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Original Article

Nutritional balance in mango plants in the Brazilian semiarid using nutritional diagnostic methods[1]

Balanço nutricional em mangueiras no semiárido brasileiro utilizando métodos diagnósticos nutricionais

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HIGHLIGHTS:

The mathematical chance diagnostic method is not recommended for evaluating nutritional imbalances in the present study.
The methods established by Beaufils-Maia and Jones have differentiated efficiencies in detecting nutritional imbalances.
The DRIS Beaufils diagnostic method updated by Maia is sensitive to the detection of nutritional imbalances.

ABSTRACT: Nutritional assessment of mango trees based on diagnostic methods considering nutritional balance is recommended. This study aimed to establish optimum nutritional ranges using diagnostic methods, compare them, identify the most efficient diagnostic method, and select the nutrients responding best to the application of the diagnostic method. The study was conducted in commercial mango orchards in the São Francisco Valley. Nutritional content was calculated using the diagnosis and recommendation integrated system (DRIS-Beaufils, DRIS-Jones), modified DRIS (M-DRIS-Beaufils; M-DRIS-Jones), compositional nutrient diagnosis (CND), and mathematical chance (ChM) methods and compared using the chi-square test. Principal component analysis was applied to select the most efficient diagnostic method and the nutrients responsible for the greatest variability. The DRIS-Beaufils, M-DRIS-Beaufils, DRIS-Jones, M-DRIS-Jones, CND, and ChM methods generated nutritional sufficiency ranges for the evaluated cultivars. The nutritional diagnoses of the DRIS-Beaufils and M-DRIS-Beaufils methods were similar and discordant with those of DRIS-Jones, M-DRIS-Jones, and CND. The DRIS-Beaufils method, updated by Maia, proved to be more consistent for the nutritional assessment of mango trees. The nutrients N, P, K, Mg, and S in the Tommy Atkins cultivar; N, P, Mg, S, B, Mn, Zn, Mo, and Cl in the Kent cultivar; and N, P, K, Ca, S, B, Cu, Fe, Zn, Mo, and Cl in the Keitt cultivar showed significant responses to the application of the DRIS-Beaufils method updated by Maia.

Key words: *Mangifera indica* L., diagnosis and recommendation integrated system, modified DRIS, compositional nutrient diagnosis, mathematical chance

RESUMO: A avaliação nutricional em mangueiras baseada em métodos diagnósticos que consideram o equilíbrio nutricional tem sido recomendada. Os objetivos deste estudo foram: estabelecer faixas nutricionais ótimas por métodos diagnósticos e compará-las entre si; identificar o método diagnóstico mais eficiente na determinação de desequilíbrios nutricionais; e selecionar os nutrientes que melhor respondem à aplicação do método diagnóstico. O estudo foi realizado em pomares comerciais de mangueira no Vale do São Francisco-PE, Brasil. Foram calculados os teores nutricionais pelos métodos Sistema Integrado de Diagnóstico e Recomendação (DRIS-Beaufils, DRIS-Jones), DRIS Modificado (M-DRIS-Beaufils; M-DRIS-Jones), Diagnose da Composição Nutricional (CND) e Chance Matemática (ChM) e comparados entre si pelo teste qui-quadrado. A análise de componentes principais foi aplicada para selecionar o método diagnóstico mais eficiente e os nutrientes responsáveis pela maior variabilidade. Os métodos DRIS Beaufils, M-DRIS Beaufils, DRIS Jones, M-DRIS Jones, CND e ChM geraram faixas de suficiência nutricional para as cultivares avaliadas. Os diagnósticos nutricionais dos métodos DRIS-Beaufils e M-DRIS Beaufius foram semelhantes entre si e discordantes dos métodos DRIS-Jones, M-DRIS-Jones e CND que foram semelhantes. O método DRIS Beaufils atualizado por Maia mostrou-se mais consistente na avaliação nutricional de mangueiras. Os nutrientes N, P, K, Mg e S na cultivar Tommy Atkins; N, P, Mg, S, B, Mn, Zn, Mo e Cl na cultivar Kent; e N, P, K, Ca, S, B, Cu, Fe, Zn, Mo e Cl na cultivar Keitt apresentam potencial de resposta significativa à aplicação do método DRIS-Beaufils atualizado por Maia.

Palavras-chave: *Mangifera indica* L., sistema integrado de diagnose e recomendação, DRIS modificado, diagnose da composição nutricional, chance matemática

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Introduction

Nutritional imbalances have been reported, potentially interfering with commercial mango production in the semiarid regions of Brazil. Thus, nutritional assessment based on the diagnostic methods that consider nutritional balance is recommended (Devi et al., 2020; Rezende et al., 2022a, b; Rezende et al., 2023).

Therefore, the diagnosis and recommendation integrated system (DRIS) has emerged as a proposal to improve nutritional diagnoses using classical methods (Beaufils, 1973).

To improve the efficiency of DRIS, different formulas for calculating DRIS indices have been suggested, with emphasis on those proposed by Jones (1981), Elwali & Gascho (1983), and Maia (1999). Additionally, other methods have been used, such as: modified DRIS (M-DRIS) (Hallmark et al., 1987); compositional nutrient diagnosis (CND) (Parent & Dafir, 1992); and mathematical chance (ChM) (Wadt et al., 1998).

Studies have been developed to compare these methods for identifying nutritional imbalances. However, these comparisons did not clearly define which method was more efficient, as these studies were limited to assessing the degree of concordance between the diagnoses, comparing the amplitudes of reference nutritional ranges, and correlating the mean nutritional balance index (NBIm) with productivity, to indicate differences in performance (Calheiros et al., 2018; Silva et al., 2021; Rezende et al., 2022b; Traspadini et al., 2022; Souza et al., 2023).

Therefore, this study aimed to establish optimum nutritional ranges using diagnostic methods and their comparisons with each other, to identify which diagnostic method was more efficient in determining nutritional imbalances of cultivars namely, Tommy Atkins, Kent, and Keitt, in the sub-middle region of the São Francisco Valley, and select the nutrients that best responded to the application of the diagnostic method.

Material and Methods

The study was conducted in seven commercial mango orchards, located in the sub-middle São Francisco Valley, Pernambuco, Brazil (8° 40’ 29” S; 39° 9’ 38” W; 332 m above sea level). The climate of the study area is BshW type, hot semi-arid, steppe type, with summer rains (Alvares et al., 2013). The average annual temperature is 26.7 °C and the average annual rainfall is 494 mm (Clima Tempo, 2020).

The database used to generate DRIS norms for mango tree was formed from the results of the analysis of leaves and productivity of irrigated mango trees in 2015/2016 and 2016/2017 harvests. Sampling for database formation consisted of 66 leaf samples the cultivar Tommy Atkins, 52 samples of Kent, and 38 samples of Keitt, totaling 156 leaf samples randomly chosen in 156 orchards. For this, 20 plants were randomly chosen in each orchard during the pre-flowering phase. The selected plants were of ≥5 years of age, uniform size and good health status (Politi et al., 2013).

Leaf samples were packed in paper bags and sent to the laboratory. Chemical analysis of the plant tissues was performed according to Malavolta et al. (1997), where the total leaf contents of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, Mo, and Cl were determined.

For the three cultivars, the plant population was separated into two subpopulations according to the orchard productivity- high and low. The separation limit of the two subpopulations was defined as the average productivity + 0.5 of the standard deviation (Urano et al., 2007).

The mean (Md), minimum (Min), maximum (Max), standard deviation (s), coefficient of variation (CV), variance (s2), coefficients of asymmetry (Asym), kurtosis (Kurt), and normality test (p-value) of the productivity, for the three cultivars can be calculated as described by Rezende et al. (2022a).

Subsequently, DRIS norms were established using the Md, s^2, s, and CV of the bivariate relationships among all nutrients in the high-productivity subpopulation (Partelli et al., 2014). The selection of the nutrient ratios as DRIS norms was based on the highest variance ratio between the low- and high-productivity subpopulations (s^2b/s^2a) (Beaufils, 1973; Urano et al., 2007).

DRIS indices were calculated based on the methods developed by Jones (1981) and Beaufils (1973) and updated by Maia (1999).

The method proposed by Jones (1981) is based on Eq. 1:

$$f(A/B) = \left[\frac{(A/B) - (a/b)}{s(a/b)}\right]k \tag{1}$$

The formula proposed by Maia (1999) is an update of the Beaufils method (1973) according to the criteria presented in Eqs. 2, 3, and 4, respectively.

a) For A/B > a/b

$$f(A/B) = \left[\frac{(A/B) - (a/b)}{s(a/b)}\right]k \tag{2}$$

b) For A/B = a/b

$$f(A/B) = 0 \tag{3}$$

c) For A/B < a/b

$$f(A/B) = \left[\frac{(A/B) - (a/b)}{s(a/b)}\right]k\left[\frac{(a/b)}{(A/B)}\right] \tag{4}$$

where f(A/B) - DRIS function for nutrients A and B; A/B - nutrient ratio A and B in the sample; a/b - nutrient ratio A and B in the high-productivity subpopulation or reference; s - standard deviation of the relationship between the nutrients A and B of the reference population; and K - sensitivity constant with a value of 10.

DRIS indices were calculated using Eq. 5:

$$\text{Index A} = \frac{\sum_{i=1}^{n} f(A/Bi) - \sum_{i=1}^{m} f(Bi/A)}{n+m} \tag{5}$$

where A - DRIS index of nutrient "A"; $\Sigma^{n}_{i=1}$ f(A/Bi) - sum of functions in which nutrient "A" is in the numerator; $\Sigma^{m}_{i=1}$ f(Bi/A) - sum of functions in which nutrient "A" is in the denominator; n - number of functions in which nutrient is in numerator; and m - number of functions in which nutrient is in the denominator of relationship.

The M-DRIS functions were calculated using the formulas proposed by Jones (1981) and Beaufils (1973), and updated by Maia (1999). The M-DRIS method, in addition to considering the relationships among nutrients, incorporates the nutrient content in its calculations.

M-DRIS Jones was calculated according to Eq. 6:

$$f(A) = \left(\frac{A - B}{s}\right)k \tag{6}$$

M-DRIS updated by Maia (1999) was calculated using Eqs. 7, 8, and 9, respectively.

a) For A > B

$$f(A) = \left(\frac{A - B}{s}\right)k \tag{7}$$

b) For A = B

$$f(A) = 0 \tag{8}$$

c) For A < B

$$f(A) = \left(\frac{A - B}{s}\right)k\left(\frac{B}{A}\right) \tag{9}$$

where f(A) - DRIS function of nutrient content; A - nutrient content of the sample; B - nutrient content of the reference population; s - standard deviation of the nutrient content of the reference population; and K - sensitivity constant with a value of 10.

Using the results of each M-DRIS function, the DRIS index was calculated for each nutrient using Eq. 10:

$$\text{Index A} = \frac{\sum_{i=1}^{n} f(A/Bi) - \sum_{i=1}^{m} f(Bi/A) + f(A)}{n + m + 1} \tag{10}$$

According to Parent and Dafir (1992), to determine the CND norms, the foliar nutrient content was adjusted to the same unit (mg kg^{-1}). The value of the organic complement of leaf biomass (R-value) was then calculated. This value corresponds to the leaf biomass after subtracting the nutrients evaluated in the dry matter using Eq. 11:

$$R = 10^{6} - \sum_{i=1}^{d} Ai \tag{11}$$

where R - complement value for 10^6 mg kg^{-1} of dry matter, in relation to the sum of nutrient contents (vX = N, P, …, Cl), in mg kg^{-1}.

The geometric mean of nutritional content was obtained for each sample using Eq. 12:

$$G = \left(N \times P \times K \ldots R\right)^{\left(\frac{1}{d+1}\right)} \tag{12}$$

where G - geometric mean of the plant nutritional composition and d - number of nutrients involved in the diagnosis.

The value of the multinutrient variable (zX) was determined using Eq. 13:

$$zX = \ln\left(\frac{vX}{G}\right) \tag{13}$$

where zX - value of the multivariate relationship between the evaluated nutrient content (vX) and geometric mean of these levels (G).

The arithmetic mean (mX) and standard deviation (sX) were calculated using the zX value of each sample. These two descriptive parameters of the reference population form the CND norms.

The CND index (IA) was calculated as the difference between the multinutrient variable of the sample (Vi) and the mean of the reference population (Va), divided by the standard deviation of this variable in the reference population [s(a)], according to Eq. 14:

$$IA = \frac{(Vi - Va)}{s(a)} \tag{14}$$

NBI was obtained by adding the absolute values of the DRIS, M-DRIS, and CND indices, and NBIm was obtained by dividing the NBI by the number of nutrients evaluated in each leaf sample (Urano et al., 2007).

Linear statistical models of the relationships were adjusted between nutrient content and the DRIS, M-DRIS, and CND indices in the high-productivity subpopulation. As the null values (0) of the DRIS, M-DRIS, and CND indices represent nutritional balance, the optimal content was obtained by assigning the null value to these indices in the linear statistical models of the nutritional content as a function of the DRIS, M-DRIS, and CND indices. The optimal range, with its lower and upper limits, was obtained by subtracting (lower limit) or adding (upper limit) 2/3 of thes to the optimal nutritional content (Beaufils, 1973; Urano et al., 2007).

Sufficiency range were determined by the method of ChM using the recommendations of Wadt et al. (1998). Nutrient content was classified in ascending order and distributed into several classes defined by the square root of the number of observations. The range of values for each class was determined by dividing the range of nutrient contents evaluated by the number of classes established according to Eq. 15:

$$ChMi = \left[ChM(Ai/A) \times ChM(Ai/Ci)\right]^{0.5} \tag{15}$$

where ChM (Ai/A) = P(Ai/A) × PRODi, P(Ai/A) - frequency of high-productivity orchards in class i in relation to the overall total of high-productivity orchards and PRODi -

average productivity of high-productivity orchards in class i (mg ha^{-1}); ChM(Ai/Ci) = P(Ai/Ci) × PRODi, P(Ai/Ci) - frequency of high-productivity orchards in class i, in relation to the total of orchards in class i. Thereafter, the lower and upper limits of the nutrient content classes presenting the highest ChM were determined. The interval between these limits was considered as the sufficiency range.

Accordingly, for each method, the nutrients were classified as deficient, when the content was below the lower limit of the sufficiency range; adequate, when the nutrient content was between the maximum and minimum of the sufficiency range; and excess, when the nutrient content was above the upper limit of the sufficiency range.

The diagnoses generated using the evaluation methods were then compared. For this purpose, a chi-square test was used.

Data were subjected to PCA and cluster analyses (CA). These techniques was aimed at selecting a more efficient method for nutritional diagnosis in assessing nutritional imbalances in mango cultivars. This improved the effectiveness of nutritional management (Ali, 2018).

PCA evaluated the relationship (correlation) between the diagnostic methods and the DRIS, M-DRIS, and CND indices, and those responsible for the greatest variability in the data were selected.

A correlation matrix was established between the nutritional indices and the components after standardization of the data to verify their degree of importance, considering values ≥ 0.7 (Ali, 2018). The number of principal components necessary for result interpretation is based on an explanation of at least 70% of the data variability.

The CA was applied to separate the diagnostic methods into similar groups; these methods were similar within each group and less similar between the groups. Subsequently, the association between these methods and yield was verified for each mango cultivar. The XLSTAT software version 2020.5.1 was used for this purpose.

Results and Discussion

The nutritional diagnoses established by the DRIS-Jones (DJ), DRIS-Beaufils (DB), modified DRIS-Jones (MDJ), modified DRIS-Beaufils (MDB), and CND methods agreed with each other and disagreed with the diagnosis of the ChM method for orchards of all cultivars, except for N for the Tommy Atkins cultivar (Table 1), Mn and Cl for Kent (Table 2), and P, Mg, S, and Cu for Keitt (Table 3).

This discrepancy occurred because of the greater amplitude of the optimal ranges estimated by the DJ, DB, MDJ, MDB, and CND diagnostic methods compared to the ChM method, which estimated the optimal ranges of smaller amplitudes (Tables 1, 2, and 3). Optimal ranges of greater amplitudes make the method more sensitive in identifying nutritional imbalances (Silva et al., 2021), and reduce the possibility of mistakenly performing deficient and excessive nutritional diagnoses.

These results indicate that the DRIS, M-DRIS, and CND methods developed in this study are more efficient in the nutritional diagnoses of mango trees than the ChM method

Table 1. Optimum range of nutrients and chi-square likelihood ratio test of the cultivar Tommy Atkins by evaluated diagnostic methods in commercial orchards of mango trees

Diagnostic method	Optimal range	Chi-square				
		DB	MDJ	MDB	CND	ChM
	(g kg^{-1})					
	N					
DJ	14.4-18.2	1.11^{ns}	0.07^{ns}	1.11^{ns}	0.05^{ns}	5.21^{ns}
DB	15.1-18.9	-	1.68^{ns}	0.00^{ns}	0.71^{ns}	4.19^{ns}
MDJ	14.3-18.1		-	1.68^{ns}	0.21^{ns}	5.27^{ns}
MDB	15.1-18.9			-	0.71^{ns}	4.19^{ns}
CND	14.5-18.2				-	4.49^{ns}
ChM	14.9-17.5					-
	P					
DJ	1.5-2.3	3.31^{ns}	0.00^{ns}	3.31^{ns}	3.31^{ns}	44.80**
DB	1.6-2.4	-	3.31^{ns}	0.00^{ns}	0.00^{ns}	28.04**
MDJ	1.5-2.3		-	3.31^{ns}	3.31^{ns}	44.80**
MDB	1.6-2.4			-	0.00^{ns}	28.04**
CND	1.6-2.4				-	28.04**
ChM	2.1-2.4					-
	K					
DJ	11.1-14.9	0.69^{ns}	0.00^{ns}	1.49^{ns}	1.49^{ns}	76.42**
DB	11.5-15.3	-	0.69^{ns}	0.16^{ns}	0.16^{ns}	64.45**
MDJ	11.2-15.0		-	1.49^{ns}	1.49^{ns}	76.42**
MDB	11.6-15.4			-	0.00^{ns}	58.98**
CND	11.6-15.4				-	58.98**
ChM	16.7-18.1					-
	Ca					
DJ	24.1-35.8	0.37^{ns}	0.43^{ns}	0.00^{ns}	0.42^{ns}	30.23**
DB	24.6-36.4	-	0.16^{ns}	0.00^{ns}	1.58^{ns}	29.61**
MDJ	24.2-36.0		-	0.16^{ns}	0.73^{ns}	29.96**
MDB	24.7-36.5			-	1.58^{ns}	29.61**
CND	23.6-35.4				-	31.52**
ChM	23.4-29.4					-
	Mg					
DJ	1.5-2.1	2.62^{ns}	0.00^{ns}	2.62^{ns}	2.05^{ns}	13.96**
DB	1.7-2.2	-	2.62^{ns}	0.00^{ns}	0.27^{ns}	4.68^{ns}
MDJ	1.5-2.1		-	2.62^{ns}	2.05^{ns}	13.96**
MDB	1.7-2.2			-	0.27^{ns}	4.68^{ns}
CND	1.6-2.2				-	38.94**
ChM	1.9-2.4					-
	S					
DJ	1.0-1.9	0.00^{ns}	0.31^{ns}	0.31^{ns}	0.00^{ns}	30.84**
DB	1.0-1.9	-	0.31^{ns}	0.31^{ns}	0.00^{ns}	30.84**
MDJ	1.1-2.0		-	0.00^{ns}	0.31^{ns}	25.26**
MDB	1.1-1.9			-	0.31^{ns}	25.26**
CND	1.0-1.9				-	30.84**
ChM	1.7-2.1					-
	(mg kg^{-1})					
	B					
DJ	121.1-200.5	3.24^{ns}	0.00^{ns}	3.24^{ns}	83.79**	11.07**
DB	141.8-221.3	-	3.24^{ns}	0.00^{ns}	57.98**	4.76^{ns}
MDJ	119.8-199.3		-	3.24^{ns}	83.79**	11.07**
MDB	141.3-220.8			-	57.98**	4.76^{ns}
CND	272.5-352.0				-	47.58**
ChM	161.1-196.2					-
	Cu					
DJ	8.3-16.2	5.18^{ns}	0.14^{ns}	5.18^{ns}	0.00^{ns}	6.94*
DB	6.6-14.5	-	6.69*	0.00^{ns}	5.18^{ns}	9.53**
MDJ	8.5-16.4		-	6.69*	0.14^{ns}	6.23*
MDB	6.7-14.6			-	5.18^{ns}	9.53**
CND	8.2-16.2				-	6.94*
ChM	8.6-12.2					-
	Fe					
DJ	71.2-407.7	7.60*	0.21^{ns}	7.60*	0.21^{ns}	6.77*
DB	113.1-449.6	-	5.45^{ns}	0.00^{ns}	5.45^{ns}	19.02**
MDJ	72.3-408.8		-	5.45^{ns}	0.00^{ns}	8.06*
MDB	113.7-450.2			-	5.45^{ns}	19.02**
CND	81.8-418.3				-	8.06*
ChM	57.6 - 281.6					-

Continued

Continued from Table 1

Diagnostic method	Optimal range	Chi-square				
		DB	MDJ	MDB	CND	ChM
	(mg kg^{-1})					
	Mn					
DJ	409.5-765.2	3.14^{ns}	0.00^{ns}	2.51^{ns}	0.00^{ns}	6.71*
DB	328.3-684.1	-	3.14^{ns}	0.03^{ns}	3.14^{ns}	17.39**
MDJ	420.9-776.6		-	2.51^{ns}	0.00^{ns}	6.71*
MDB	336.8-692.5			-	2.51^{ns}	15.89**
CND	392.1-747.8				-	6.71*
ChM	516.8-653.4					-
	Zn					
DJ	51.7-168.1	0.11^{ns}	19.98**	0.00^{ns}	42.69**	-
DB	31.7-148.1	27.82**	0.54^{ns}	26.10**	12.09**	-
MDJ	53.8-170.2	-	21.57**	0.11^{ns}	46.11**	-
MDB	33.0-149.5		-	19.98**	13.39**	-
CND	51.2-167.6			-	42.69**	-
ChM	24.0-73.5				-	-
	Mo					
DJ	1.1-3.1	2.06^{ns}	0.00^{ns}	2.06^{ns}	0.80^{ns}	5.59^{ns}
DB	0.9-2.8	-	2.06^{ns}	0.00^{ns}	0.29^{ns}	10.31**
MDJ	1.1-3.0		-	2.06^{ns}	0.80^{ns}	5.59^{ns}
MDB	0.9-2.8			-	0.29^{ns}	10.31**
CND	1.0-2.9				-	7.91*
ChM	1.4-2.1					-
	Cl					
DJ	0.2-0.4	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.00^{ns}	14.02**
DB	0.2-0.4	-	0.00^{ns}	0.00^{ns}	0.00^{ns}	14.02**
MDJ	0.2-0.4		-	0.00^{ns}	0.00^{ns}	14.02**
MDB	0.2-0.4			-	0.00^{ns}	14.02**
CND	0.2-0.4				-	14.02**
ChM	0.2-0.3					-

**; *Significant at p ≤ 0.01 and p ≤ 0.05, respectively by the Chi-square likelihood ratio test (G); nsNon-significant; DJ - DRIS Jones; DB - DRIS Beaufils; MDJ - M-DRIS Jones; MDB - M-DRIS Beaufils; CND - Compositional Nutrient Diagnosis; ChM - Mathematical Chance

because they evaluate nutritional balance differently from the ChM method. According to Oliveira et al. (2019), nutritional diagnoses that consider the nutrient balance and are developed considering the specificities of the crop and region are necessary for efficient nutritional management.

This indicates that the excess and deficient classes estimated by the ChM method are overestimated, leading to misdiagnosis of these nutrients. When an incorrect nutritional assessment identifies a nutrient deficiency, its application is recommended, which can become excessive, resulting in nutritional imbalance and reduced productivity. Likewise, when there is a mistaken diagnosis of excess, the application of nutrients is not recommended, potentially causing nutritional deficiency and impacting productivity (Silva et al., 2021; Traspadini et al., 2022). This leads to wastage of resources and causes environmental problems (Traspadini et al., 2022).

In the present study, the DJ, DB, MDJ, MDB, and CND methods enabled the development of sufficient ranges for Mo (Tables 1, 2, and 3). These results address a gap in the current recommendation of Mo for mango tree cultivation in the sub-middle region of the São Francisco Valley.

The nutritional diagnoses of the DJ, MDJ, and CND methods were consistent for all nutrients and cultivars (Tables 1, 2, and 3). However, they were inconsistent with the diagnoses of the DB and MDB methods for some micronutrients (Cu, Fe, and Zn) in the Tommy Atkins (Table 1), B, Cu, Fe, and Mo in Kent (Table 2), and Zn in Keitt cultivar (Table 3). This difference may be associated with the correction applied to the

Table 2. Optimum range of nutrients and chi-square likelihood ratio test of the cultivar Kent by evaluated diagnostic methods in commercial orchards of mango trees

Diagnostic method	Optimal range	Chi-square				
		DB	MDJ	MDB	CND	ChM
	(g kg^{-1})					
	N					
DJ	13.4-16.7	0.68^{ns}	0.00^{ns}	0.68^{ns}	0.06^{ns}	7.04*
DB	12.7-16.0	-	0.68^{ns}	0.00^{ns}	0.37^{ns}	10.15**
MDJ	13.4-16.7		-	0.68^{ns}	0.06^{ns}	7.04*
MDB	12.6-16.0			-	0.37^{ns}	10.15**
CND	13.2-16.6				-	8.32*
ChM	15.1-17.1					-
	P					
DJ	1.7-2.1	1.50^{ns}	1.72^{ns}	1.50^{ns}	0.00^{ns}	16.77**
DB	1.6-2.0	-	0.04^{ns}	0.00^{ns}	1.50^{ns}	23.11**
MDJ	1.6-2.1		-	0.04^{ns}	1.72^{ns}	22.26**
MDB	1.6-2.0			-	1.50^{ns}	23.11**
CND	1.7-2.1				-	16.77**
ChM	2.1-2.3					-
	K					
DJ	14.0-17.9	2.17^{ns}	0.00^{ns}	2.17^{ns}	2.40^{ns}	15.33**
DB	12.8-16.7	-	2.17^{ns}	0.00^{ns}	0.71^{ns}	26.68**
MDJ	14.1-18.0		-	2.17^{ns}	2.40^{ns}	15.33**
MDB	12.9-16.8			-	0.71^{ns}	26.68**
CND	13.7-17.6				-	19.52**
ChM	16.4-18.2					-
	Ca					
DJ	18.0-30.6	0.04^{ns}	0.00^{ns}	0.04^{ns}	2.52^{ns}	16.22**
DB	18.6-31.2	-	0.04^{ns}	0.00^{ns}	1.89^{ns}	17.83**
MDJ	17.8-30.4		-	0.04^{ns}	2.52^{ns}	16.22**
MDB	18.6-31.2			-	1.89^{ns}	17.83**
CND	19.7-32.3				-	29.90**
ChM	21.3-26.6					-
	Mg					
DJ	2.2-2.8	3.00^{ns}	0.00^{ns}	1.63^{ns}	0.00^{ns}	32.70**
DB	2.0-2.6	-	3.00^{ns}	1.20^{ns}	3.00^{ns}	40.86**
MDJ	2.2-2.8		-	1.63^{ns}	0.00^{ns}	32.70**
MDB	2.0-2.7			-	1.63^{ns}	47.00**
CND	2.2-2.8				-	32.70**
ChM	2.8-3.1					-
	S					
DJ	1.0-2.1	0.78^{ns}	0.00^{ns}	0.78^{ns}	0.00^{ns}	18.35**
DB	1.2-2.3	-	0.78^{ns}	0.00^{ns}	0.78^{ns}	13.14**
MDJ	1.0-2.1		-	0.78^{ns}	0.00^{ns}	18.35**
MDB	1.2-2.3			-	0.78^{ns}	13.14**
CND	1.0-2.1				-	18.35**
ChM	1.8-2.7					-
	(mg kg^{-1})					
	B					
DJ	128.1-298.7	6.05*	0.00^{ns}	6.05*	0.00^{ns}	0.73^{ns}
DB	97.3-267.9	-	6.05*	0.00^{ns}	6.05*	8.05*
MDJ	130.5-301.1		-	6.05*	0.00^{ns}	0.73^{ns}
MDB	98.2-268.8			-	6.05*	8.05*
CND	129.3-299.9				-	0.73^{ns}
ChM	129.0-212.6					-
	Cu					
DJ	8.8-19.2	14.45**	0.23^{ns}	14.45**	0.00^{ns}	23.06**
DB	5.3-15.8	-	15.11**	0.00^{ns}	14.45**	24.30**
MDJ	9.0-19.4		-	15.11**	0.23^{ns}	19.68**
MDB	5.4-15.9			-	14.45**	24.30**
CND	8.7-19.2				-	23.06**
ChM	7.3-12.1					-
	Fe					
DJ	93.1-213.5	12.45**	0.00^{ns}	12.45**	0.05^{ns}	13.32**
DB	44.2-164.6	-	12.45**	0.00^{ns}	11.39**	5.23^{ns}
MDJ	93.5-213.9		-	12.45**	0.05^{ns}	13.32**
MDB	44.4-164.8			-	11.39**	5.23^{ns}
CND	88.5-208.9				-	13.09**
ChM	72.1-129.3					-

Continued

Continued from Table 2

Diagnostic method	Optimal range	Chi-square				
		DB	MDJ	MDB	CND	ChM
	(mg kg^{-1})					
	Mn					
DJ	495.2-873.6	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.47^{ns}	5.05^{ns}
DB	482.3-860.7	-	0.00^{ns}	0.00^{ns}	0.47^{ns}	5.05^{ns}
MDJ	489.2-867.7		-	0.00^{ns}	0.47^{ns}	5.05^{ns}
MDB	481.3-859.7			-	0.47^{ns}	5.05^{ns}
CND	465.2-843.6				-	2.89^{ns}
ChM	387.1-689.3					-
	Zn					
DJ	43.7-108.9	0.72^{ns}	0.00^{ns}	0.72^{ns}	0.00^{ns}	15.78**
DB	38.1-103.3	-	0.72^{ns}	0.00^{ns}	0.72^{ns}	11.66**
MDJ	42.1-107.3		-	0.72^{ns}	0.00^{ns}	15.78**
MDB	37.3-102.6			-	0.72^{ns}	11.66**
CND	43.3-108.5				-	15.78**
ChM	24.5-76.7					-
	Mo					
DJ	0.02-3.4	14.25**	0.00^{ns}	14.25**	1.40^{ns}	12.30**
DB	0.4-3.8	-	14.25**	0.00^{ns}	9.07*	24.46**
MDJ	0.02-3.4		-	14.25**	1.40^{ns}	12.30**
MDB	0.4-3.8			-	9.07*	24.46**
CND	0.06-3.4				-	10.42**
ChM	0.03-1.4					-
	Cl					
DJ	0.2-0.4	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.90^{ns}
DB	0.2-0.4	-	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.90^{ns}
MDJ	0.2-0.4		-	0.00^{ns}	0.00^{ns}	0.90^{ns}
MDB	0.2-0.4			-	0.00^{ns}	0.90^{ns}
CND	0.2-0.4				-	0.90^{ns}
ChM	0.25-0.41					-

**; *Significant at $p \leq 0.01$ and $p \leq 0.05$, respectively by the Chi-square likelihood ratio test (G); ^{ns}Non-significant; DJ - DRIS Jones; DB - DRIS Beaufils; MDJ - M-DRIS Jones; MDB - M-DRIS Beaufils; CND - Compositional Nutrient Diagnosis; ChM - Mathematical Chance

Beaufils formula (1973), in which the A/B nutrient ratio in the sample is lower than the norm, resulting in a slight deviation from the average values determined (Maia, 1999). This deviation is reflected by a greater intensity for micronutrients, because the range between the deficiency limits and excess was narrow, as observed in this study.

Politi et al. (2013) performed nutritional diagnoses for the cultivar Tommy Atkins, in the sub-middle São Francisco Valley region using the DRIS and CND methods. However, the study was generic, where mango trees were sampled from several orchards and farms throughout the region between 1997 and 1999. These orchards had a low technological level, utilized different spacing arrangements, and involved less nutrient-demanding and less productive plants. The methods evaluated in the present study were used under specific conditions of cultivar, site, climate, and cultivation practices, and were employed in mangoes at a high technological level. This is an evolution in relation to previous studies.

PCA showed a similarity among the DJ, MDJ, and CND diagnostic methods for all cultivars, as they belonged to quadrant 4. The DB and MDB methods were associated, and for Tommy Atkins and Keitt cultivars, the methods belonged to quadrant 1 and for Kent, they belonged to quadrant 2 (Figure 1).

The DB and MDB methods were farther from the center and closer to the principal component 1 axis, belonging to quadrants 1 and 2 (Figure 1), indicating their importance in explaining nutrient variations and efficiency in multinutrient

Table 3. Optimum range of nutrients and chi-square likelihood ratio test of the cultivar Keitt by evaluated diagnostic methods in commercial orchards of mango trees

Diagnostic method	Optimal range	Chi-square				
		DB	MDJ	MDB	CND	ChM
	(g kg^{-1})					
	N					
DJ	14.5-21.5	0.24^{ns}	0.24^{ns}	0.24^{ns}	0.06^{ns}	24.13**
DB	14.7-21.7	-	0.00^{ns}	0.00^{ns}	0.06^{ns}	20.41**
MDJ	14.8-21.8		-	0.00^{ns}	0.06^{ns}	20.41**
MDB	14.8-21.8			-	0.06^{ns}	20.41**
CND	14.6-21.6				-	22.22**
ChM	22.6-25.0					-
	P					
DJ	1.6-2.2	1.17^{ns}	1.09^{ns}	1.09^{ns}	5.01^{ns}	10.20**
DB	1.7-2.2	-	0.11^{ns}	0.11^{ns}	1.40^{ns}	4.59^{ns}
MDJ	1.7-2.3		-	0.00^{ns}	1.54^{ns}	4.97^{ns}
MDB	1.7-2.3			-	1.54^{ns}	4.97^{ns}
CND	1.8-2.3				-	0.99^{ns}
ChM	2.0-2.4					-
	K					
DJ	10.8-24.6	5.24^{ns}	0.00^{ns}	5.24^{ns}	0.00^{ns}	11.10**
DB	7.7-21.5	-	5.24^{ns}	0.00^{ns}	5.24^{ns}	5.85^{ns}
MDJ	11.1-24.8		-	5.24^{ns}	0.00^{ns}	11.10**
MDB	7.9-21.7			-	5.24^{ns}	5.85^{ns}
CND	10.8-24.5				-	11.10**
ChM	9.0-15.4					-
	Ca					
DJ	23.5-30.4	0.10^{ns}	0.08^{ns}	0.10^{ns}	0.08^{ns}	18.54**
DB	24.3-31.2	-	0.07^{ns}	0.00^{ns}	0.07^{ns}	18.58**
MDJ	23.6-30.5		-	0.07^{ns}	0.00^{ns}	20.80**
MDB	24.3-31.2			-	0.07^{ns}	18.58**
CND	23.5-30.5				-	20.80**
ChM	29.2-32.2					-
	Mg					
DJ	2.0-2.5	0.07^{ns}	0.00^{ns}	0.07^{ns}	0.07^{ns}	0.56^{ns}
DB	2.0-2.6	-	0.07^{ns}	0.00^{ns}	0.00^{ns}	1.62^{ns}
MDJ	2.0-2.5		-	0.07^{ns}	0.07^{ns}	0.56^{ns}
MDB	2.0-2.6			-	0.00^{ns}	1.62^{ns}
CND	2.0-2.6				-	1.62^{ns}
ChM	2.1-2.6					-
	S					
DJ	1.4-2.3	1.18^{ns}	0.10^{ns}	1.18^{ns}	0.00^{ns}	2.54^{ns}
DB	1.2-2.1	-	1.62^{ns}	0.00^{ns}	1.18^{ns}	1.42^{ns}
MDJ	1.4-2.4		-	1.62^{ns}	0.10^{ns}	3.65^{ns}
MDB	1.2-2.1			-	1.18^{ns}	1.42^{ns}
CND	1.4-2.3				-	2.54^{ns}
ChM	1.3-1.9					-
	(mg kg^{-1})					
	B					
DJ	95.0-154.9	1.02^{ns}	0.09^{ns}	0.34^{ns}	0.00^{ns}	9.49**
DB	107.3-167.3	-	1.66^{ns}	0.32^{ns}	1.02^{ns}	15.56**
MDJ	91.0-150.9		-	0.78^{ns}	0.09^{ns}	7.84*
MDB	105.5-165.4			-	0.34^{ns}	13.10**
CND	95.0-154.9				-	9.49**
ChM	49.8-115.7					-
	Cu					
DJ	10.0-18.9	0.27^{ns}	0.00^{ns}	0.27^{ns}	0.00^{ns}	3.53^{ns}
DB	11.0-19.9	-	0.27^{ns}	0.00^{ns}	0.27^{ns}	2.24^{ns}
MDJ	10.0-18.9		-	0.27^{ns}	0.00^{ns}	3.53^{ns}
MDB	11.0-19.9			-	0.27^{ns}	2.24^{ns}
CND	10.0-19.0				-	3.53^{ns}
ChM	12.0-16.5					-
	Fe					
DJ	91.5-165.6	0.94^{ns}	0.57^{ns}	0.84^{ns}	0.00^{ns}	10.42**
DB	109.1-183.2	-	2.92^{ns}	0.82^{ns}	0.94^{ns}	14.00**
MDJ	81.3-155.4		-	2.75^{ns}	0.57^{ns}	7.89*
MDB	104.7-178.8			-	0.84^{ns}	14.93**
CND	91.5-165.6				-	10.42**
ChM	42.2-285.2					-

Continued

Continued from Table 3

Diagnostic method	Optimal range	Chi-square				
		DB	MDJ	MDB	CND	ChM
	(mg kg^{-1})					
	Mn					
DJ	446.5-713.3	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.00^{ns}	23.39^{**}
DB	436.7-703.5	-	0.00^{ns}	0.00^{ns}	0.00^{ns}	23.39^{**}
MDJ	448.1-714.9		-	0.00^{ns}	0.00^{ns}	23.39^{**}
MDB	437.5-704.3			-	0.00^{ns}	23.39^{**}
CND	439.4-706.2				-	23.39^{**}
ChM	791.1-945.5					-
	Zn					
DJ	55.8-219.0	7.16^{*}	0.00^{ns}	7.16^{*}	0.00^{ns}	13.80^{**}
DB	39.9-203.0	-	7.16^{*}	0.00^{ns}	7.16^{*}	5.06^{ns}
MDJ	55.6-218.7		-	7.16^{*}	0.00^{ns}	13.80^{**}
MDB	39.7-202.9			-	7.16^{*}	5.06^{ns}
CND	55.0-218.2				-	13.80^{**}
ChM	32.9-103.2					-
	Mo					
DJ	0.9-3.2	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.00^{ns}	22.79^{**}
DB	0.6-2.9	-	0.00^{ns}	0.00^{ns}	0.00^{ns}	22.79^{**}
MDJ	0.9-3.2		-	0.00^{ns}	0.00^{ns}	22.79^{**}
MDB	0.6-2.9			-	0.00^{ns}	22.79^{**}
CND	0.8-3.1				-	22.79^{**}
ChM	0.1-1.5					-
	Cl					
DJ	0.2-0.4	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.00^{ns}	6.79^{*}
DB	0.2-0.4	-	0.00^{ns}	0.00^{ns}	0.00^{ns}	6.79^{*}
MDJ	0.2-0.4		-	0.00^{ns}	0.00^{ns}	6.79^{*}
MDB	0.2-0.4			-	0.00^{ns}	6.79^{*}
CND	0.2-0.4				-	6.79^{*}
ChM	0.3-0.4					-

**; *Significant at $p \leq 0.01$ and $p \leq 0.05$, respectively by the Chi-square likelihood ratio test (G); ^{ns}Non-significant; DJ - DRIS Jones; DB - DRIS Beaufils; MDJ - M-DRIS Jones; MDB - M-DRIS Beaufils; CND - Compositional Nutrient Diagnosis; ChM - Mathematical Chance

diagnosis. Therefore, they are more sensitive in detecting possible nutritional disorders.

Furthermore, the DRIS and M-DRIS methods for the Kent cultivar were associated with the IN, IP, IK, ICa, IMg, ICu, IFe, IB, and ICl indices, the DRIS and M-DRIS methods for Tommy Atkins and Keitt were related to the IP, IK, ICu, ICl, IZn, and IMn indices, and the DJ, MDJ, and CND methods for all cultivars were associated with the IS and IMo indices (Figure 1). This shows the greater efficacy of the nutritional diagnosis of mango orchards using the DRIS and M-DRIS methods established by Beaufils and adjusted by Maia.

The association between the groups is evident in the similarity dendrogram. Three groups were formed: the first group comprised the DJ, MDJ, and CND methods for all cultivars; the second group comprised DB and MDB methods for the cultivars Tommy Atkins and Keitt; and the third group comprised the DB and MDB methods for the cultivar Kent (Figure 2).

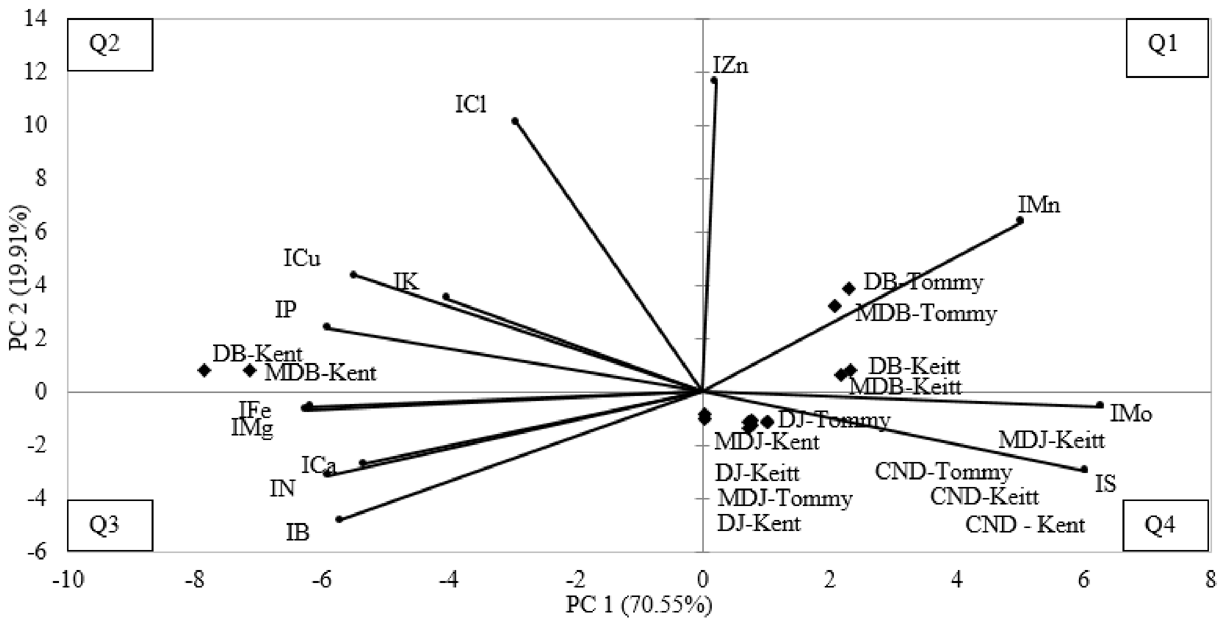
The similarity between the DJ, MDJ, and CND methods (Figure 2) indicates that these methods can be used regardless of the cultivar.

The DB and MDB methods did not influence the nutritional diagnosis of the Tommy Atkins and Keitt cultivars; however, the Kent cultivar responded differently (Figure 2). Therefore, nutritional diagnosis using these methods must be specifically established for the Kent cultivar. The performance of cultivars is influenced by the genetics and environment because they affect the nutritional requirements and dynamics of nutrient absorption (Alexandre et al., 2015; Oliveira et al., 2019).

A significant correlation between NBIm and the productivity of Kent orchards was observed when the DB and MDB methods were applied, as the productivity along with DB and MDB methods formed a single group (Figure 3B).

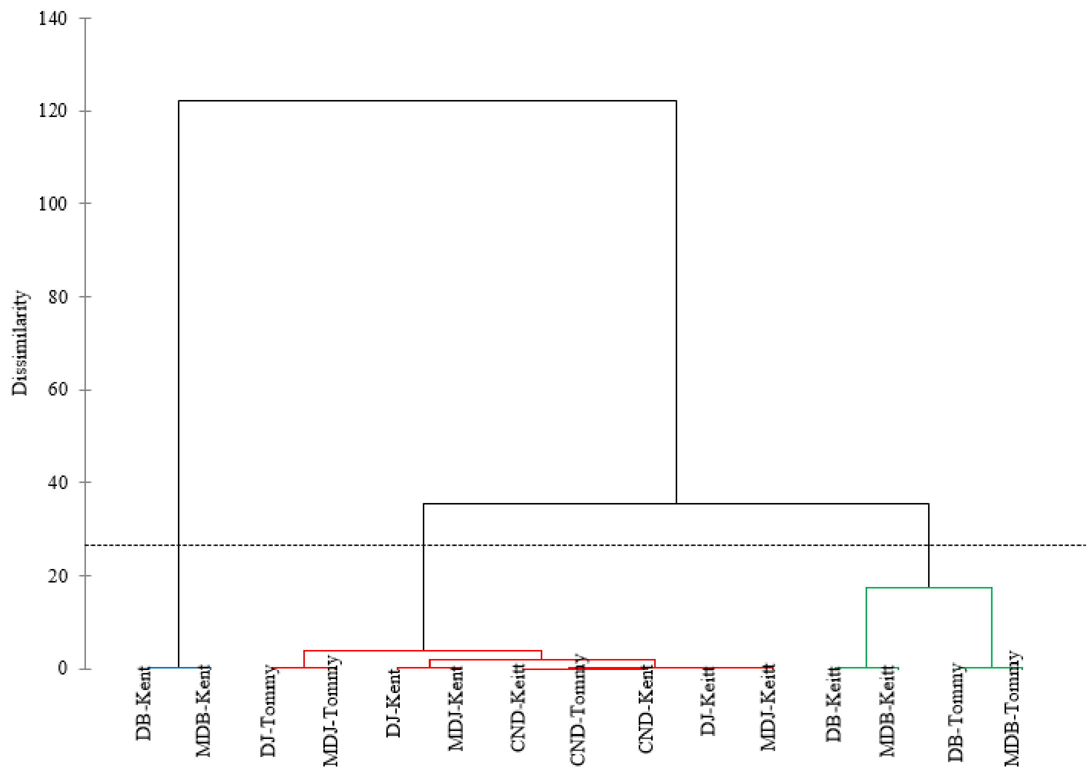
This indicated that the productivity of the Kent cultivar was significantly associated with the nutritional status of the plants. However, there was no significant correlation between Tommy Atkins and Keitt cultivars (Figures 3A and C), suggesting that factors other than plant nutrition interfered with their productivity (Beaufils, 1973; Villaseñor et al., 2020; Rezende et al., 2023).

PCA results showed that the diagnostic method DB, updated by Maia (1999), was efficient in detecting nutritional



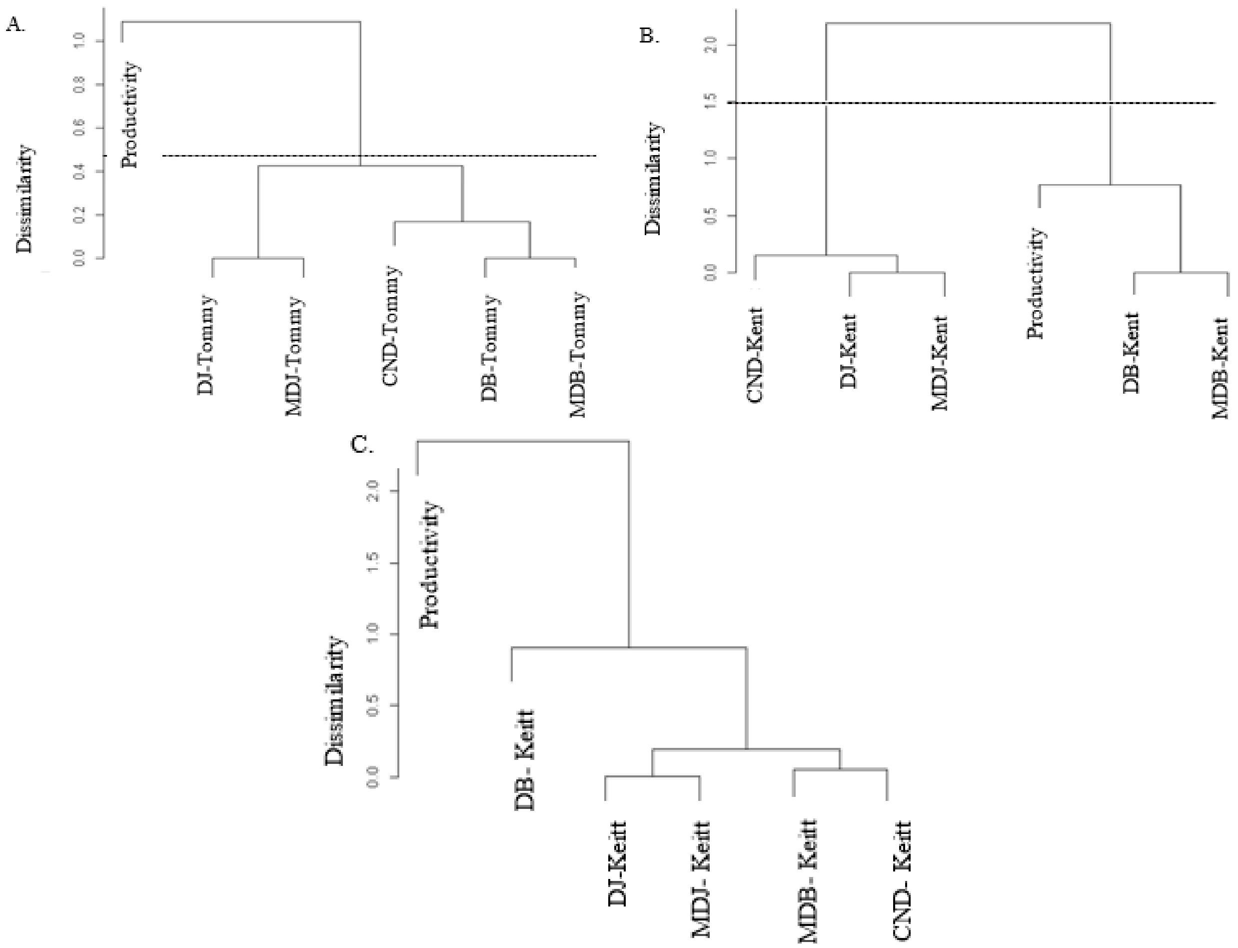
DJ - DRIS Jones; DB - DRIS Beaufils; MDJ - M-DRIS Jones; MDB - M-DRIS Beaufils; CND - Compositional Nutrient Diagnosis; Q1, Q2, Q3 and Q4 - Quadrants 1, 2, 3 and 4 respectively; PC 1 and PC 2 - Principal Components 1 and 2, respectively

Figure 1. Dispersion of DRIS indices (IN, IP, IK, ICa, IMg, IS, IB, ICu, IFe, IMn, IZn, ICl and IMo) and evaluated diagnostic methods of cultivars Tommy Atkins, Kent and Keitt mango tree in commercial orchards



DJ - DRIS Jones; DB - DRIS Beaufils; MDJ - M-DRIS Jones; MDB - M-DRIS Beaufils; CND - Compositional Nutrient Diagnosis

Figure 2. Similarity dendrogram showing the formation of groups according to the evaluated diagnostic methods of cultivars Tommy Atkins, Kent and Keitt mango tree in commercial orchards



DJ - DRIS Jones; DB - DRIS Beaufils; MDJ - M-DRIS Jones; MDB - M-DRIS Beaufils; CND - Compositional Nutrient Diagnosis

Figure 3. Similarity dendrogram showing the formation of groups according to the evaluated diagnostic methods and their relationship with the productivity of Tommy Atkins (A), Kent (B) and Keitt (C) mango tree cultivars in commercial orchards

Table 4. Correlation, absolute and relative variance between the principal components and the nutritional indices (IN, IP, IK, ICa, IMg, IS, IB, ICu, IFe, IMn, IZn, IMo and ICl) established by the DRIS Beaufils method updated by Maia (1999) of cultivars Tommy Atkins, Kent and Keitt mango tree in commercial orchards

Variable	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC1	PC2	PC3
	Tommy Atkins				Kent			Keitt		
IN	0.70*	0.07	-0.57	-0.11	0.89*	0.11	-0.25	0.84*	0.36	-0.11
IP	0.27	-0.81*	0.27	-0.26	0.91*	-0.15	0.10	0.74*	-0.03	-0.44
IK	0.72*	0.16	0.44	-0.18	0.66	-0.55	-0.15	-0.42	0.73*	0.25
ICa	-0.19	-0.57	0.12	0.07	0.38	0.11	0.41	0.88*	-0.12	-0.17
IMg	0.78*	0.11	0.20	-0.05	0.90*	0.01	-0.22	0.65	0.32	0.44
IS	0.08	0.91*	-0.07	0.18	-0.30	0.89*	-0.18	0.32	0.90*	0.08
IB	0.63	-0.16	-0.03	-0.19	0.36	0.15	0.80*	0.72*	-0.51	-0.04
ICu	-0.24	0.04	-0.20	0.22	0.53	-0.03	-0.42	-0.14	-0.82*	-0.10
IFe	-0.51	0.07	0.68	-0.02	0.22	-0.58	-0.17	-0.38	0.32	-0.72*
IMn	-0.43	-0.13	-0.24	-0.74	0.15	0.22	0.74*	0.28	-0.42	0.56
IZn	-0.60	0.26	0.49	-0.14	0.09	-0.38	0.73*	-0.85*	0.12	-0.40
IMo	-0.51	-0.26	-0.63	0.15	-0.51	-0.80*	-0.15	-0.71*	-0.35	0.00
ICl	0.22	-0.47	0.17	0.74	0.34	0.86*	-0.19	-0.51	0.03	0.75*
Absolute variance (%)	25.26	17.44	14.77	10.74	30.90	23.83	18.16	38.34	22.86	16.04
Cumulative variance (%)	25.26	42.70	57.47	68.21	30.90	54.73	72.89	38.34	61.20	77.24

*Values ≥ |0.70| are significant; PC - Principal component

imbalances for the nutrients N, P, K, Mg, and S in the Tommy Atkins; N, P, Mg, S, B, Mn, Zn, Mo, and Cl in Kent; and N, P, K, Ca, S, B, Cu, Fe, Zn, Mo, and Cl in Keitt cultivar (Table 4).

This indicates that these nutrients were sensitive to the application of the DB method updated by Maia, as it showed diagnostic sensitivity, reinforcing the highest efficiency of this method in detecting nutritional disorders. This method has the potential for use in assessing the nutritional status of mango orchards in the sub-middle region of the São Francisco Valley.

The response of a several nutrients indicates that the diagnosis of nutritional imbalance of a particular nutrient is strongly dependent on others (Manzoor et al., 2022). The diagnosis must be comprehensive and thorough, ensuring that no other nutrients influence this interaction, allowing the farmer to deal with these interactions without concern about the influence of another non-evaluated nutrient (Saúco, 2020). This shows the efficiency of the diagnostic method selected in the present study, a multinutrient approach that considers the interrelation of nutrient contents (nutritional balance). This method was developed under specific conditions of climate, soil, cultivar, and production system.

Conclusions

1. The DRIS Jones (DJ), DRIS Beaufils (DB), DRIS Jones (MDJ), M-DRIS Beaufils (MDB), Compositional nutrient diagnosis (CND) and Mathematical chance (ChM) diagnostic methods generated sufficient nutritional ranges for the evaluated cultivars.

2. The nutritional diagnoses of the DB and MDB methods updated by Maia were similar, but discordant between DJ, MDJ, and CND methods.

3. The DB diagnostic method updated by Maia proved to be more consistent in the nutritional assessment of mango trees.

4. Nutrients N, P, K, Mg, and S in the Tommy Atkins; N, P, Mg, S, B, Mn, Zn, Mo, and Cl in Kent; and N, P, K, Ca, S, B, Cu, Fe, Zn, Mo, and Cl in Keitt cultivar showed significant responses to the application of the DRIS diagnostic method developed by Beaufils and updated by Maia, which is sensitive in detecting nutritional disorders of these nutrients.

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