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Determination of adequate ranges of supply for the most demanded nutrients of mango during the pruning phase

- Final report of research project -

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Abstract: A research project was carried out to determine the adequate range of supply for mango sprout phase (pre-pruning) in two different mango leaves (from the first and second vegetative flushes after pruning) and evaluate effect of biochemical activity on mango sprouting and correlate it with fruit yield. Two experiments with 'Ataulfo' and 'Kent' mangoes were carried out from 2021 to 2023. To induce the nutritional variation of the orchards before/after the production pruning, N fertilizing was performed in different sources and doses. The experiments were arranged in randomized blocks with treatments distributed in subdivided plots referring to two N sources (NO_3^-, NH_4^+) in the plots and N doses (0, 50, 100, 150 and 200% of the recommended dose) in the subplots, with four replicates of five plants per plot. The leaf nutrient concentrations, sodium, and α-amylase were evaluated in leaves of the 1st and 2nd vegetative flush, the number of shoots per pruned branch, and productivity. The number of shoots per pruned branch, influenced by the nutritional status prior to production pruning, varies with different nutrients, and the 2nd vegetative flush after the previous pruning has a greater impact on shoot development in the current cycle. The shoot growth of the 'Ataulfo' cultivar after production pruning depends on leaf concentrations of P, K, Ca, S, Cu, Mn, Zn, and Mo, in addition to sodium, while 'Kent' depends only on P, Cu, Fe, Mn, and Zn. The highest productivity indices are recorded under the average number of sprouts per pruned branch of 2.72 for 'Ataulfo' and 2.63 for 'Kent'.
keywords: *Mangifera indica* L.; nutritional diagnosis; sprouts of mango trees

1. Introduction

Historically and until nowadays, the adequate ranges of supply for mango (*Mangifera indica* L.) are defined during flowering phase and they consider as parameter the fruit yield obtained of each nutrient demanded by mango plant (Quaggio 1996; Winston 2007; Rezende et al. 2022a). However, each nutrient present specific functions (Marschner 2012) and they are specifically more demanded according to each phase considering the pruning as the beginning of the cycle (Torres 2019; Rezende et al. 2023).

Basically the mango production phases in high fruit orchards are sequentially defined as: production pruning => shoot flush => paclobutrazol (PBZ) application => shoot maturation induction (and water management) => flowering induction => flowering => fruit set => 1st fruit abortion => 2nd fruit abortion => fast fruit development (width mainly) => fruit development (diameter mainly) => fruit harvest in an early maturation phase (Davenport 2009; Cavalcante et al. 2018; Lino et al. 2023). In addition, the production cycle from the production pruning until the fruit harvest can take 12-13 months, so it is long and susceptible to biotic and abiotic factors.

In some recently published data for mangoes Lobo et al. (2019) and Ferraz et al. (2020) observed that mango fruit yield is directly related to the terminal branch density, if the other management practices are well performed, i.e., the plant side that presented the higher density of terminal branch also promoted the higher fruit density per m^2. Therefore, it is assumed that to achieve consistently high fruit yields, high branch densities per m^2 are necessary in each production cycle. This is only achievable through the practice of production pruning, as according to Ramirez and Davenport (2016), the strong dominance of the terminal bud prevents lateral buds from emerging and highlights the importance of performing the production pruning focusing higher terminal branches density, at each producing cycle.

Understanding the nutritional dynamics before pruning is essential to elucidate how nutrient reserves, such as nitrogen, phosphorus, and potassium, affect the mango tree's ability to regenerate

tissues and sustain subsequent sprouting. In this sense, Silva et al. (2022) concluded that phosphorus and magnesium, and cooper and boron are the nutrients more efficient to generate plant biomass and fruit production in mango orchards.

Evaluating the physiological determinants underlying uniform post-pruning sprouting is a fundamental component for the development of more refined management strategies, and it agrees with Rezende et al. (2023) who found that nutritional diagnoses for P, K, Ca, Mg, S, Zn, and Cl altered between phenological phases, and the nutritional diagnosis performed in the postharvest phase showed that the nutritional imbalance affected fruit yield.

Thus, in the specific context of mango species, the correlation between the pre-pruning nutritional state and the subsequent sprouting process assumes a critical role in the effectiveness of management to obtain high fruit yields, and it constitutes a gap in the scientific literature and, horst, a challenge for mango fruit industry.

This way, a research project was carried out to determine the adequate range of supply for mango sprout phase (pre-pruning) in two different mango leaves (from the first and second vegetative flushes after pruning) and evaluate effect of biochemical activity on mango sprouting and correlate it with fruit yield.

2. Materials and methods

2.1 Characterization of the orchards studied

The experiments with 'Ataulfo' and 'Kent' mangoes were carried out from 2021 to 2023 (two growing seasons) at Casa Nova and Nogueira Farms. 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 Nogueira, 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). During the execution of the experiment the meteorological data recorded by automatic weather stations were rainfall (25.6 mm), average air temperature (25.62 ºC), and average relative air humidity (58.01 %) were monitored during the experiment, recorded (Figure 1).

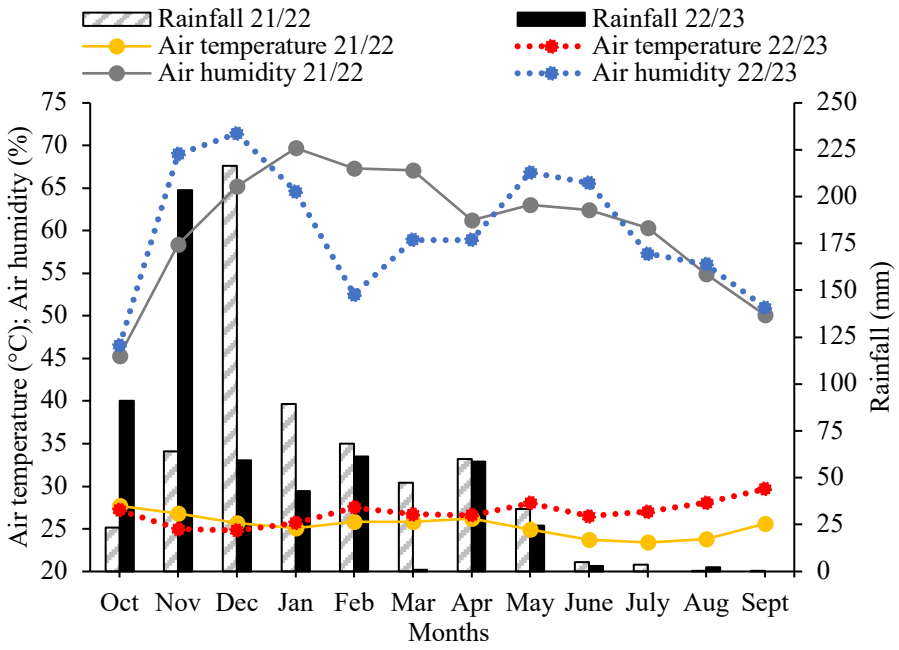

Figure 1. Monthly average air temperature and air humidity, and accumulated rainfall during the execution of the experiments (seasons 2021/2022 and 2022/2023).

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}	---------- $cmol_c\ dm^{-3}$ ----------							%	%
2021/2022 season													
Ataulfo	0-30	6.21	17.10	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	19.40	11.0	0.27	0.03	2.39	0.54	0.00	0.76	3.23	80.95	59.9
2022/2023 season													
Ataulfo	0-30	6.54	11.70	39.9	0.15	0.03	5.18	1.09	0.00	1.10	6.46	85.45	68.5
Kent	0-30	6.30	8.00	24.9	0.22	0.02	3.41	1.45	0.01	1.97	5.11	67.25	48.2

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}				
2021/2022 season											
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
2022/2023 season											
Ataulfo	12.8	1.2	5.9	22.4	1.6	2.1	88.1	13.7	73.1	167.2	14.0
Kent	11.2	1.2	6.3	28.3	3.3	1.1	187.6	18.3	118.1	1278.9	20.5

Before the experiments the plants of both experiments were characterized also for plant height (cm), stem diameter (mm) and crown volume (Table 3). Plant height (m) was measured with a leveling rod (Geodetic), stem diameter (cm) with a digital caliper (ZAAS-1.0004™) and crown volume (m^3) with a leveling rod and measuring tape, according to Rossi et al. (2004). The activity of α-amylase enzyme in leaves with sprouts of the last vegetative flush was determined following the Fuwa (1954) methodology.

Table 3. Biometrical characterization and α-amylase activity of 'Ataulfo' and 'Kent' mango leaves before the application of treatments.

Determination	cv. Ataulfo		cv. Kent	
	2021/2022	2022/2023	2021/2022	2022/2023
Plant height (cm)	217.52	295.89	257.41	276.19
Stem diameter (mm)	90.56	96.86	67.21	85.75
Crown volume (m^3)	1436.07	2765.48	405.11	775.50
α-amylase (μg of de hydrolyzed starch min^{-1} g of FM^{-1})	440	1488	1304	808

FM: fresh mass

2.2 Experimental procedure and study material

With the objective to induce the nutritional variation of the orchards before/after the production pruning, nitrogen fertilizing was performed in different sources and doses since, according to Torres (2019), N is the most required nutrient by mangoes due to its importance in vegetative development, flower bud and fruit production. Vegetative growth in the mango crop is decisive for production, and the higher the number of vegetative sprouts, the higher the chance of occurrence of panicles and fruits (Ferraz et al. 2020).

The experiments (mango trees cv. 'Ataulfo' and 'Kent') were arranged in randomized blocks with treatments distributed in subdivided plots referring to two N sources (NO_3^-, NH_4^+) in the plots and N doses (0, 50, 100, 150 and 200% of the recommended dose) in the subplots, with four replicates of five plants per plot. The recommended dose was defined considering the expected productivity and the leaf N content, according to criteria established by Genú and Pinto (2002), using 30 kg of N ha^{-1} to 'Kent' and 70 of N ha^{-1} to 'Ataulfo' for the entire season. From the total N applied during the mango cycle, 50% (15 kg of N ha^{-1} to 'Kent' and 35 kg of N ha^{-1} to 'Ataulfo) was applied between pre-pruning and post-pruning, while the remaining 50% was distributed during the crop cycle. All N applications were carried out in weekly fertigation and between pre-pruning and post pruning (50% of N), of which 30% was applied in pruning and 70% after pruning.

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}.

In both orchards the plants were submitted to the recommended practices for mango crop in the regional conditions for pruning, fertilizing, control of weeds, pests and diseases, plant growth regulators for gibberellin inhibition (PBZ), shoot maturation and break dormancy (calcium/potassium nitrate), following the instructions of Genú and Pinto (2002), Cavalcante et al. (2018) and Torres (2019). The nutrient management was performed through a fertigation system, according to plant demand.

2.3 Data gathered

One day before the production pruning leaf samples were collected to diagnose the nutritional status of 'Ataulfo' and 'Kent' mango trees. Leaves of two different positions of the branch were collected and evaluated separately to determine the most suitable and reliable to reflect their nutritional status effect on mango sprout after production pruning. Thus, leaves of the 1st flush and 2nd flush were collected stored in paper bags, then sent to the Plant Soil Laboratories® for leaf analysis. According to Silva (2019) the diagnostic leaf is that located in newly matured branches, in the midsection of the branch during flowering, i.e., leaves of the 2nd flush as can be seen in Figure 2.

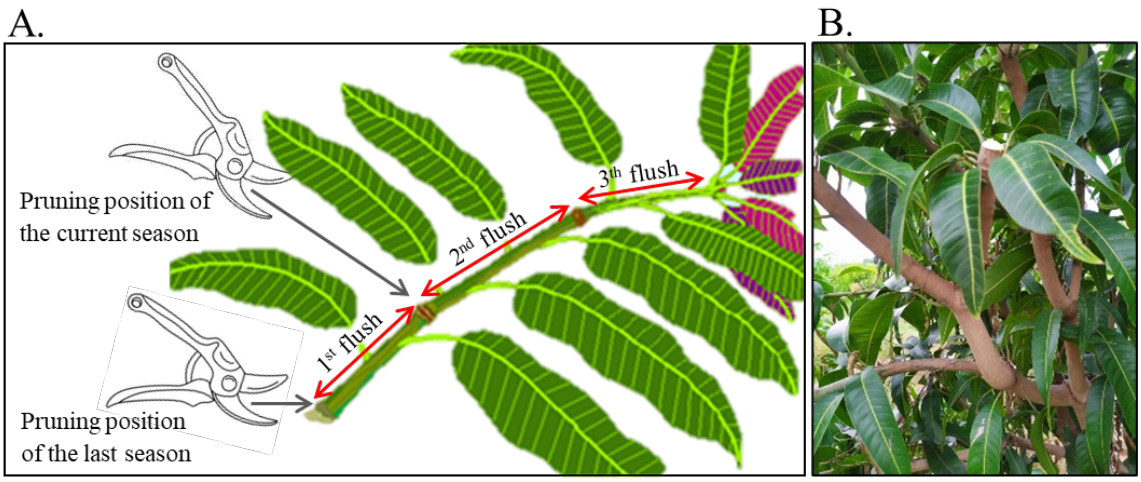

Figure 2. Visual expression of the vegetative flushes (first, second and third vegetative flushes) developed as a function of the pruning position (A) and 1st vegetative flush after the production pruning of the last season (B)

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 macronutrients N (g kg^{-1}), P (g kg^{-1}), K (g kg^{-1}), Ca (g kg^{-1}), Mg (g kg^{-1}), S (g kg^{-1}); micronutrients B (mg kg^{-1}), Fe (mg kg^{-1}), Cu (mg kg^{-1}), Mn (mg kg^{-1}), Zn (mg kg^{-1}) and Mo (mg kg^{-1}); and beneficial elements Na (mg kg^{-1}) and Si (mg kg^{-1}), according to the methodology proposed by Silva (2009).

After the production pruning which exact position is indicated in Figure 2 (pruning position of the current season) until paclobutrazol (PBZ) application, the number of sprouts per pruned branch until stabilized and total number of new sprouts per pruned branch was recorded were recorded in all pruned branches of each mango tree.

Fruit harvesting was carried out in 2022 and 2023 for both mango cultivars 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 per hectare for 'Ataulfo' and 1,428 plants per hectare for 'Kent' to obtain fruit yield in tons per hectare of commercial yield. Non-commercial fruits were not counted and considered for fruit yield.

Before statistical analysis, the data were subjected to normality (Shapiro-Wilk) and homogeneity analysis. Subsequently, the data from each cultivar were individually subjected to multivariate analysis by principal component analysis (PCA), and those showing positive relationships (same quadrant) and negative relationships (opposite quadrant) with the number of sprouts per pruned branch were further subjected to regression analysis based on the number of sprouts per pruned branch, with a minimum coefficient of determination (R^2) of 0.60 for the model fit to be considered significant. The fruit yield data of each cultivar were subjected to correlation and regression analyzes as a function of the number of sprouts per pruned branch. Statistical analyses and graph creation were conducted using R software version 3.5.2 and Sigma Plot version 14.0.

3. Results

Figure 3 presents the results of multivariate analysis of principal components (PCA) used to examine interrelationships between the number of sprouts per pruned branch and the foliar levels of macro and micronutrients, beneficial elements, and α-amylase enzyme activity prior to production pruning in leaves of the 1st and 2nd vegetative flushes of 'Ataulfo' and 'Kent' mango cultivars cultivated in the São Francisco Valley, Brazil.

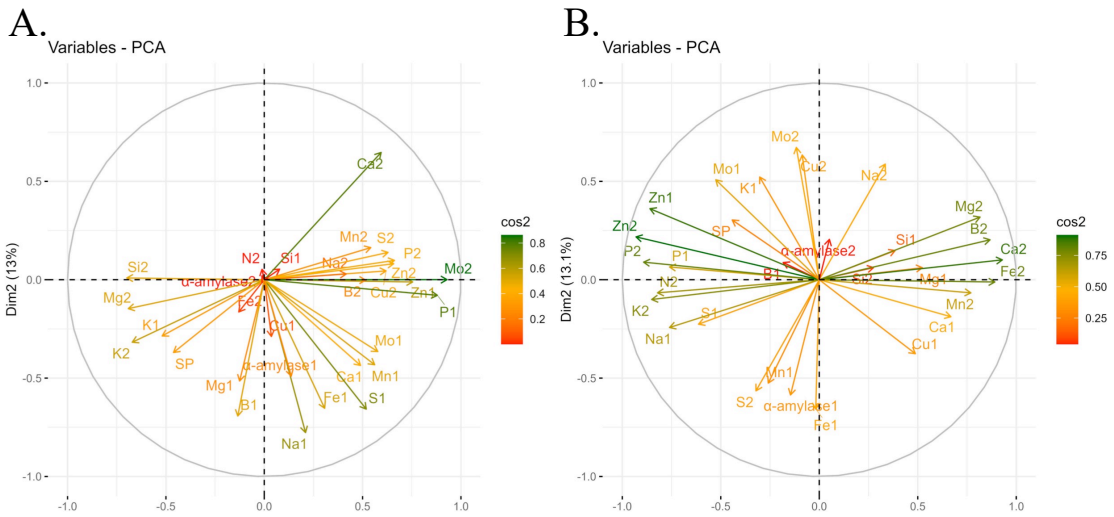

Figure 3. Principal component analysis for the number of sprouts per pruned branch and foliar levels of macro and micronutrients, beneficial elements, and α-amylase enzyme activity before production pruning in leaves of the 1st and 2nd vegetative flushes of 'Ataulfo' (A) and 'Kent' (B) mango cultivars grown in São Francisco Valley, Brazil.
1: leaves from the 1st vegetative flush; 2: leaves from the 2nd vegetative flush; SP: number of sprouts per pruned branch.

Analyzing the results for the 'Ataulfo' cultivar (Figure 3A), which accounted for 37.4% of the sum of dimensions 1 and 2, in relation to the number of sprouts, a positive relationship was observed between this variable and foliar levels of Mg, K, B, and Fe. Both Mg and K exhibited this relationship for both vegetative flushes, while B was significant only for the 1st flush and Fe for the 2nd vegetative flush, as they are in the same quadrants. Conversely, foliar levels of N, P, Ca, S, Cu, Mn, Zn, and Mo in the 2nd flush were negatively correlated with the number of sprouts, along with Si and Zn in the 1st flush (Figure 3). It is worth noting that negative relationships are not necessarily antagonistic and may simply be limiting due to nutrient deficiency.

The PCA analysis with all the studied variables for the 'Kent' cultivar resulted in the sum of dimensions 1 and 2 at 50.1%. Leaf nutrient levels of K, P, B, Mo, and Zn in the 1st vegetative flush, as well as Mo, Zn, and Cu in the 2nd vegetative flush, showed a positive relationship, while Cu and Ca levels in the 1st vegetative flush and Mn in the 2nd vegetative flush exhibited a negative relationship.

It is noteworthy that the contribution of the number of sprouts per pruned branch was slightly higher for the 'Ataulfo' cultivar compared to the 'Kent' cultivar, as indicated by the distance of the eigenvector

from the center of the graph and the arrow coloration. This suggests that these variables were more responsive to the stimulus of new sprouts after pruning.

Regarding the α-amylase enzyme, its relationship with the number of sprouts per pruned branch was quite low or indifferent, varying by cultivar. For the 'Ataulfo' cultivar, there was a negative relationship, but with minimal contribution from the enzyme, which was the lowest among all the analyzed variables. Conversely, for the 'Kent' cultivar, the relationship was considered indifferent.

From the PCA in Figure 3, the key variables (nutrients, beneficial elements, or α-amylase enzyme activity) from the second vegetative flush that showed positive and/or negative correlations with the number of sprouts were selected. Subsequently, polynomial regressions were performed for these variables, and the results are presented in Table 4.

Table 4. Mathematical regression models to estimate the number of sprouts per pruned branch as a function of leaf concentrations of macronutrients, micronutrients and sodium, and α-amylase enzyme activity before production pruning of 'Ataulfo' and 'Kent' mango cultivars.

cv. Ataulfo			**cv. Kent**		
Variable	Equation	R^2	Variable	Equation	R^2
N	$y = 1.335^{ns}x^2 - 39.228^{ns}x + 291.01^{ns}$	0.45	-	-	-
P	$y = -36.757^{*}x^2 + 105.59^{ns}x - 72.808^{ns}$	0.88	P	$y = -4.9378^{*}x^2 + 16.515^{ns}x - 10.836^{ns}$	0.71
K	$y = -0.3851^{*}x^2 + 6.0336^{ns}x - 20.623^{ns}$	0.72	-	-	-
Ca	$y = -0.1821^{*}x^2 + 6.5208^{ns}x - 55.307^{ns}$	0.79	-	-	-
Mg	$y = 4.2013^{ns}x^2 - 16.391^{ns}x + 18.834^{ns}$	0.30	-	-	-
S	$y = -14.562^{ns}x^2 + 48.531^{*}x - 37.385^{ns}$	0.66	-	-	-
B	$y = 0.0056^{**}x + 2.6039^{ns}$	0.15	-	-	-
Cu	$y = -0.0103^{*}x^2 + 0.3588^{*}x - 0.1264^{ns}$	0.77	Cu	$y = -0.0155^{ns}x^2 + 0.4308^{*}x + 0.0659^{*}$	0.96
Fe	$y = 0.0016x^{2ns} - 0.2376x^{ns} + 11.593^{ns}$	0.27	Fe	$y = -0.0441^{*}x^2 + 5.9425^{ns}x - 197.21^{ns}$	0.65
Mn	$y = -0.0003^{*}x^2 + 0.0882^{*}x - 3.0007^{ns}$	0.81	Mn	$y = -0.0032^{**}x + 4.2803^{**}$	0.93
Zn	$y = -0.004^{*}x^2 + 0.2383^{*}x - 0.4969^{*}$	0.90	Zn	$y = -0.0037^{*}x^2 + 0.321^{ns}x - 3.9766^{ns}$	0.84
Mo	$y = -8.3652^{*}x^2 + 6.3127^{ns}x + 1.8274^{ns}$	0.67	Mo	$y = -2635.6^{ns}x^2 + 100.61^{ns}x + 2.5719^{ns}$	0.11
Na	$y = -0.0001^{ns}x^2 + 0.0363^{*}x + 0.7594^{*}$	0.80	-	-	-
Si	$y = 2E\text{-}05^{ns}x^2 - 0.0319^{ns}x + 17.059^{ns}$	0.24	-	-	-
a-amylase	$y = 0.0108^{*}x^2 - 0.2181^{ns}x + 3.9221^{ns}$	0.38	-	-	-

R^2: determination coefficient; *: significant at $p \leq 0.05$ by the F-test; **: Significant at $p \leq 0.01$ by the F-test; ^{ns}: not significant by the F-test

The foliar levels of nutrients N, Mg, B, Fe, and Si, as well as the α-amylase enzyme of the 'Ataulfo' cultivar, despite being in the same quadrant or opposite quadrants to the number of sprouts per pruned branch (Figure 3A), did not show a clear logical relationship. This is reflected in the coefficient of determination (R^2), which did not exceed 0.60 (Table 4), preventing their representation through conventional mathematical models (linear and ascending quadratic polynomials). A similar pattern was observed for the foliar content of Mo in the 'Kent' cultivar.

Despite the positive relationship between Mg and Fe levels in the leaves of the 2nd vegetative flush of 'Ataulfo' with the number of sprouts per pruned branch (Figure 3A), the regressions did not exhibit high coefficients of determination (R^2), with only the nutrient K associated with a substantially elevated relationship (Table 4). In contrast, for 'Kent' (Figure 3B), most nutrients that showed a positive relationship with the number of sprouts per pruned branch had R^2 values above 0.60 (Table 4).

Furthermore, considering the R^2 value, estimates were made for nutrient levels that provided the maximum number of sprouts per pruned branch for each cultivar (as detailed in Table 4). Additionally, four nutrients coincided between the two cultivars: P, Cu, Mn, and Zn (Table 5).

Table 5. Leaf concentrations of some macronutrients, micronutrients and sodium before production pruning that provided the maximum number of sprouts per pruned branch in 'Ataulfo' and 'Kent' mango cultivars.

cv. Ataulfo				**cv. Kent**			
Variable	Leaf concentration	SD	Maximum SP	Variable	Leaf concentration	SD	Maximum SP
P (g kg^{-1})	1.44	± 0.05	3.02	P (g kg^{-1})	1.67	± 0.08	2.97
K (g kg^{-1})	7.83	± 0.38	3.01	-	-	-	-
Ca (g kg^{-1})	17.90	± 0.82	3.07	-	-	-	-
S (g kg^{-1})	1.67	± 0.08	3.05	-	-	-	-
Cu (mg kg^{-1})	17.42	± 2.20	3.00	Cu (mg kg^{-1})	13.90	± 3.52	2.93
Mn (mg kg^{-1})	147.00	± 11.69	3.48	Mn (mg kg^{-1})	406.35	± 54.32	3.02
Zn (mg kg^{-1})	29.79	± 5.01	3.05	Zn (mg kg^{-1})	43.38	± 3.66	2.99
Mo (mg kg^{-1})	0.38	± 0.07	3.02	-	-	-	-
Na (mg kg^{-1})	181.50	± 17.48	4.05	-	-	-	-
-	-	-	-	Fe (mg kg^{-1})	67.38	± 1.61	2.98

SD: standard deviation; SP: number of sprouts per pruned branch.

In the case of the 'Ataulfo' cultivar, the maximum number of shoot sprouts per pruned branch was recorded using the Na equation, albeit with a quadratic response. Nevertheless, significantly high concentrations of Na were found to decrease the number of shoot sprouts per pruned branch, with the estimated maximum value being 2.72 shoot sprouts per pruned branch at a foliar content of 164.65 mg kg^{-1}. In other words, there was a 9.28% reduction in the number of shoot sprouts with an increase in Na foliar content. The next nutrient that exhibited a substantial impact on the number of shoot sprouts for the 'Ataulfo' cultivar was Mn, while for the 'Kent' cultivar, it proved to be the most influential.

Regression analyses between the number of shoot sprouts per pruned branch and the yield of each cultivar were also conducted, and the results are presented in Figure 4.

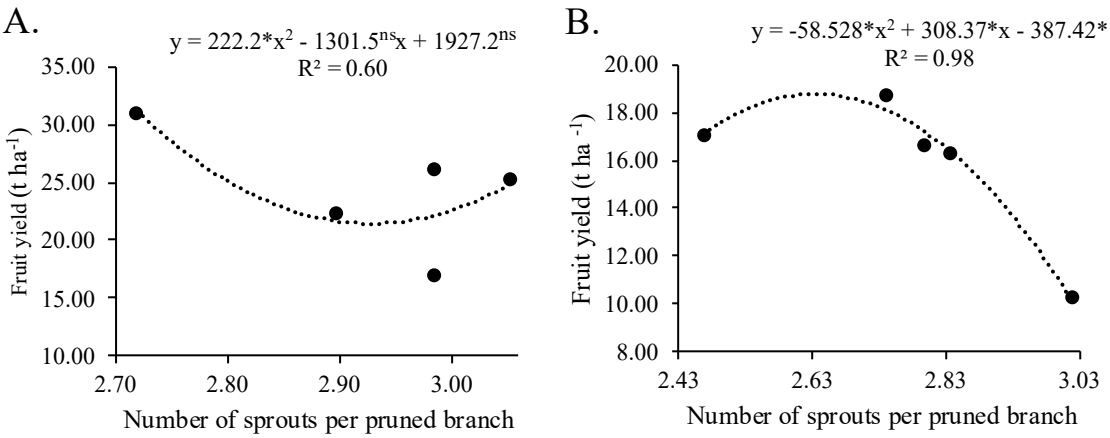

Figure 4. Fruit yield (t ha^{-1}) of 'Ataulfo' (A) e 'Kent' (B) mango cultivars as a function of the number of sprouts per pruned branch.
R^2: determination coefficient; *: significant at p≤0.05 by 'F' test; **: significant at p≤0.01 by 'F' test; ns: non-significant by 'F' test

As can be observed for both evaluated cultivars (Figure 3), it is evident that fruit yield was significantly influenced by the number of sprouts per pruned branch. However, the trends in results are distinct between the two cultivars; mango trees that produced more fruits had approximately 2.72 sprouts per pruned branch for 'Ataulfo' and 2.634 sprouts per pruned branch for 'Kent', resulting in respective yields of 31.08 and 18.8 t ha^{-1}. Above 3 sprouts per plant, fruit yield decreased by 32% for

‘Ataulfo’ and 55% for ‘Kent’, indicating that an excessive number of sprouts after production pruning is also deleterious to fruit yield. Therefore, an optimal number of sprouts is necessary for the maximum productivity of each cultivar.

On the other hand, 'Kent' exhibited pruned branches with 2.43 sprouts, leading to a slight reduction in production compared to the peak of the trend line. Table 6 contains the nutritional values before production pruning calculated for the number of sprouts per pruned branch that provided maximum fruit yield for 'Ataulfo' and 'Kent' mango cultivars.

Table 6. Leaf concentrations of some macronutrients, micronutrients and sodium before production pruning that provided the number of sprouts per pruned branch for maximum fruit yield of 'Ataulfo' and 'Kent' mango cultivars.

cv. Ataulfo				**cv. Kent**			
Variable	Ideal leaf concentration	Ideal SP	Maximum fruit yield (t ha^{-1})	Variable	Ideal leaf concentration	Ideal SP	Maximum fruit yield (t ha^{-1})
P (g kg^{-1})	1.346			P (g kg^{-1})	1.410	2.634	18.8
K (g kg^{-1})	6.966			-	-	-	-
Ca (g kg^{-1})	16.521			-	-	-	-
S (g kg^{-1})	1.516			-	-	-	-
Cu (mg kg^{-1})	22.615	2.72	31.08	Cu (mg kg^{-1})	8.659	2.634	18.8
Mn (mg kg^{-1})	96.602			Mn (mg kg^{-1})	514.469	2.634	18.8
Zn (mg kg^{-1})	38.902			Zn (mg kg^{-1})	33.630	2.634	18.8
Mo (mg kg^{-1})	0.188			-	-	-	-
Na (mg kg^{-1})	66.017			-	-	-	-
-	-	-	-	Fe (mg kg^{-1})	64.579	2.634	18.8

SP: number of sprouts per pruned branch.

The nutrients that promoted a significant effect on the number of sprouts per pruned branch for both 'Kent' and 'Ataulfo' cultivars were P, Cu, Mn, and Zn (Table 6), among which Mn and Cu values showed notable discrepancies between the cultivars. Specifically, 'Ataulfo' required 136.76% less Cu compared to 'Kent', but 89.25% more Cu.

When evaluating each cultivar individually (Table 6), it is observed that achieving the maximum fruit yield of 'Ataulfo' in terms of the number of sprouts per pruned branch depends on a greater number

of nutrients (P, K, Ca, S, Cu, Mn, Zn, and Mo), in addition to Na. On the other hand, for 'Kent', the nutrients that exhibited an effect were P, Cu, Mn, Zn, and Fe.

4. Discussion

The nitrogen sources and doses applied induced changes in the nutritional status and α-amylase enzyme activity, stimulating sprouting with varying intensities after production pruning. The results suggest that the foliar nutritional levels of mango trees before production pruning affect the quantity of sprouts emitted post-pruning. However, the nutritional requirements before pruning vary among cultivated mango varieties (Rezende et al. 2022a), and the nutritional effects are not uniform for all nutrients; only certain nutrients demonstrated an effect on the sprouting that occurs after production pruning, which is carried out practically in every productive cycle (Table 4).

Although there are discrepancies among cultivars, four nutrients (P, Cu, Mn, and Zn) coincided in exerting a significant effect on sprouting for both studied varieties, indicating that these may be more decisive for mango trees and should be considered in further research with additional mango varieties.

The nutrients P, Cu, Mn, and Zn play vital roles in plants, being essential for various metabolic processes. These nutrients have a special involvement in photosynthesis, either through the transfer of ATP energy, as in the case of P, or as enzymatic cofactors in chlorophyll formation, as in the cases of Cu and Mn, and Zn, acting as an enzymatic cofactor and participating in the synthesis of auxins, a hormone vital for cellular development. These nutrients also contribute to defense against environmental stresses, which can limit plant development (Barben et al. 2011; Dutta et al. 2020; Liščáková et al. 2022).

Specifically for P, although this nutrient is only the fifth most demanded by mango trees, according to the extraction order defined by Silva et al. (2022a), K>N>Ca>Mg>P>Mn>Fe>Zn>B>Cu, it holds fundamental importance throughout the phenological cycle of mango trees, and its supply should begin as soon as production pruning is carried out in each respective production cycle. The vital role of P in respiration and energy production, the enhancement of cell division, its contribution to reserve

substances such as starch and albuminoids, and its role in root system development (Taiz and Zeiger 2017) characterize this nutrient as crucial for achieving high productivity in mango trees. This way, Nascimento et al. (2008) reported that an adequate strategy to fertilize mango plants should consider the different phases of plant development since each phase presents different nutrient demand levels. Additionally, Prado (2010) concluded that phosphorous fertilization effects on mango plant growth are slow, which advocates for the recommendation of application well in advance of the desired effect.

Despite the importance of phosphorus (P) for mango trees, caution is needed in fertilizer recommendations to avoid excess, particularly in sandy and calcareous soils, as highlighted by Wang et al. (2022). They concluded that previous studies focused on examining the response of mango to escalating P doses without considering the existing P levels in the soil.

The positive relationship of Copper (Cu) with sprouting after mango tree pruning, despite its low demand for this nutrient in the crop (Rezende et al. 2023), can be attributed to its role as an activator of various enzymes in the plant (laccase, ascorbic acid oxidase, and cytochrome oxidase complex), as well as being a constituent of ascorbate oxidase enzyme and essential for oxidation and reduction processes in plants.

The findings of this study partially align with Silva et al. (2022a), who asserted that Phosphorus (P), Magnesium (Mg), Copper (Cu), and Boron (B) are the most efficient nutrients for generating plant biomass and fruit production in mango orchards, although these authors studied the 'Palmer' cultivar.

The significance of Phosphorus (P) and Copper (Cu) in generating plant biomass and fruit production in mango trees was also observed by Silva et al. (2022a) with the 'Palmer' mango tree of 1, 4, 7, and 12 years. However, Magnesium (Mg) and Boron (B), which did not show a significant emphasis in this study, were highlighted by Silva et al. (2022a). This difference could be attributed to the age of the cultivated plants, or the different varieties evaluated.

Manganese (Mn) provided the second-highest value of sprouting for 'Ataulfo' (second only to Na) and the highest for 'Kent' (Table 4). However, the relationship was opposite in the principal component

analysis (PCA), possibly due to manganese levels being below the recommended range, such as the range of 495.2 to 873.6 for 'Kent' (Rezende et al. 2022a).

Manganese is the most demanded micronutrient by mango trees (Silva et al. 2022a; Rezende et al. 2022b), with foliar levels significantly higher than other nutrients, especially during the flowering phase of the crop. Kirby et al. (2023) clarify that Manganese is necessary for chlorophyll formation, nitrate reduction, respiration, acts as a catalyst in some metabolic processes, and contributes to the formation of ascorbic acid (Vitamin C). Parallel, Taiz et al. (2017) reported that some plant tissues, such as mesophyll, contain almost as much Mn or Fe as Mg and S. It is important to detach the importance of Mn fertilizing after the production pruning, since according to Silva et al. (2022a) Mn is accumulated predominantly in the mango leaves (70.8% on average), whereas in the other plant compartments. Regarding Zinc (Zn), also identified as crucial for both studied cultivars, although it does not have a clearly defined structural function, it is a micronutrient that activates various enzymes (including constituting some of them, such as superoxide dismutase). Its main functions in plants include the synthesis of indoleacetic acid (IAA), protein synthesis (RNA), and nitrate reduction (Kirby et al. 2023).

Zinc accumulates in mango plants especially in leaves (45.2%), but other expressive organs are verified such as thin twigs (18.2%) and roots (17.2%) (Silva et al. 2022a), thus it is regularly distributed in mango tree. Since it is required for biosynthesis of chlorophyll, carbohydrates and proteins, and consequently its deficiency inhibits plant growth (Elsheery et al. 2020) the regular and adequate supply of Zn is essential for plant growth and development.

As shown in Table 6, the sprouting of the 'Ataulfo' cultivar after production pruning depended on the foliar levels of eight nutrients (P, K, Ca, S, Cu, Mn, Zn, and Mo), in addition to sodium, while the 'Kent' cultivar depended on only five nutrients (P, Cu, Fe, Mn, and Zn). This result may have occurred due to differentiated genetic characteristics, given that 'Ataulfo' is a polyembryonic cultivar originating in Tapachula, Chiapas, Mexico. It produces small, elongated fruits (200–300 g) of good quality, sweet

with slight acidity. According to Knight Jr et al. (2009) the tree is vigorous and upright, a mid-range producer with production averages of 10–20 t ha^{-1} possible, and it is not highly adaptive to different climatic/edaphic conditions. On the other hand, 'Kent' is a monoembryonic cultivar originated from Florida, USA, with a large and vigorous tree of a dense, upright canopy that produces greenish yellow fruits with a red or crimson blush, numerous small yellow dots, oval, with rounded base, 11–13 cm long by 9.5–11 cm broad by 9.9.5 cm thick, weighing 600–750 g (Knight Jr et al. 2009). 'Kent' is more productive than 'Ataulfo' and it can reach, according to Lobo et al. (2019) 54 t ha^{-1}.

These genetic differences, including embryonic variations, can also lead to differences in metabolic activity and, consequently, nutritional demands. Mango varieties may exhibit significant differences in nutritional requirements, as observed by Rezende et al. (2022a) when comparing and establishing specific Diagnosis and Recommendation Integrated System (DRIS) nutritional standards for 'Tommy Atkins,' 'Kent,' and 'Keitt' mango trees. The study concluded that the specific DRIS norms for each cultivar are more consistent and could serve as a reference for nutritional diagnostics of mango trees.

In addition, Amariz et al. (2023) reported that according to the deviation from the optimum percentage (DOP) indexes obtained, there were differences between the mango cultivars evaluated and Israeli mango cultivar 'Omer' showed the greatest nutritional imbalance in comparison to 'Shelly' and 'Agam', thus demanding specific information. Andrade et al. (2023) also verified differences between mango cultivars for water use efficiency, Chlorophyll *a* index, stomatal conductance and internal CO_2 concentration as a function of the mango cultivar during the vegetive formation phase.

Therefore, the specificities of the cultivars indicate that sprouting after production pruning in 'Ataulfo' is dependent on a greater number of nutrients, highlighting the differences in the nutritional demands of this cultivar. The nutritional status of 'Ataulfo' was assessed by Salazar-García et al. (2019), who recorded an average of 1.3 g kg^{-1} (P), 6.6 g kg^{-1} (K), 21.3 g kg^{-1} (Ca), 2.2 g kg^{-1} (S), 21.05 mg kg^{-1} (Cu), 630.85 mg kg^{-1} (Mn), and 14.16 mg kg^{-1} (Zn) during the flowering phase of the crop. In contrast, these results are significantly different from the 10.9 g kg^{-1} (K) and 7.1 g kg^{-1} (Ca) observed by Peralta-

Antonio et al. (2015) during the pre-flowering phase. The variations between the mentioned studies may be partially explained by differences in orchard management and the distinct phenological phases evaluated, as Salazar-García et al. (2018) highlight that the periods of greatest stability in leaf nutrient concentration differ among 'Ataulfo,' 'Kent,' and 'Tommy Atkins' mango cultivars, their vegetative flushes, and the specific nutrient being analyzed; in other words, the nutritional status changes according to the phenological phase.

When comparing the results from Table 6 with the sufficiency ranges defined by Rezende et al. (2022a) during the pre-flowering phase, notable differences are observed. For 'Ataulfo,' the only nutrient with compatibility of sufficiency was S, while Cu was the only nutrient demanded in higher quantities for sprouting. Additionally, all other nutrients (P, K, Ca, Mn, Zn, and Mo) presented lower demands during the sprouting phase. On the other hand, for 'Kent,' the only nutrients with sufficiency compatibility were Cu and Mn, while P, Zn, and Fe were demanded in lower quantities during the sprouting of this cultivar.

The vegetative flow from which the leaf is collected influences the nutritional status and the activity of the α-amylase enzyme, indicating that the second vegetative flow occurs after the last production pruning. For 'Ataulfo,' the relationship between the number of sprouts and enzyme activity was negative, with this variable also having the least contribution. In contrast, for 'Kent,' the relationship was indifferent. These results suggest that, although enzyme activity is crucial for carbohydrate accumulation, it does not guarantee effective use for the differentiation of buds in vegetative branches (new sprouts). The energy from these carbohydrates may be utilized for other metabolic components, such as enzymatic activation for defense against oxidative stresses (Kofroňová et al. 2020). This type of stress is common in semi-arid regions, and during the experimental period, the climate conditions (Figure 1) were conducive to such stresses (Silva et al. 2022b).

It is also evident that the nutrients determined in leaves from the second vegetative flow after the production pruning of the previous cycle have a greater influence on the number of sprouts after

production pruning. These results contrast with recommendations from both classical and more recent scientific literature. Silva (2019) recommends collecting leaves from the first vegetative flow, while Quaggio et al. (1997) recommend collecting leaves from the middle of the last vegetative flow, from branches with flowers at the end. However, the recommendations of Quaggio et al. (1997) and Silva (2019) pertain to the flowering phase, correlating the results with plant production. In contrast, the present study focuses on the nutritional status that can provide the plant with better shoot uniformity after pruning, by emitting the ideal number of sprouts per pruned branch and, consequently, increasing the possibility of fruit production. Indeed, Ferraz et al. (2020) detaches the importance of the production pruning focusing higher terminal branches density as a fundamental key to reach high mango yields, since, according to Ramirez and Davenport (2016) the strong dominance of the mango terminal bud prevents lateral buds from emerging.

A distinction in the phenological timing of analysis between the present study and the works of Quaggio et al. (1997) and Silva (2019) should serve as a tool for improvements in crop management. This is because it is after pruning that new sprouts will emerge, which will later flower and form fruits. If fertilization does not allow for enough healthy branches, flowering may be compromised, leading to a potential reduction in productivity (Ferraz et al. 2020; Silva et al. 2021).

Li et al. (2020) found that the variation of nutrients in plant tissues is broader than previously thought, not only among organs (leaves, roots, branches, and fruits) or among plant ages but also within the same leaf used for nutritional analyses. Different portions of a leaf (edges, center, tip, near the vein) accumulate nutrients differently, posing a challenge for the accurate description of nutrients in plants. This underscores the prominence of the observed distinction between leaves from the first and second vegetative flows.

The results also showed a significant trend, indicating that there is an ideal number of sprouts per pruned branch for each cultivar, neither too few nor too many. This tendency may be related to the source-sink relationship (Kirkby et al. 2023). Interestingly, this finding contradicts what Ferraz et al.

(2020) claimed, as their study suggested that plants with a higher density of branches exhibited greater production. However, both sets of results support the idea that there is indeed a relationship between the number of branches and production. The discrepancy in results could be attributed to differences in orchard spacing, with larger plants in the 8 x 5 spacing, as well as the use of a different variety ('Tommy Atkins') and older plants (26 years old). This emphasizes the need for further studies to observe the effects of various factors on this relationship for each cultivar under investigation.

In conclusion, these results reinforce the need for fertilization practices tailored to the productive potential of the crop. Plants that have formed more branches may require supplements (nutrients and water for increased photosynthetic activity) to have sufficient energy to flower and sustain satisfactory growth and development for harvest (Falchi et al. 2020). Therefore, fertilizer management throughout the crop cycle should consider phenological phases, and the nutritional levels presented in Table 6 should be achieved to maximize the productivity of the plants. When these nutritional levels for each nutrient and each cultivar before production pruning are not attained, the full productive potential of the crop may not be realized, leading to reductions in yields for both cultivars.

5. Conclusions

The number of shoots per pruned branch, influenced by the nutritional status prior to production pruning, varies with different nutrients, and the second vegetative flush after the previous pruning has a greater impact on shoot development in the current cycle.

The shoot growth of the 'Ataulfo' cultivar after production pruning depends on leaf concentrations of P, K, Ca, S, Cu, Mn, Zn, and Mo, in addition to sodium, while 'Kent' depends only on P, Cu, Fe, Mn, and Zn.

The highest productivity indices are recorded under the average number of shoots per pruned branch of 2.72 for 'Ataulfo' and 2.63 for 'Kent'.

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7. Declaration of interest statement

The authors report there are no competing interests to declare.

8. References

Alvares, C. A., J. L. Stape, P. C. Sentelhas, J. L. M. Gonçalves, G. Sparovek. 2013. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift* 22 (6):711–28. Doi: 10.1127/0941-2948/2013/0507.

Amariz, R. A. e, Í. H. L. Cavalcante, A. G. de L. Souto, R. dos S. Martins, F. A. L. Gomes, A. da S. Santos, W. F. dos Santos, M. C. R. Zuffo Borges, A. C. R. da Silva. 2023. Biomass accumulation and nutritional status in seedlings of Agam, Omer and Shelly mango cultivars as a function of the rootstock. *Horticultural Science and Technology* 41 (6):718-32. doi:10.7235/HORT.20230062.

Andrade, M. J. K. L., A. S. de Oliveira, W. F. dos Santos, L. dos S Silva, J. G. da Cunha, A. G. de L. Souto, Í. H. L. Cavalcante. 2023. Development of Israeli mango cultivars in the Brazilian semiarid region. *Pesquisa Agropecuária Brasileira* 58:e03173. doi: 10.1590/S1678-3921. pab2023.v58.03173.

Barben, S., B. Hopkins, V. Jolley, B. Webb, B. Nichols, E. Buxton. 2011. Zinc, manganese and phosphorus interrelationships and their effects on iron and copper in chelator-buffered solution grown russet burbank potato. *Journal of Plant Nutrition* 34:1144-63. doi: 10.1080/01904167.2011.558158.

Cavalcante, Í. H. L., G. N. F. Santos, M. A. Silva, R. S. Martins, A. M. N. Lima, P. I. R. Modesto, A. M. Alcobia, T. R. S. Silva, R. A. E. Amariz, M. Z. Beckmann-Cavalcante. 2018. A New approach to induce mango shoot maturation in Brazilian semi-arid environment. *Journal of Applied Botany and Food Quality* 91:281-6. doi: 0.5073/JABFQ.2018.091.036.

Davenport, T. L. 2009. Reproductive physiology. In: *The Mango: botany, production and uses*, ed. R. E. Litz, 97-169. Wallingford: CAB International

Dutta, T., N. R. R. Neelapu, C. Surekha. 2020. Iron, zinc, and copper application in overcoming environmental stress. In: *Protective chemical agents in the amelioration of plant abiotic stress: biochemical and molecular perspectives*, ed. A. Roychoudhury and D. K. Tripathi, 582-596. Hoboken: Wiley. doi: 10.1002/9781119552154.ch29.

Elsheery, N. I., M. N. Helaly, H. M. El-Hoseiny, S. M. Alam-Eldein. 2020. Zinc oxide and silicone nanoparticles to improve the resistance mechanism and annual productivity of salt-stressed mango trees. *Agronomy* 10 (4):558. doi: 10.3390/agronomy10040558.

Falchi, R., C. Bonghi, M. F. Drincovich, F. Famiani, M. V. Lara, R. P. Walker, G. Vizzotto. 2020. Sugar metabolism in stone fruit: source-sink relationships and environmental and agronomical effects. *Frontiers in Plant Science* 11:573982. doi: 10.3389/fpls.2020.573982.

Ferraz, L. E. C. de S., Í. H. L. Cavalcante, J. T. Lobo, J. G. da Cunha. 2020. Terminal branch density and fruit production in the canopy of high-yield mango orchards. *European Journal of Horticultural Science* 85 (2):118-22. doi: 10.17660/eJHS.2020/85.2.6.

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

Fuwa, H. 1954. A new method for microdetermination of amylase activity by the use of amylose as the substrate. *The Journal of Biochemistry* 41 (5):583–603. doi: 10.1093/oxfordjournals.jbchem.a126476

Genú, P. J. C., and A. C. A, Pinto. 2002. *A cultura da mangueira*. 2nd ed. Brasília: Embrapa Informação Tecnológica.

Kirkby, E. A., M. Nikolic, P. J. White, G. Xu. 2023. Mineral nutrition, yield, and source–sink relationships. In: *Marschner's mineral nutrition of higher plants*, ed. Z Rengel, I. Cakmak, P. J. White, 131-200. London: Academic Press.

Knight Jr., R.J. Campbell, I. Maguire. 2009. Important mango cultivars and their descriptors. In: *The mango – Botany, production and uses*. ed. R. E. Litz, 42-66. Wallingford: CAB International.

Kofroňová, M., A. Hrdinová, P. Mašková, J. Tremlová, P. Soudek, Š. Petrová, D. Pinkas, H. Lipavská. 2020. Multi-component antioxidative system and robust carbohydrate status, the essence of plant arsenic tolerance. *Antioxidants* 9 (4):283. doi: 10.3390/antiox9040283.

Li, D., C. Li, Y. Yao, M. Li, L. Liu. 2020. Modern imaging techniques in plant nutrition analysis: A review. *Computers and Electronics in Agriculture* 174:105459. doi: 10.1016/j.compag.2020.105459.

Lino J. de O. S., L. E. D. Mudo, J. T. Lobo, Í. H. L. Cavalcante, A. G. de L. Souto, L. G. Sanches, Paiva Neto, V. B. de. 2023. Application of *Rhodopseudomonas palustris* moderates some of the crop physiological parameters in mango cultivar 'Keitt'. *Erwerbs-Obstbau* 65:1633-45. 10.1007/s10341-023-00863-2.

Liščáková, P., A. Nawaz, M. Molnárová. Reciprocal effects of copper and zinc in plants. 2022. *International Journal of Environmental Science and Technology* 19(9):9297-312. doi: 0.1007/s13762-021-03854-6.

Lobo, J. T., Í. H. L. Cavalcante, A. M. N. Lima, Y. A. C. Vieira, P. I. R. Modesto, J. G. da Cunha. 2019. Biostimulants on nutritional status and fruit production of mango 'Kent'in the Brazilian semiarid region. *HortScience* 54 (9):1501-8. doi: 10.21273/HORTSCI13753-18.

Marschner, P. *Mineral nutrition of higher plants*. 2012. 3rd ed. New York: Academic Press.

Nascimento, V. M., F. M. Fernandes, R. M. Prado, L. S. Correa, W. Natale. 2008. *Adubação da mangueira: alternativa para alta produção com qualidade*. 1st ed. Ilha Solteira: UNESP/FEIS.

Peralta-Antonio, N., A. E. Becerril-Román, A. Rebolledo-Martínez, D. Jaén-Contreras. 2015. Estado nutricional foliar de tres cultivares de mango fertilizados con abonos orgánicos. *Idesia (Arica)*, 33 (3):65-72. doi: 10.4067/S0718-34292015000300010.

Prado, R. D. M. 2010. Phosphorus effects in the nutrition and growth of developing mango plants. *Journal of Plant Nutrition* 33 (14):2041-49. doi: /10.1080/01904167.2010.519079.

Quaggio, J. A. 1996. Adubação e calagem para a mangueira e qualidade dos frutos. In: *Manga: tecnologia de produção e mercado,* ed. A. R. São José, I. V. B. Souza, J. Martins Filho, O. M. Morais, 106-135. Vitória da Conquista: DBZ/UESB.

Quaggio, J. A., B. van Raij, C. T. Piza Junior. 1997. Frutíferas. In: *Recomendações de adubação e calagem para o estado de São Paulo*, ed. B. van Raij, H. Cantarella, J. A. Quaggio, A. M. C. Furlani, 121-153. 2nd ed. Campinas: Instituto Agronômico/Fundação IAC.

Ramirez, F., T. L. Davenport. 2016. Mango (*Mangifera indica* L.) pollination: A review. *Scientia Horticulturae* 203:158–68. doi: 10.1016/j.scienta.2016.03.011.

Rezende, J. S., F. J. Freire, S. R. da Silva, R. D. S. Musser, Í. H. L. Cavalcante, E. C. M. Saldanha, R. L. dos Santos, J. C. Cunha. 2023. Nutritional diagnosis of mango plants post-harvest in anticipation of pre-flowering avoids nutritional stress. *Revista Brasileira de Engenharia Agrícola e Ambiental* 27:359-66. doi: 10.1590/1807-1929/agriambi.v27n5p359-366.

Rezende, J. S., F. J. Freire, S. R. V. da Silva, R. D. S. Musser, Í. H. L. Cavalcante, E. C. M. Saldanha, R. L. dos Santos, J. C. Cunha. 2022b. Nutritional status of mango by the boundary line and mathematical chance methods. *Journal of Agricultural Science* 14 (8):90. doi: 10.5539/jas.v14n8p90 .

Rezende, J. S., F. J. Freire, S. R. V. Silva, R. S. Musser, Í. H. L. Cavalcante, E. C. M. Saldanha, R. L. Santos, J. C. C. Cunha. 2022a. 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 (17): 2627-54. doi: 10.1080/01904167.2022.2064294.

Rossi, A. de, J. C. Fachinello, L. Rufato, E. Parisotto, L. Picolotto, L. R. Kruger. 2004. Comportamento do pessegueiro 'Granada' sobre diferentes porta-enxertos. *Revista Brasileira de Fruticultura* 26:446-9. doi: 10.1590/S0100-29452004000300018.

Salazar-García, S., M. E. Ibarra-Estrada, E. F. Hernández-Valdés, R. Medina-Torres, L. E. Fregoso-Tirado. 2019. Site-specific fertilization approach increased productivity of rainfed ‘Ataúlfo’ mango. *Terra Latinoamericana* 37 (4):415-423. doi: 10.28940/terra.v37i4.526.

Salazar-García, S., R. Medina-Torres, M. E. Ibarra-Estrada, J. González-Valdivia. 2018. Appropriate leaf sampling period for nutrient diagnosis in three mango cultivars. *Revista Chapingo* 24 (3):167-179. doi: 10.5154/r.rchsh.2017.09.035.

Silva, A. R., Í. H. L. Cavalcante, M. A. Silva, V. B. Paiva Neto, R. A. Amariz, L. Y. Amorim, 2022b. Does the sunblock alleviate abiotic stress in mango trees grown in the tropical semiarid? *Folia Horticulturae* 34 (2):211-221. 10.2478/fhort-2022-0016.

Silva, D. J. 2019. Nutrição e adubação. In: *Manga do plantio a colheita*, Ed D. L. Siqueira, L. C. C. Salomão, A. Borém, 111-128. Viçosa: UFV.

Silva, F. C. S. 2009. *Manual de análises químicas de solos, plantas e fertilizantes*. 2nd ed. Brasília: Embrapa Informação Tecnológica, Rio de Janeiro: Embrapa Solos.

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

Silva, R. L., R. L. F. Fontes, J. C. L. Neves, A. M. N. Lima, E. M. B. Soares, C. I. F. S. Carvalho, Í. H. L. Cavalcante. 2022a. 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. doi: 10.5433/1679-0359.2022v43n4p1671.

Taiz, L., E. Zeiger, I. M. Møller, A. Murphy. 2017. *Fisiologia e desenvolvimento vegetal,* 6th ed. Porto Alegre: Artmed Editora.

Torres, A. P. 2019. *Ácidos orgânicos na nutrição, produtividade e qualidade de frutos de mangueira cv. Palmer no Vale do São Francisco*. 76 p. M.Sc. thesis (Agronomy – Plant Production), Federal University of São Francisco Valley, Brazil.

Wang, J., M. Elbagory, Y. He, X. Zhang, Y. Hui, M. A. Eissa, Z. Ding, S. El-Nahrawy, A.E.-D. Omara, M. G. Zoghdan, et al. 2022. Modeling of P-Loss risk and nutrition for mango (*Mangifera indica* L.) in sandy calcareous soils: a 4-years field trial for sustainable P management. *Horticulturae 8*: 1064. doi: 10.3390/horticulturae8111064

Winston, T. 2007. *Understanding crop nutrition: A guide for Australian mango growers*. Horticulture Innovation Australia Limited. Accessed January 15, 2024. https://www.horticulture.com.au/globalassets/hort-innovation/resource-assets/mg15006-understanding-crop-nutrition-mango.pdf