zona da Mata mineira. Revista Ceres, 56: 783-789, 2009.

Silva, D.J., Pereira, J.R., Mouco, M.A.C., Albuquerque, J.A.S. Raij, B.V., Silva, C.A. Nutrição mineral e adubação da mangueira em condições irrigadas. EMPRABA, Circular Técnica, Petrolina, Brazil, 2004.

Silva, D.J., Quaggio, J.A., Pinto, P.A.C., Pinto, A.C.Q., Magalhães, A.F.J. Nutrição e Adubação. In: Genú, P.J.C., Pinto, C.A.Q. (Ed.). A cultura da mangueira. Brasília: Embrapa Informação Tecnológica, 2002. p.191-222.

Silva, L.M.DA., Berti, M.P. da S. Manganês no solo e nas plantas: uma revisão. Scientific Electronic Archives, 15(3): 21-25, 2022. https://doi.org/10.36560/15320221512

Silva, L.S., Sousa, K.A.O., Pereira, E.C.V., Rolim, L.A., Cunha, J.G., Oliveira, M.P., Silva, M.A., Cavalcante, Í.H.L. Advances in mango 'Keitt' production system: PBZ interaction with fulvic acids and free amino acids. Scientia Horticulturae, 277: 109787, 2021. https://doi.org/10.1016/j.scienta.2020.109787

Silva, R.L., Fontes, R.L.F., Neves, J.C.L., Lima, A.M.N., Soares, E.M.B., Carvalho, C.I.F.S., Cavalcante, Í.H.L. Nutrient partition and nutritional efficiency of mango cv. Palmer as a function of plant age in São Francisco Valley, Brazil. Semina: Ciências Agrárias, 43(4): 1671-1694, 2022. https://doi.org/10.5433/1679-0359.2022v43n4p1671

Simmons, S.L., P. Hofman, A. Whiley, S. Hetherington. Effects of preharvest calcium sprays and fertilizers, leaf: fruit ratios, and water stress on mango fruit quality. ACIAR Proc. 81: 19-26, 1998.

Simões, L.W., Andrade, V.P.M., Mouco, M.A.C., Sousa, J.S.C., Lima, J.R.F. Produção e qualidade da mangueira 'Kent' (*Mangifera indica* L.) submetida a diferentes lâminas de irrigação no semiárido nordestino. RAMA, 14: 305-314, 2021. https://doi.org/10.17765/2176-9168.2021v14n2e7832

Soares, N.R. Manutenção da firmeza de frutos intactos e minimamente processados utilizando pectinametilesterase (PME) e cálcio. 34 p. 2020.

Spreer, W., Nagle, M., Neidhart, S., Carle, R., Ongprasert, S., Müller, J. Effect of regulated deficit irrigation and partial rootzone drying on the quality of mango fruits (*Mangifera indica* L., cv. 'Chok Anan'). Agricultural Water Management, 88(1–3): 173–180, 2007 https://doi.org/10.1016/j.agwat.2006.10.012

Taiz, L., Zeiger, E., Moller, I., Murphy, A. Fisiologia e desenvolvimento vegetal. 6. ed. Porto Alegre: Artmed, 2017. 888 p.

Tedesco, M.J., Gianello, C., Bissani, C.A., Bohnen, H., Volkweiss, S.J. Análises de solo, plantas e outros materiais. 2ª ed. Porto Alegre: Universidade Federal do Rio Grande do Sul, p.174, 1995.

Teixeira. N.T. Aminoácidos – A chave-mestra na produção de manga. Revista Campo e Negócios. 2017. Available at <https://revistacampoenegocios.com.br/aminoacidos-a-chave-mestra-na-producao-de-manga/>Access in: 10/09/2023.

Tenreiro, I.G.P. Fontes e formas de aplicação de cálcio na produtividade e qualidade de frutos de mangueira no Vale do Submédio São Francisco. M.Sc. Thesis. Federal University of São Francisco Valley, Brazil. 2020.

Tenreiro, I.G.P., De Castro Sá, M. H., De Souza, I.M., Da Silva, K.A., Cavalcante, Í.H.L., De Freitas, S.T., Lima, A.M.N., Rodrigues, M.S., Dos Santos, K.S.M. Calcium fertilization strategy to improve production and quality of 'Tommy Atkins' mango in semi-arid conditions. Communications in Soil Science and Plant Analysis, 54(22): 1-12, 2023. https://doi.org/10.1080/00103624.2023.2254340

Tharanathan, R.N., Yashoda, H.M., Prabha, T.N. Mango (*Mangifera indica* L.), the king of fruits - An overview. Food Reviews International, 22: 95-123, 2006. ttps://doi.org/10.1080/87559120600574493

Thor, K. Calcium - Nutrient and Messenger. Frontiers in Plant Science, 10: 40, 2019. https://doi.org/10.3389/fpls.2019.00440.

Tobias, R.B., Conway, W.S., Sams, C.E. Cell wall composition of calcium-treated apples inoculated with *Botrytis cinerea*. Phytochemistry, 3235-39, 1992. https://doi.org/10.1016/0031-9422(92)80102-K

Torres, A.P. Efeito dos ácidos fúlvicos e húmicos na nutrição e produtividade de mangueira no Vale do São Francisco. M.Sc. Thesis. Federal University of São Francisco Valley, Brazil. 2019.

Ueda, M., Sasaki, K., Utsunomiya, N., Inaba, K., Shimabayashi, Y. Changes in physical and chemical properties during maturation of mango fruit (*Mangifera indica* L. 'Irwin') cultured in a plastic greenhouse. Food Science and Technology Research 6: 299-305, 2009. https://doi.org/10.3136/fstr.6.299

Wei, J., Liu, G., Liu, D., Chen, Y. Influence of irrigation during the growth stage on yield and quality in mango (*Mangifera indica* L.). PLoS One, 12: e0174498, 2017. https://doi.org/10.1371/journal.pone.0174498

Winston, T. A guide for Australian mango growers. <http://horticulture.com.au/wp-content/uploads/2017/01/Mango-crop-nutrition.pdf>. Access in 20 Nov. 2023.

Yamamoto, E.L.M., Ferreira, R.M.A., Fernandes P.L.O., Albuquerque, L.B., Alves, E.O. Função do cálcio na degradação da parede celular vegetal de frutos. RVADS, 6: 49-55, 2011.

Yan, R., Han, C., Fu, M., Jiao, W., Wang, W. Inhibitory effects of CaCl2 and pectin methylesterase on fruit softening of raspberry during cold storage. Horticulturae, 8: 1, 2022. https://doi.org/10.3390/horticulturae8010001

Zenebon, O., Pascuet, N.S., Tiglea, P. Métodos físico-químicos para análise de alimentos. 4.ed. São Paulo: Instituto Adolfo Lutz, 2008. p.1002.