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Nutritional diagnosis of mango plants post-harvest in anticipation of pre-flowering avoids nutritional stress[1]

Diagnóstico nutricional de mangueiras na pós-colheita em antecipação ao pré-florescimento evita estresse nutricional

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HIGHLIGHTS:

Nutrient concentrations and nutrient relationships change with phenological phases of mango plants.
Nutritional diagnosis of mango plants in the post-harvest phenological phase is essential to mitigate nutritional stress.
Nutritional diagnosis of mango plants in post-harvest avoids reduced productivity due to deficiency or excess of nutrients.

ABSTRACT: The São Francisco Valley region of Brazil is a leading exporter of mango fruits. Previous nutritional diagnosis can identify stresses, provide adjustments for nutritional limitations, and promote more efficient fertilization and nutrient management. This study aimed to compare the nutritional diagnosis of mango trees in the post-harvest and pre-flowering phases and to correlate them with productivity. Norms and indices of the Integrated System of Diagnosis and Recommendation (DRIS), as well as the Nutritional Balance Index and the Potential of Response to Fertilization were generated for each phenological phase of the mango trees. Optimal concentrations and ranges of nutrients were established, classified as deficient, balanced, or excessive, and subsequently compared to each other and to values recommended in the literature. The indices were correlated with the productivity of the orchards in each phenological phase of the mango trees. When comparing the DRIS norms of post-harvest and pre-flowering phenological phases, 55% of the averages differed. The sufficiency ranges of the post-harvest and pre-flowering phases were generally different from those referenced in the literature. Nutritional diagnoses for P, K, Ca, Mg, S, Zn, and Cl altered between phenological phases. The nutritional diagnosis performed in the post-harvest phase showed that nutritional imbalance affected productivity.

Key words: *Mangifera indica* L., integrated system of diagnosis and recommendation, potential of response to fertilization, nutritional balance

RESUMO: A região do Vale do São Francisco no Brasil destaca-se na exportação de frutos de manga. O diagnóstico nutricional prévio pode identificar estresses, antecipar a correção de limitações nutricionais e promover um manejo nutricional da fertilização mais eficiente. O estudo objetivou comparar o diagnóstico nutricional em mangueiras nas fases de pós-colheita e pré-florescimento e correlacionar com a produtividade. Normas e índices do Sistema Integrado de Diagnose e Recomendação foram geradas para cada fase fenológica das mangueiras, bem como o Índice de Balanço Nutricional e o Potencial de Resposta a Adubação. Os teores e faixas ótimas de nutrientes foram estabelecidos e classificados em deficientes, equilibrados ou excessivos. Esses teores e faixas ótimas de nutrientes foram comparados entre si e com valores recomendados na literatura. Os índices foram correlacionados com a produtividade dos pomares em cada fase fenológica das mangueiras. Ao comparar as normas DRIS das fases fenológicas pós-colheita e pré-floração, 55% das médias diferiram. As faixas de suficiência das fases pós-colheita e pré-floração, em geral, foram diferentes das referenciadas na literatura. Os diagnósticos nutricionais para os nutrientes P, K, Ca, Mg, S, Zn e Cl diferiram entre as fases fenológicas. O diagnóstico nutricional realizado na fase de pós-colheita mostrou que o desequilíbrio nutricional afetou a produtividade.

Palavras-chave: *Mangifera indica* L., sistema integrado de diagnose e recomendação, potencial de resposta à adubação, balanço nutricional

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Introduction

The northeast region of Brazil constitutes 75% of Brazilian mango production, and includes the São Francisco Valley, which is responsible for 66% of the mango exports in the country (Carvalho et al., 2020; Ferreira et al., 2020).

Commercial crops with a high production capacity and nutritional demand require efficient nutrient management (Gomes et al., 2016; Oliosi et al., 2020) to avoid stress. To identify stressors, it is necessary to conduct an efficient nutritional diagnosis, such as that of the Integrated Diagnosis and Recommendation System (DRIS) (Beaufils, 1973; Ávila-Juárez & Rodríguez-Ruiz, 2020; Villaseñor et al., 2020).

Nutritional diagnosis in mango trees is usually performed during the pre-flowering phenological phase (Rezende et al., 2022). Faria et al. (2016) evaluated the nutritional status of the Tommy Atkins cultivar in São Francisco Valley during the flowering and fruiting phases. Pinto et al. (2010) and Politi et al. (2013) studied the nutritional assessment of the same cultivar using the DRIS method, and considered only the flowering phase, while Rezende et al. (2022) also considered only the flowering phase for nutritional assessment of mango trees. This method can reduce the time required to correct nutritional stress. Therefore, a previous nutritional diagnosis, such as that during the post-harvest phase, can facilitate correction of this stress.

Nutritional diagnoses performed in different phenological phases can return contrasting results due to the changes in nutritional requirements throughout the cultivation cycle (Tomio et al., 2015; Faria et al., 2016; Gomes et al., 2016). A diagnosis performed in the previous post-harvest phase can provide for the correction of limitations and allow for nutritional adjustments and more efficient management of fertilization.

Therefore, this study aimed to compare the nutritional diagnoses of mango trees in the post-harvest and pre-flowering phases and correlate them with productivity.

Material and Methods

The study was conducted on seven commercial mango farms in the Submiddle São Francisco Valley (8º 40' 29" S; 39º 9' 38" W; 332 m above sea level). The climate, according to the Köppen and Geiger classification system, is BshW: hot semi-arid, steppe type, with summer rains (Alvares et al., 2013). The average annual temperature is 26.7 ºC and average annual rainfall is 494 mm (Clima Tempo, 2020).

The database used to generate the DRIS norms used in this study was obtained from the results of leaf analysis and irrigated mango tree productivity during the 2015/2016 and 2016/2017 harvests by a company located in the municipality of Belem do São Francisco, Pernambuco, Brazil. To create the database, 66 leaf samples of the cultivar Tommy Atkins were collected at random from 66 orchards on seven commercial farms. Each sample consisted of four leaves collected from the median portion of the crown at the four cardinal points (Trani et al., 1983) of 20 randomly selected plants in each orchard. The collections were performed from plants ≥ 5 years old, with uniform size and good health statuses, one week after harvesting the fruits in the post-harvest phase, and before the application of calcium and potassium nitrate to break dormancy of the floral buds in the pre-flowering phase.

The leaf samples were packed in paper bags containing the identification of the variety, time of collection, and identification of the orchard. Subsequently, these samples were sent to the laboratory and subjected to sequential cleaning with water, acidic solution (HCl 0.1 mol L^{-1}), and distilled water. The samples were dried in an oven under mechanical air circulation and maintained at 65 °C. They were then ground and sieved through 1 mm mesh sieves (Politi et al., 2013). Chemical analysis of the plant tissue was conducted according to Malavolta et al. (1997), whereby the total leaf contents of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, Mo, and Cl were determined.

The plant population was divided into two subpopulations: high productivity and low productivity. The separation limit of the two subpopulations was defined as the average productivity + 0.5 standard deviation (Urano et al., 2007), which resulted in a value of 34 Mg ha^{-1}.

Subsequently, the mean (MD), minimum (MIN), maximum (MAX), standard deviation (S), coefficient of variation (CV), variance (S^2), and asymmetry coefficients (ASYM) of the nutrient concentrations in the leaves were determined for the phenological phases of post-harvest and pre-flowering. The Student's t-test was applied to compare the means of nutrient concentration data between the high and low productivity subpopulations ($p \leq 0.05$).

The DRIS norms were established using the MD, S, S^2, and CV of the bivariate relationships among all nutrients in the high-productivity subpopulation (Partelli et al., 2014). The nutrient ratios chosen as DRIS norms were based on the highest variance ratio between the low- and high-productivity subpopulations (s^2b/s^2a) (Beaufils, 1973; Urano et al., 2007). The means of the DRIS norms established in the post-harvest and pre-flowering phases were compared using the Student's t-test ($p < 0.05$).

The DRIS indices were calculated based on the method developed by Beaufils (Beaufils, 1973) and updated by Maia (Maia, 1999). The nutritional balance index (NBI) was obtained by adding the absolute values of the DRIS indices for each nutrient and dividing by the total number of nutrients (Urano et al., 2007).

Linear regressions of the relationship between nutrient concentrations and DRIS indices in the high-productivity subpopulation were adjusted to determine the optimal concentration and appropriate nutrient concentration range (Urano et al., 2007). As null values (0) of the DRIS indices represent nutritional balance, the optimal content was obtained when a null value was assigned to the DRIS indices in the linear statistical models of the nutritional content as a function of the DRIS indices. The optimal range, with its lower and upper limits, was obtained by subtracting (lower limit) or adding (upper limit) 2/3 of the standard deviation to the optimal nutritional content (Beaufils, 1973; Urano et al., 2007). Thus, nutrients were classified into three categories: adequate (z), deficient (p), and excessive (n). Nutrients were classified as

balanced when the nutrient content was between the maximum and minimum levels of the optimal range, deficient when the nutrient content was below the lower limit of the optimal range, and excessive when the nutrient content was above the upper limit of the optimal range (Partelli et al., 2014).

The optimal ranges of nutrients generated by the DRIS method in this study in the post-harvest and pre-flowering phenological phases were compared with the optimal ranges in the literature (Quaggio, 1996; Malavolta et al., 1997; Medeiros et al., 2004).

The interpretation of the nutritional diagnosis in the two mango plant phases by the DRIS methodology was performed using the Potential Response to Fertilization (PRF) method, adapted from Wadt et al. (1998). This method compares the DRIS index module for each nutrient with the NBI value to determine whether the imbalance attributed to a nutrient is greater or less than that attributed to the average of all nutrients, using three classes of the PRF: P (positive), Z (null), and N (negative). Thus, the 66 samples were distributed into these three PRF classes in the post-harvest and pre-flowering phenological phases, and the distributions were compared using the chi-squared test to evaluate whether the nutritional diagnoses were concordant or discordant between the phenological phases.

Subsequently, the frequency of nutrient distribution was calculated as a percentage of the three classes of PRF in the phenological phases of post-harvest and pre-flowering to evaluate and classify the nutrients in order of limitation.

The data were also subjected to principal components analysis (PCA), at each phenological phase of the mango plants.

Results and Discussion

The high-productivity orchards showed higher Ca and B concentrations in the post-harvest phase, and higher N, K, and S concentrations in the pre-flowering phase. The concentrations of other nutrients were not influenced by phenological phase (Table 1).

The nutrients N and K show high mobility in the phloem and a large degree of translocation (Silva et al., 2020; Sampaio et al., 2021). As the reproductive organs have priority, these nutrients are commonly mobilized from the leaf to the fruit (Dias et al., 2013). However, Ca and B accumulate in leaf tissues as plants develop because of their limited mobility in the phloem (Dias et al., 2013; Llanderal et al., 2019; Llanderal et al., 2021). This may explain the common problem of internal collapse in mango fruits in the São Francisco Valley region.

When comparing the DRIS norms of the post-harvest and pre-flowering phenological phases, 55% of the averages differed (Table 2). This indicates that nutritional diagnoses performed in one phenological phase cannot be used in the other phase. Nutritional requirements are influenced by the phenological phase of the crop due to the physiological aspects of the plant (Dias et al., 2013; Partelli et al., 2014). Other studies have shown that different phenological phases provided dissimilar

Table 1. Mean (MD), minimum (MIN), and maximum (MAX) values, along with standard deviations (S), coefficients of variation (CV), variances (S^2), and asymmetries (ASYM) of nutrient concentrations in the high productivity subpopulation of mango plants orchards in the phenological phases of post-harvest and pre-flowering, as well as the results of the Student's t tests comparing the nutritional concentrations of the two phases

Nutrient	MD	MIN	MAX	S	CV	S^2	ASYM	Student's t test
				Post-harvest				
N (g kg^{-1})	15.00	11.68	19.56	1.99	13.24	3.94	0.57	*
P (g kg^{-1})	1.85	1.29	2.46	0.39	21.08	0.15	0.01	ns
K (g kg^{-1})	10.78	7.95	13.78	1.58	14.62	2.48	0.26	*
Ca (g kg^{-1})	32.96	24.25	40.00	4.43	13.44	19.61	-0.02	*
Mg (g kg^{-1})	1.92	0.80	3.70	0.79	41.25	0.63	1.09	ns
S (g kg^{-1})	0.93	0.18	5.43	1.05	113.40	1.10	3.64	*
B (mg kg^{-1})	208.26	33.50	413.35	92.15	44.25	8491.65	0.22	*
Cu (mg kg^{-1})	15.36	2.67	34.46	9.97	64.94	99.45	0.49	ns
Fe (mg kg^{-1})	270.18	95.77	745.76	187.80	69.51	35267.71	1.58	ns
Mn (mg kg^{-1})	665.33	207.28	1200.00	257.24	38.66	66173.19	-0.12	ns
Zn (mg kg^{-1})	88.57	32.08	205.00	46.14	52.09	2128.58	1.08	ns
Mo (mg kg^{-1})	1.76	0.18	4.40	1.39	79.04	1.93	0.65	ns
Cl (mg kg^{-1})	0.27	0.08	1.05	0.19	69.51	0.04	3.06	ns
				Pre-flowering				
N (g kg^{-1})	16.38	10.52	22.84	2.85	17.41	8.13	0.35	*
P (g kg^{-1})	2.03	1.17	3.68	0.60	29.53	0.36	0.85	ns
K (g kg^{-1})	13.53	8.25	19.50	2.84	21.03	8.10	0.19	*
Ca (g kg^{-1})	29.53	17.50	65.00	8.79	29.78	77.36	2.80	*
Mg (g kg^{-1})	1.92	0.93	2.94	0.43	22.85	0.19	-0.08	ns
S (g kg^{-1})	1.44	0.11	2.78	0.67	46.48	0.45	0.09	*
B (mg kg^{-1})	160.75	55.80	317.47	59.63	37.09	3556.65	0.26	*
Cu (mg kg^{-1})	12.21	5.50	30.50	5.94	48.68	35.36	1.73	ns
Fe (mg kg^{-1})	250.05	82.98	1250.00	252.37	100.93	63694.34	2.96	ns
Mn (mg kg^{-1})	569.99	224.63	1200.00	266.79	46.80	71181.05	0.82	ns
Zn (mg kg^{-1})	109.43	32.00	420.00	87.30	79.78	7622.80	2.22	ns
Mo (mg kg^{-1})	1.96	0.10	4.89	1.43	73.24	2.06	0.77	ns
Cl (mg kg^{-1})	0.32	0.17	0.59	0.12	38.57	0.01	0.54	ns

* Significant by Student's t-test ($p \leq 0.05$); ^{ns}, not significant

Table 2. Mean values (MD) and standard deviations (S) of the DRIS norms of mango plant orchards in the post-harvest and pre-flowering phenological phases, and the Student's t test comparing these norms in the two phases

Phenological phase												
Post-harvest			Pre-flowering				Post-harvest			Pre-flowering		
Ratio	MD	S	Ratio	MD	S	Student's t test	Ratio	MD	S	Ratio	MD	S	Student's t test
N/P	8.52	2.48	N/P	8.82	3.18	ns	Ca/Zn	0.47	0.24	Ca/Zn	0.38	0.2	ns
K/N	0.73	0.15	N/K	1.27	0.37	*	Ca/Mo	43.08	46.78	Ca/Mo	42.69	79.82	ns
N/Ca	0.46	0.07	N/Ca	0.58	0.11	*	Cl/Ca	0.01	0.01	Ca/Cl	105.01	41.79	*
Mg/N	0.13	0.05	Mg/N	0.12	0.03	*	Mg/S	4.59	4.96	Mg/S	2.2	3.37	ns
N/S	30.03	21.98	N/S	18.14	25.35	*	Mg/B	0.01	0.01	Mg/B	0.01	0.01	ns
N/B	0.01	0.09	B/N	9.99	3.85	*	Mg/Cu	0.26	0.33	Mg/Cu	0.18	0.08	ns
N/Cu	1.73	1.49	N/Cu	1.55	0.53	*	Mg/Fe	0.01	0.01	Fe/Mg	142.57	151.8	*
N/Fe	0.08	0.04	N/Fe	0.1	0.06	*	Mg/Mn	0.01	0.01	Mg/Mn	0.01	0.01	ns
N/Mn	0.03	0.02	N/Mn	0.03	0.02	ns	Mg/Zn	0.03	0.02	Mg/Zn	0.03	0.02	ns
N/Zn	0.21	0.09	N/Zn	0.22	0.11	ns	Mg/Mo	2.18	1.97	Mg/Mo	1.33	0.89	ns
N/Mo	20.38	22.31	N/Mo	23.56	40.73	*	Cl/Mg	0.17	0.16	Mg/Cl	7.15	3.67	*
Cl/N	0.02	0.01	N/Cl	61.33	29.22	*	S/B	0.005	0.01	B/S	190.78	291.52	*
K/P	6.04	1.39	K/P	7.09	2.12	*	S/Cu	0.08	0.07	S/Cu	0.13	0.07	*
P/Ca	0.06	0.01	P/Ca	0.07	0.03	*	S/Fe	0.01	0.01	Fe/S	270.77	353.35	*
Mg/P	1.11	0.6	Mg/P	1.03	0.41	ns	S/Mn	0.01	0.01	S/Mn	0.01	0.01	*
P/S	3.4	2.13	P/S	1.39	0.52	ns	S/Zn	0.01	0.01	Zn/S	103.86	114.13	*
P/B	0.01	0.01	B/P	85.27	47.82	*	Mo/S	3.74	3.79	S/Mo	2.72	6.21	ns
P/Cu	0.21	0.19	P/Cu	0.2	0.12	ns	Cl/S	0.53	0.48	S/Cl	5.57	3.67	*
P/Fe	0.01	0.01	Fe/P	129.00	127.3	*	Cu/B	0.09	0.07	B/Cu	15.75	9.16	*
P/Mn	0.01	0.01	P/Mn	0.01	0.01	ns	B/Fe	1.04	0.72	B/Fe	0.98	0.63	ns
P/Zn	0.03	0.01	P/Zn	0.03	0.02	ns	B/Mn	0.37	0.23	B/Mn	0.36	0.23	ns
Mo/P	0.98	0.79	P/Mo	3.18	6.18	ns	Zn/B	0.55	0.44	B/Zn	2.3	2.06	*
Cl/P	0.16	0.14	P/Cl	7.15	3.26	*	Mo/B	0.01	0.01	B/Mo	277.98	556.19	*
K/Ca	0.33	0.05	K/Ca	0.49	0.17	*	Cl/B	0.01	0.01	B/Cl	581.36	325.71	*
Mg/K	0.18	0.07	Mg/K	0.14	0.03	*	Cu/Fe	0.07	0.05	Fe/Cu	22.95	21.36	*
K/S	21.87	16.78	K/S	14.95	19.59	ns	Cu/Mn	0.03	0.02	Mn/Cu	52.44	26.46	*
K/B	0.07	0.07	B/K	12.33	5.19	*	Zn/Cu	8.27	5.53	Zn/Cu	9.37	5.85	ns
K/Cu	1.25	1.08	K/Cu	1.33	0.66	ns	Mo/Cu	0.22	0.32	Cu/Mo	16.92	28.56	*
K/Fe	0.05	0.03	Fe/K	19.37	20.68	*	Cl/Cu	0.03	0.04	Cl/Cu	0.03	0.01	ns
K/Mn	0.02	0.01	K/Mn	0.03	0.02	*	Fe/Mn	0.45	0.32	Fe/Mn	0.49	0.43	ns
K/Zn	0.15	0.07	K/Zn	0.19	0.12	ns	Zn/Fe	0.40	0.17	Fe/Zn	2.67	1.78	*
K/Mo	13.47	13.06	K/Mo	8.91	5.31	ns	Mo/Fe	0.09	0.01	Fe/Mo	383.83	866.56	*
Cl/K	0.02	0.02	K/Cl	47.93	20.57	*	Cl/Fe	0.01	0.01	Fe/Cl	890.32	978.41	*
Mg/Ca	0.06	0.03	Mg/Ca	0.07	0.03	ns	Zn/Mn	0.16	0.11	Zn/Mn	0.21	0.13	ns
Ca/S	67.02	52.45	Ca/S	37.46	70.16	ns	Mo/Mn	0.01	0.01	Mo/Mn	0.01	0.01	ns
Ca/B	0.21	0.17	B/Ca	5.86	2.71	*	Cl/Mn	0.01	0.01	Mn/Cl	2174.31	1565.98	*
Ca/Cu	3.74	3.08	Ca/Cu	2.76	1.01	ns	Mo/Zn	0.02	0.02	Mo/Zn	0.02	0.02	ns
Ca/Fe	0.17	0.08	Fe/Ca	6.88	3.25	*	Cl/Zn	0.01	0.01	Zn/Cl	408.59	314.24	*
Ca/Mn	0.06	0.03	Ca/Mn	0.06	0.03	ns	Cl/Mo	0.41	0.6	Cl/Mo	0.44	0.68	ns

* Significant by Student's t-test ($p \leq 0.05$); ns, not significant

norms for "pear" orange tree (Dias et al., 2013), upland rice (Tomio et al., 2015), conilon coffee (Gomes et al., 2016), pepper (Llanderal et al., 2021) and the persimmon 'Rojo Brillante' (Morales et al., 2022).

In general, the sufficiency ranges of the post-harvest and pre-flowering phases were different from those referenced in the literature (Quaggio, 1996; Malavolta et al., 1997; Medeiros et al., 2004) (Table 3).

The lower and upper limits were higher in the ranges estimated in this study than those in the literature for N, P, K, Ca, B, Fe, Mn, and Zn, while the limits were lower for Mg, S, Cu, and Cl. In addition, the nutrient contents of the high-productivity population in the two phenological phases were within the optimal ranges estimated using the DRIS method (Tables 1 and 3). This suggests a strong reliability of the estimated ranges in this study. Therefore, sufficient ranges, considering the specificities of the region, cultivation practices, genetic material, and nutritional balance, are increasingly necessary (Oliveira et al., 2019).

The optimal ranges for the post-harvest phase were narrower than those for pre-flowering for N, P, K, Ca, Fe, Mn, Zn, and Mo. However, they exhibited greater amplitudes for Mg, S, B, and Cu (Table 3). Adequate ranges obtained from the DRIS method with smaller amplitudes reduce diagnostic errors due the lower variability of the data. This suggests greater reliability of the established optimal ranges (Urano et al., 2007).

Nutritional diagnoses for P, K, Ca, Mg, S, Zn, and Cl differed between the phenological phases (Table 4). The nutrients K and Ca were diagnosed in most orchards (51.5 and 53%) as deficient in the post-harvest phase, while in the pre-flowering phase, they were balanced in 60 and 68% of the orchards, respectively (Table 4).

The nutrients P, S, Zn, and Cl were within the nutritional balance range in both phenological phases (Table 4). However, P was diagnosed as excessive in 18% of the orchards post-harvest and in 4% of the orchards pre-flowering. No S deficiency was observed during the post-harvest phase. However, S was deficient in 40% of the orchards in the pre-

Table 3. Optimal ranges of nutrients for mango plant orchards in the post-harvest and pre-flowering phenological phases from the current study by the DRIS method, as well as those referenced in the literature

Nutrient	Phenological phase		Quaggio (1996)	Malavolta et al. (1997)	Medeiros et al. (2004)
	Post-harvest	Pre-flowering			
			(g kg^{-1})		
N	14.2-16.9	15.1-18.9	12-14	10-12	10.4-12.9
P	1.6-2.1	1.6-2.4	0.8-1.6	0.9-1.2	0.8-1.2
K	10.2-12.3	11.5-15.3	5-10	4-5	5.3-10.2
Ca	30.9-36.9	24.6-36.4	20-35	28-34	9.4-41.4
Mg	1.7-2.7	1.7-2.2	2.5-5	5-8	2.1-4
S	0.1-1.4	1.0-1.9	0.8-1.8	1.5-1.8	-
			(mg kg^{-1})		
B	121.5-244.3	141.8-221.3	50-100	-	-
Cu	6.4-19.7	6.6-14.5	10-50	-	78-352
Fe	77.5-327.9	113.1-449.6	50-200	-	114-252
Mn	380.3-723.3	328.3-684.1	50-100	-	69-888
Zn	50.2-111.7	31.7-148.1	20-40	-	18-96
Mo	1.1-2.9	0.9-2.8	-	-	-
Cl	0.2-0.4	0.2-0.4	100-900	-	-

Table 4. Distribution of the Potential Response to Fertilization (PRF) in mango plant orchards in the post-harvest and pre-flowering phenological phases, and chi-squared test results comparing this distribution in these two phases

Phenological phase	PRF			Chi-square test	Phenological phase	PRF			Chi-square test
	p	z	n			p	z	n	
	Nitrogen					Boron			
Post-harvest	21	30	15	0.59^{ns}	Post-harvest	12	34	20	4.56^{ns}
Pre-flowering	17	33	16	-	Pre-flowering	22	31	13	
	Phosphorus					Copper			
Post-harvest	26	28	12	9.35**	Post-harvest	17	36	13	2.98^{ns}
Pre-flowering	20	43	3		Pre-flowering	10	45	11	
	Potassium					Iron			
Post-harvest	34	23	9	10.25**	Post-harvest	3	57	6	5.12^{ns}
Pre-flowering	17	40	9		Pre-flowering	11	50	5	
	Calcium					Manganese			
Post-harvest	35	22	9	16.35**	Post-harvest	32	20	14	2.10^{ns}
Pre-flowering	18	45	3		Pre-flowering	26	28	12	
	Magnesium					Zinc			
Post-harvest	15	40	11	12.88**	Post-harvest	24	33	9	21.40**
Pre-flowering	11	25	30		Pre-flowering	3	54	9	
	Sulphur					Molybdenum			
Post-harvest	0	59	7	30.78**	Post-harvest	25	30	11	0.37^{ns}
Pre-flowering	24	34	8		Pre-flowering	22	31	13	
						Chlorine			
					Post-harvest	19	40	7	7.15*
					Pre-flowering	13	34	19	

* and ** - Significant by the chi-squared test at 0.05 and 0.01 probability; ^{ns} - not significant; p – positive response to fertilization; z – null response to fertilization; n – negative response to fertilization

flowering phase. Zn was diagnosed as deficient in 36% of the orchards in the post-harvest phase and 4% of the orchards in the pre-flowering phase. Cl was excessive in only 10% of the orchards in the post-harvest phase and was diagnosed in excess in 29% of those in the pre-flowering phase (Table 4). Mg was balanced in 60% of the orchards post-harvest and was excessive in 45% of orchards in the pre-flowering phase (Table 4).

Nutritional diagnosis of mango plants in Brazil is based on leaf samples collected during the flowering phase. This can cause fertilization management to be inadequate, because possible nutritional stresses will only be identified after the management techniques have been implemented. However, when nutritional stress is diagnosed early, fertilization correction can be performed before productivity is negatively affected.

The nutrients Ca, K, Mn, P, Mo, Zn, and N at post-harvest and Mn, S, B, Mo, and P at pre-flowering were deficient in more than 30% of the orchards, indicating high probabilities of positive responses to fertilization (Table 5).

The nutrients B, N, Mn, and Cu were excessive in 30, 23, 21, and 20%, respectively, of the orchards in the post-harvest phase, while Mg, Cl, N, and B showed high probabilities of negative responses to fertilization in 45, 29, 24, and 20% of the orchards in the pre-flowering phase (Table 5).

Identification of the most limiting nutrients is an advantage of using the DRIS method. This allows for the establishment of a priority order for the correction of these limitations for each phenological phase in a specific manner (Tomio et al., 2015).

The deficiencies of the nutrients N, P, K, Ca, and Mn were more pronounced in the post-harvest phase than in the pre-flowering phase (Table 5), suggesting that this phase is the most suitable for sampling and nutritional diagnosis in mango trees. Early nutritional diagnosis is essential and allows for the specific calibration of fertilizers for each nutrient during this

Table 5. Mean frequency of the distribution of the Potential Response to Fertilization (PRF) of nutrients in mango plant orchards in the post-harvest and pre-flowering phenological phases

Nutrient	PRF (%)					
	Post-harvest			Pre-flowering		
	p	z	n	p	z	n
N	32	45	23	26	50	24
P	40	42	18	30	65	5
K	51	35	14	26	60	14
Ca	53	33	14	27	68	5
Mg	23	60	17	17	38	45
S	0	89	11	36	52	12
B	18	52	30	33	47	20
Cu	26	54	20	15	68	17
Fe	5	86	9	17	76	7
Mn	49	30	21	40	42	18
Zn	36	50	14	4	82	14
Mo	38	45	17	33	47	20
Cl	29	60	11	20	51	29

p, positive response to fertilization; z, null response to fertilization; n, negative response to fertilization

phase. According to Gonçalves et al. (2017), foliar sampling and nutritional diagnosis become more advantageous in the post-harvest phase because the effects of dilution in the dry matter of the plants are reduced in more developed tissues. The large number of orchards deficient in P, Mn, and Mo in the two phenological phases indicates that the lack of correction for these limitations soon after harvest reflects the deficiencies of these nutrients in the pre-flowering phase, thereby impacting productivity.

The post-harvest phase was strongly associated with the DRIS indices of N, K, Ca, Mg, S, Cu, and Mo and productivity (Figure 1A), whereas the pre-flowering phase influenced the DRIS indices of N, P, K, Mg, S, B, Zn, Mn, and Cl (Figure 1B).

The strong association in the post-harvest phase between the nutrients N, K, Ca, Mg, S, Cu, and Mo indicates the need for an early nutritional diagnosis of these nutrients. This allows for early correction before the flowering period of the crop.

In addition, Ca, Cu, and Mo showed high variability only in the post-harvest phase (Figure 1A), while P, B, Zn, Mn, and Cl presented high variability during the pre-flowering phase (Figure 1B). This shows that the phenological phases influenced the nutrient content in the leaves of mango plants differently, suggesting the need to perform a specific diagnosis for each phenological phase.

The productivity vector was located far from the origin and close to the ordinate axis (small angle of inclination) during the post-harvest phase (Figure 1A). Therefore, it was strongly associated with Principal Component 2 (PC2). In addition, productivity was observed in the first quadrant (Figure 1A). This indicates that productivity was important in explaining the variation in the data and that it is strongly related to the nutritional diagnosis and the correction of nutritional imbalances in the post-harvest phase, evidencing the importance of anticipating this diagnosis.

Productivity showed low variability during the pre-flowering phase. The vector was located close to the origin and far from the two axes (Figure 1B). This represents a weak association between productivity and nutrient concentrations

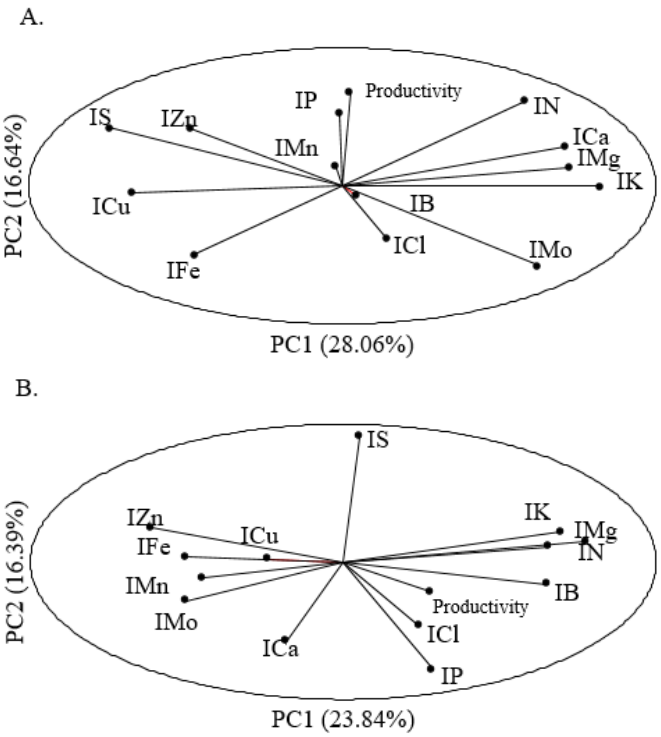

Figure 1. Two-dimensional projections obtained from the analysis of principal components (PC1 and PC2) of the DRIS indices and productivity of mango plant orchards in the phenological phases of post-harvest (A) and pre-flowering (B)

during this phenological phase, suggesting that other factors influenced productivity (Beaufils, 1973; Villaseñor et al., 2020).

There was a positive correlation between the IN, IK, ICa, and IMg indices in the post-harvest phase (Figure 1A). The high proximity between the vectors revealed that N, K, Ca, and Mg had synergistic effects on the other elements. However, these indices were negatively associated with the IS and ICu indices, as observed by the obtuse angle between these vectors (Figure 1A).

The IN, IK, IMg, and IB indices were positively associated with each other and negatively associated with IZn in the pre-flowering phase (Figure 1B). The IP and IS indices were also negatively associated with each other (Figure 1B).

The nutrients N, P, K, Ca, and Mg were associated with the productivity vector in the post-harvest phase because they were close and in the same quadrant. This greater proximity indicates that these nutrients are the main contributors to the increase in productivity and should be priorities when adjusting nutrients for fertilization.

Conclusions

1. Nutritional diagnoses for P, K, Ca, Mg, S, Zn, and Cl differed between phenological phases.

2. The limiting nutrients due to deficiency were Ca > K > Mn > P > Mo > Zn > N > Cl > Cu > Mg > B > Fe > S in the post-harvest phase, and MN > S > B = Mo > P > Ca > N = K > Cl > Mg = Fe > Cu > Zn in the pre-flowering phase.

3. The limiting nutrients due to excess were B > N > Mn > Cu > P > Mg = Mo > K = Ca = Zn > S = Cl > Fe in the post-harvest phase, and Mg > Cl > N > B = Mo > Mn > Cu > K = Zn > S > Fe > P = Ca in the pre-flowering phase.

4. The nutritional diagnosis performed in the post-harvest phase showed that the nutritional imbalance affected productivity.

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