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Nutritional Status of Mango by the Boundary Line and Mathematical Chance Methods

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Abstract

The objective of this study was to establish the optimal content and sufficiency range of the nutrients in mango of the cultivars Tommy Atkins, Kent and Keitt in the Sub-middle San Francisco Valley by the Boundary Line and Mathematical Chance methods and compare them to other nutritional diagnosis methods used in Brazil and Australia. The study was carried out in seven commercial farms cultivated with mangoes, located in the Sub-Middle São Francisco Valley. The database used was formed from the results of the analysis of leaves and the productivity of irrigated mango trees. For Boundary Line and Mathematical Chance methods were estimated the optimal nutrient content, as well as the sufficiency range and later were compared between them and with the optimal contents and sufficiency ranges recommended in literature. The optimal nutrient contents for mango tree cultivars by the Boundary Line and Mathematical Chance methods were close to the mean contents of the high productivity population, and also disagreed of the diagnoses of the methods the literature, suggesting that these methods were more consistent and expressed better the regional management of mango tree cultivation in the Sub-Middle São Francisco Valley. The Mo sufficiency range developed by the Boundary Line and Mathematical Chance methods made it possible to assess the nutritional status of this nutrient in the region. These results show the importance of creating and validating specific nutritional standards for the edapho-climatic conditions of the Valley, taking into account the production management and nutritional requirement of the cultivars.

Keywords: *Mangifera indica* L, semiarid, nutritional diagnosis, nutritional standards

1. Introduction

Northeast region of Brazil concentrates 75% of the Brazilian mango production, with emphasis on the São Francisco Valley in the northeastern semiarid, that is the largest producer and exporter of mango of the country (Carvalho, Lima, Lobo, Mudo, & Santos 2020; Ferreira et al., 2020; IBGE, 2020; Oliveira, 2020; Silva et al., 2020).

Considering the importance of this region and mango farming for the Brazilian fruit agribusiness, it is necessary to improve management practices in order to maximize productivity and use inputs in a rational and sustainable. In this scenario, the need for efficient nutritional management is highlighted, as commercial crops with high productive capacity have high nutritional demand (Almeida et al., 2014; Gomes et al., 2016; Oliosi et al., 2020).

Nutritional assessment for nutrients efficient management has been based on reference values (Critical Level and Sufficiency Range) proposed by Quaggio (1996), Malavolta, Vitti, and Oliveira (1997), Medeiros, Amorim, Silva, Dantas, and Guerra (2004), and Winston (2007). However, these methods do not consider the nutritional balance and are very sensitive to variations of the environmental factors, which can interfere with the accuracy of nutritional diagnoses (Villaseñor, Prado, Silva, Carrillo, & Durango, 2020). Therefore, proposals such as the Boundary Line (BL) and Mathematical Chance (ChM) methods have emerged with the aim of improving nutritional diagnosis.

BL method associate the nutritional contents to crop productivity, through a second degree polynomial function (Walworth, Letzsch, & Summer, 1986). In this approach, some outliers are removed, leaving only the points on the curve boundary. In addition, BL method allows determining optimal ranges or levels of nutrients in plant tissue and mathematically estimate the maximum yield for a given nutritional content (Almeida, de Deus, Corrêa, Crisostomo, & Neves, 2016; Ali, 2018). This makes this method more advantageous.

ChM method allows the classification of the leaf contents of the nutrients in ascending order and the relationship of these contents with the productivity (Wadt, Alvarez, Novais, Fonseca, & Barros, 1998). This indicates the range of nutritional values most associated with the expectation of an increase in productivity (Wadt et al., 1998; Urano et al., 2007; Serra, Marchetti, Vitorino, Novelino, & Camacho, 2010).

Nutritional standards was developd using BL for various agricultural crops such as mango, melon, soybean, cotton, cowpea, peanut, pitaya, palm, blueberry, grape, ficus-indica, eucalyptus, banana, orange, sugarcane and rice (Blanco-Macías et al., 2010; Bhat & Sujatha, 2013; Lafond, 2013; Myburgh & Howell, 2014; Almeida et al., 2016; Maia & Morais, 2016; Ali, 2018; Lima Neto, Neves, Martinez, Sousa, & Fernandes, 2019; Melo, Souza, Bastos, & Cardoso, 2020; Souza et al., 2020; Rodrigues Filho, Neves, Donato, & Guimarães, 2021) as well as using ChM (Urano et al., 2007; Serra et al., 2010; Camacho, Silveira, Camargo, & Natale, 2012; De Deus et al., 2012; Santos, Donha, Araújo, Lavres Junior, & Camacho 2013; Almeida et al., 2016). However, those studies are still scarce and was developed in conditions different this study. The edaphoclimatic conditions of the Sub-middle San Francisco Valley are peculiar due to the high temperatures and low rainfall.

We hypothesized that the nutritional standards and the nutritional assessment of the mango cultivars Tommy Atkins, Kent and Keitt using the BL and ChM methods are different from other methods used in Brazil and Australia due to management of fertilization used in the Sub-middle San Francisco Valley by the cultivation conditions different, soil and climate.

Therefore, the objective of this study was to establish the optimal content and sufficiency range of the nutrients N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, Mo and Cl in mango of the cultivars Tommy Atkins, Kent and Keitt in the Sub-middle San Francisco Valley by the Boundary Line and Mathematical Chance methods, as well as perform nutritional diagnosis using these methods and compare them to other nutritional diagnosis methods used in Brazil and Australia.

2. Method

The study was carried out in seven commercial farms cultivated with mangoes, located in the Sub-Middle São Francisco Valley (8.674725° S; 39.160595° W). The climate is of the BshW type, according to the Köppen and Geiger classification (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013), characterized by the warm semi-arid, steppe type, with summer rains. The average annual temperature is 26.7 °C and the average annual rainfall is 494 mm (Climate Weather, 2020).

The database used was formed from the results of the analysis of leaves and the productivity of irrigated mango trees in the 2015/2016 and 2016/2017 harvests in farm located in the municipality from Belém do São Francisco, in Pernambuco, Brazil. The number of leaf samples of the cultivars was composed of 66 leaf samples from cultivar Tommy Atkins, 52 samples from cultivar Kent and 38 samples from cultivar Keitt. The samples were collected totaling 156 leaf samples chosen at random from 156 orchards representative. Each sample consisted of four leaves collected in the median portion of the crown, in the center of the last vegetative flow (diagnostic leave of mango tree) and in the four cardinal points (Trani, Hiroce, & Bataglia, 1983) of 20 plants chosen at random in each orchard. The collections were carried out in the pre-flowering stage, before the application of calcium and potassium nitrate to break dormancy of the floral buds, in plants of five or more years of age, of uniform size and and adequate phytosanitary status (Politi et al., 2013).The leaf samples were packed in paper bags logging information such as identification of the variety, time of collection and orchard. The samples were sent to the laboratory and subjected to sequential cleaning with water, acidic solution (HCl 0.1 Mol L^{-1}) and distilled water. Subsequently, the samples were dried in an oven with mechanical air circulation and maintained at 65 °C until reach constant weight. Subsequently, the samples were ground in a Wiley mill and sieved in 1 mm mesh sieves (Politi et al., 2013). The chemical analysis of the plant tissue was carried out according to Malavolta et al. (1997), being determined the total leaf contents of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, Mo and Cl.

P, K, Ca, Mg, S, Cu, Fe, Mn, Zn were determined by digestion with nitroperchloric acid. The reading of Ca, Mg, S, Cu, Fe, Mn, Zn was performed by the atomic absorption spectrophotometer, of P by spectrometry in the presence of Mo blue and of K by the flame photometer. The N was determined by digestion with sulfuric acid and the reading performed in the spectrophotometer in the presence of indophenol blue. B and Mo were determined by dry digestion, where B reading was performed in a UV-VIS spectrometer in the presence of azomethine-H and Mo reading was performed in an atomic absorption spectrometer in the presence of a nitrous oxide-acetylene flame. Cl was determined wet and measured by titration using the Volhard Method.

Plants population of the cultivars Tommy Atkins, Kent and Keitt was divided into two subpopulations: high and low productivity. The separation limit of the two subpopulations was defined as the average productivity of the cultivar + 0.5 of the standard deviation (Urano et al., 2007). Therefore, the limit between the high and low productivity subpopulations for the cultivars Tommy Atkins, Kent and Keitt was 34, 33 and 45 Mg ha^{-1}, respectively. The high productivity subpopulation was composed of 36, 25 and 29% of the total samples of the cultivars Tommy Atkins, Kent and Keitt, respectively. The high productivity subpopulation should be composed of at least 10% of the total samples of the database (Letzsch & Sumner, 1984).

Mean (Md), minimum (Min), maximum (Max), standard deviation (s), coefficient of variation (CV), variance (s^2), coefficient of asymmetry (Asym), coefficient of kurtosis (Kurt) and normality test of Kolmogorov-Smirnov (p-value) were determined for productivity and leaf contents. This procedure was performed for each cultivar (Table 1).

Table 1. Mean (Md), minimum (Min), maximum (Max), standard deviation (s), coefficient of variation (CV), variance (s^2), asymmetry (Asym), kurtosis (kurt) and normality test (p-value) of the nutrient content in the leaves and of the productivity (Mg ha^{-1}) of the cultivars Tommy Atkins, Kent and Keitt in the population of high productivity in commercial orchards of mango trees in Belém do São Francisco, Pernambuco, Brazil

Variável	Md	Min	Max	s	CV	s^2	Asym	kurt	p-value
High productivity population (PHP)—Tommy Atkins (≥ 34 Mg ha^{-1})									
Productivity	39.47	34.18	48.23	3.98	10.10	15.91	0.76	2.70	0.71
N (g kg^{-1})	16.38	10.52	22.84	2.85	17.41	8.13	0.35	3.18	0.55
P (g kg^{-1})	2.03	1.17	3.68	0.60	29.53	0.36	0.79	4.19	0.26
K (g kg^{-1})	13.53	8.25	19.50	2.84	21.03	8.10	0.19	2.54	0.88
Ca (g kg^{-1})	29.53	17.50	65.00	8.79	29.78	77.36	2.80	12.28	0.09
Mg (g kg^{-1})	1.92	0.93	2.94	0.43	22.85	0.19	-0.08	3.13	0.98
S (g kg^{-1})	1.44	0.11	2.78	0.67	46.48	0.45	0.09	2.52	0.98
B (mg kg^{-1})	160.75	55.80	317.47	59.63	37.09	3556.65	0.26	3.50	0.95
Cu (mg kg^{-1})	12.21	5.50	30.50	5.94	48.68	35.36	1.73	5.64	0.08
Fe (mg kg^{-1})	250.05	82.98	1250.00	252.37	100.93	63694.34	2.96	11.72	0.02
Mn(mg kg^{-1})	569.99	224.63	1200.00	266.79	46.80	71181.05	0.82	2.99	0.36
Zn (mg kg^{-1})	109.43	32.00	420.00	87.30	79.78	7622.80	2.22	8.06	0.23
Mo(mg kg^{-1})	1.96	0.10	4.89	1.43	73.24	2.06	0.77	2.43	0.24
Cl (mg kg^{-1})	0.32	0.17	0.59	0.12	38.57	0.01	0.54	2.26	0.25
High productivity population (PHP)—Kent (≥ 33 Mg ha^{-1})									
Productivity	39.71	33.52	51.26	5.28	13.31	27.95	0.63	2.72	0.95
N (g kg^{-1})	14.90	8.95	17.28	2.49	16.75	6.24	-1.15	3.41	0.33
P (g kg^{-1})	1.87	1.37	2.27	0.30	16.11	0.09	-0.23	1.63	0.71
K (g kg^{-1})	15.65	9.75	21.00	2.90	18.53	8.42	-0.30	3.01	0.75
Ca (g kg^{-1})	26.04	5.50	42.50	9.43	36.21	88.98	-0.31	3.17	0.99
Mg (g kg^{-1})	2.53	1.75	3.33	0.47	18.64	0.22	-0.07	2.02	0.98
S (g kg^{-1})	1.59	0.12	3.00	0.82	51.51	0.67	-0.34	2.50	0.96
B (mg kg^{-1})	214.62	58.53	490.03	127.95	59.61	16371.63	1.10	3.47	0.20
Cu (mg kg^{-1})	13.98	8.50	36.00	7.85	56.17	61.70	2.03	5.98	0.04
Fe (mg kg^{-1})	148.67	75.14	415.00	90.30	60.74	8155.42	2.13	6.97	0.28
Mn(mg kg^{-1})	654.39	85.00	1300.00	283.84	43.37	80570.71	0.36	3.99	0.77
Zn (mg kg^{-1})	75.93	34.47	190.00	48.93	64.44	2394.35	1.58	4.11	0.17
Mo(mg kg^{-1})	2.00	0.03	8.49	2.71	135.19	7.36	1.55	4.04	0.14
Cl (mg kg^{-1})	0.29	0.08	0.42	0.10	34.83	0.01	-0.38	2.61	0,69
High productivity population (PHP)—Keitt (≥ 45 Mg ha^{-1})									
Productivity	51.50	46.42	64.32	5.63	10.94	31.77	1.23	3.33	0.32
N (g kg^{-1})	18.08	11.75	25.00	5.24	29.03	27.55	0.30	1.41	0.69
P (g kg^{-1})	2.05	1.46	2.81	0.43	21.41	0.19	0.57	2.43	0.72
K (g kg^{-1})	17.65	10.75	47.50	10.33	58.52	106.78	2.45	7.69	0.17
Ca (g kg^{-1})	27.01	20.25	33.75	5.20	19.28	27.12	-0.08	1.42	0.70
Mg (g kg^{-1})	2.30	1.63	3.05	0.40	17.50	0.16	0.34	2.50	0.91
S (g kg^{-1})	1.87	1.12	3.60	0.68	36.64	0.46	1.49	4.81	0.63
B (mg kg^{-1})	124.95	69.19	192.69	44.93	35.96	2019.53	0.31	1.58	0.63
Cu (mg kg^{-1})	14.51	3.00	30.00	6.68	46.04	44.65	0.75	4.19	0.80
Fe (mg kg^{-1})	128.56	42.20	260.00	55.57	43.23	3089.08	0.90	4.18	0.57
Mn(mg kg^{-1})	572.80	340.00	867.30	200.09	34.93	40038.54	0.31	1.47	0.73
Zn (mg kg^{-1})	136.62	32.91	455.00	122.37	89.56	14975.48	1.84	5.29	0.14
Mo(mg kg^{-1})	1.95	0.28	5.68	1.73	88.87	3.02	0.92	2.79	0.61
Cl (mg kg^{-1})	0.29	0.08	0.70	0.15	54.47	0.02	1.37	5.01	0.33

Fertilization management occurs as follows: The N is applied 50% post harvest; 30% on fructification and 20% after fructification. The P is applied 100% post harvest. The K is applied 25% post harvest; 25% before induction; 15% at flowering; 15% on fructification and 20% after fructification. The Ca is supplied via liming and gypsum, with the application of gypsum on the surface, after liming, and before induction, in order to raise the base saturation of the soil to 90%. To complement, Calcium Nitrate and Ca Chloride in the induction and production phases, respectively. Micronutrients are applied weekly via fertigation. Boric acid (17% B) is used as a source of B. Zinc Sulfate (20% Zn, 9% S) and Cheletized Zinc are used as sources of Zn. As a source of Fe, cheletized iron (Tradecorp Ferro or Qelmax Ferro) is used. As a source of Mn, Manganese Sulfate (30% Mn, 16% S) is used.

BL diagnostic method was carried out according to the following steps: graphs of productivity (y-axis) as a function of nutrient content in leaves (x-axis) were constructed to estimate the optimal nutrient content, as well as the sufficiency range. The outliers in the scatter plots were eliminated and the range of nutritional contents was subdivided into 10 equal intervals. The use of 10 representative observations in model development has the function of limiting the choice of points to the upper limit of point dispersion and maximizing the probability of developing significant models. Then, the highest point of each interval was selected and the new dataset was adjusted for second degree polynomial functions. The optimal nutrient content was obtained by solving the first derivative of the regression equation. The sufficiency ranges were obtained by solving the quadratic regression equation for the nutritional contents corresponding to 90% of the maximum fruit yield (Blanco-Macías et al., 2009; Bhat & Sujatha, 2013; Ali, 2018).

The optimal nutrient content and sufficiency range by method of the ChM were determined using the recommendations of Wadt et al. (1998). Nutrients contents in the leaves were classified in ascending order and distributed in a number of classes defined by the square root of the number of observations. The ranges of values for each class were determined by dividing the range of the nutrient contents evaluated by the number of classes established, according to the equation:

$$ChMi = [ChM\ (Ai/A) \times ChM\ (Ai/Ci)]^{0.5} \quad (1)$$

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 general total of orchards in class i.

After determining of the ChM for each class, the lower and upper limits of the nutrient content classes that presented the highest ChM were determined. The interval between these limits was considered the sufficiency range (Serra et al., 2010).

Optimal nutrient contents and the sufficiency ranges from the BL and ChM methods were compared between them and with the optimal contents and sufficiency ranges recommended by the authors Quaggio (1996), Malavolta et al. (1997), Medeiros et al. (2004) and Winston (2007). Thus, the nutrient content of the samples of cultivars Tommy Atkins (66), Kent (52) and Keitt (38) were distributed into adequate (Z), deficient (P) and excess (N) nutritional classes, which were established and interpreted by Fertilization Response Potential (FRP), method adapted from Wadt et al. (1998). Chi-square test was applied to statistically evaluate the comparison between the methods BL and ChM and these with the methods described in the literature (Guimarães et al., 2015), according to the following equation.

$$G = 2 \cdot \sum^{k} fo \cdot \ln(fo/fe) \quad (2)$$

Where, G = Chi-square likelihood ratio test (G test); fo = observed frequency; fe = expected frequency; K = number of classes.

3. Results and Discussion

The application of the BL method resulted in significant polynomial regression equations, with R^2 values ranging from 0.56 to 0.95 (Table 2). Optimum nutrient contents and sufficiency ranges were obtained on sheets of mango tree, based on values corresponding to 90% of the maximum production (Table 2).

Table 2. Polynomial equation, contents and optimum range of nutrients obtained by the Boundary Line method of the cultivars Tommy Atkins, Kent and Keitt in commercial orchards of mango trees in Belém do São Francisco, Pernambuco, Brazil

Nutrient	Regression coefficients[a]			R^2	P[b]	Optimum content	Sufficiency range (90% yield)	
	a	b	c				Minimum	Maximum
Tommy Atkins								
N ($g\ kg^{-1}$)	0.9648	8.82	26.93	0.71	0.0126	14.9	11.9	17.9
P ($g\ kg^{-1}$)	-39.55	154.27	-61.50	0.70	0.0500	2.0	**1.5**	**2.4**
K ($g\ kg^{-1}$)	-1.18	30.84	-106.24	0.66	0.0406	13.0	10.2	15.9
Ca ($g\ kg^{-1}$)	-0.61	34.82	-396.05	0.81	0.0029	28.2	24.3	32.1
Mg ($g\ kg^{-1}$)	-62.19	244.39	-141.10	0.95	0.0000	2.0	1.6	2.4
B ($mg\ kg^{-1}$)	-0.0022	0.71	26.04	0.62	0.0337	163.1	101.1	225.1
Cu ($mg\ kg^{-1}$)	-0.36	3.72	77.34	0.64	0.0480	5.1	0.2	10.0
Fe ($mg\ kg^{-1}$)	-0.0027	0.86	23.19	0.71	0.0139	159.0	100.8	217.2
Mn ($mg\ kg^{-1}$)	-0.0002	0.22	32.28	0.87	0.0020	564.7	345.5	783.9
Zn ($mg\ kg^{-1}$)	-0.003	0.5417	72.851	0.72	0.0759	90.2	33.3	147.2
Cl ($mg\ kg^{-1}$)	-561.29	351.87	41.22	0.72	0.0431	0.3	0.2	0.4
Kent								
N ($g\ kg^{-1}$)	-1.54	48.62	-308.97	0.68	0.0340	15.7	13.5	17.9
P ($g\ kg^{-1}$)	-35.38	142.12	-69.24	0.68	0.0337	2.0	**1.5**	**2.5**
K ($g\ kg^{-1}$)	-0.5113	13.362	-17.475	0.67	0,0613	13.1	9.4	16.8
Ca ($g\ kg^{-1}$)	-0.1482	8.4268	-43.285	0.60	0.0991	28.4	21.2	35.6
Mg ($g\ kg^{-1}$)	-32.132	138.99	-83.86	0.91	0,0074	2.1	1.7	2.6
B ($mg\ kg^{-1}$)	-0.0019	0.53	39.21	0.72	0.0427	141.0	77.3	204.7
Cu ($mg\ kg^{-1}$)	-0.63	13.89	-2.42	0.83	0.0019	10.9	7.5	14.3
Fe ($mg\ kg^{-1}$)	-0.0014	0.3687	49.36	0.70	0.0151	131.7	59.2	204.2
Mn ($mg\ kg^{-1}$)	-0.00009	0.15	42.87	0.95	0.0026	776.2	345.3	1207.1
Zn ($mg\ kg^{-1}$)	-0.0168	2.23	-10.51	0.68	0.0324	66.5	47.0	86.0
Cl ($mg\ kg^{-1}$)	-486.01	258.58	43.16	0.88	0.0437	0.27	0.14	0.40
Keitt								
N ($g\ kg^{-1}$)	-0.31	8.83	11.15	0.70	0.0286	14.7	10.5	19.0
P ($g\ kg^{-1}$)	-57.29	220.47	-129.27	0.70	0.0258	1.9	**1.5**	**2.3**
K ($g\ kg^{-1}$)	-0.62	18.45	-54.42	0.65	0.0420	14.8	11.2	18.4
Ca ($g\ kg^{-1}$)	-0.29	16.48	-146.62	0.73	0.0203	28.1	22.7	33.5
Mg ($g\ kg^{-1}$)	-55.12	243.33	-185.41	0.56	0.0500	2.3	2.0	2.6
B ($mg\ kg^{-1}$)	-0.002	0.4802	50.53	0.72	0.0109	120.0	57,0	183.0
Cu ($mg\ kg^{-1}$)	-0.1977	5.3823	45.05	0.70	0.0256	13.6	7.2	20.0
Fe ($mg\ kg^{-1}$)	-0.0324	9.8097	-666.69	0.89	0.0359	151.4	136.1	166.7
Mn ($mg\ kg^{-1}$)	-0.0003	0.2459	26.57	0.80	0.0168	409.8	249.7	570.0
Zn ($mg\ kg^{-1}$)	-0.0035	0.48	63.98	0.62	0.0389	65.1	8.4	121.8
Cl ($mg\ kg^{-1}$)	-251.17	116.71	64.76	0.92	0.0228	0.25	0.1	0.4

Note. [a] $Y = aX^2 + bX + c$, where, Y is the relative yield, X is the nutrient concentration, and a, b, and c are regression coefficients. [b] probability value.

The application of the BL method for Tommy Atkins mango showed that optimal nutrient contents and the sufficiency ranges of N, P, K, Ca, Mg, B, Cu, Fe, Mn, Zn and Cl were 14.9 g kg^{-1} (11.9-17.9); 2.0 g kg^{-1} (1.5-2.4); 13.0 g kg^{-1} (10.2-15.9); 28.2 g kg^{-1} (24.3-32.1); 2.0 g kg^{-1} (1.6-2.4); 163.1 mg kg^{-1} (101.1-225.1); 5.1 mg kg^{-1} (0.2-10.0); 159.0 mg kg^{-1} (100.8-217.2); 564.7 mg kg^{-1} (345.5-783.9); 90.2 mg kg^{-1} (33.3-147.2) and 0.3 mg kg^{-1} (0.2-0.4), respectively (Table 2).

The application of the BL method for Kent mango showed that optimal nutrient contents and the sufficiency ranges of N, P, K, Ca, Mg, B, Cu, Fe, Mn, Zn and Cl were 15.7 g kg^{-1} (13.5-17.9); 2.0 g kg^{-1} (1.5-2.5); 13.1 g kg^{-1} (9.4-16.8); 28.4 g kg^{-1} (21.2-35.6); 2.1 g kg^{-1} (1.7-2.6); 141.0 mg kg^{-1} (77.3-204.7); 10.9 mg kg^{-1} (7.5-14.3); 131.7 mg kg^{-1} (59.2-204.2); 776.2 mg kg^{-1} (345.3-1207.1); 66.5 mg kg^{-1} (47.0-86.0) and 0.27 mg kg^{-1} (0.14-0.40), respectively (Table 2).

The application of the BL method for Keitt mango showed that optimal nutrient contents and the sufficiency ranges of N, P, K, Ca, Mg, B, Cu, Fe, Mn, Zn and Cl were 14.7 g kg^{-1} (10.5-19.0); 1.9g kg^{-1} (1.5-2.3); 14.8 g kg^{-1} (11.2-18.4); 28.1 g kg^{-1} (22.7-33.5); 2.3 g kg^{-1} (2.0-2.6); 120.0 mg kg^{-1} (57.0-183.0); 13.6 mg kg^{-1} (7.2-20.0); 151.4 mg kg^{-1} (136.1-166.7); 409.8 mg kg^{-1} (249.7-570.0); 65.1 mg kg^{-1} (8.4-121.8) and 0.25 mg kg^{-1} (0.1-0.4), respectively (Table 2).

Optimal nutrient contents estimated by the BL method (Table 2) were very close to the average contents of these nutrients in the high productivity population (Table 1), except for N, Cu, Fe and Zn in all cultivars; K and Mn in cultivars Kent and Keitt; and B in cultivar Kent. This indicated that the BL method was useful for establishing critical contents and the nutrients sufficiency ranges in mango tree.

The highest average productivity of the Tommy Atkins mango tree when the ChM method was applied for the nutrients N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, Mo and Cl were obtained in classes 5, 1, 4, 8, 4, 8, 1, 5, 3, 7, 8, 7 and 4, respectively (Table 3). However, for the nutrients N, K, Mg, Cu and Cl, only 30, 30, 10, 30 and 30% of the plants within the respective classes were estimated as of high productivity. The highest percentages of high productivity plants were estimated in classes 1 and 2 (50%) for N, class 1 (100%) for K, class 1 (80%) for Mg, class 8 (100%) for Cu and classes 2, 3 and 7 (50%) for Cl (Table 3).

Table 3. Mathematical chance for different nutrient distribution classes of the cultivar Tommy Atkins in commercial orchards of mango trees in Belém do São Francisco, Pernambuco, Brazil

Class[a]	N					P					K				
	Li[b]	Ls[c]	P(Ai/Ci)[d]	Prod[e]	ChM[f]	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	----- g kg^{-1} -----			--- Mg ha^{-1} ---		--- g kg^{-1} ---			-- Mg ha^{-1} --		----- g kg^{-1} -----			-- Mg ha^{-1} --	
1	9.8	12.4	0.5	43.3	6.2	1.2	1.4	0.5	41.1	0.0	8.3	9.7	1.0	37.0	10.7
2	12.4	14.9	0.5	38.6	14.2	1.5	1.8	0.1	36.3	1.8	9.7	11.1	0.3	41.0	7.6
3	14.9	17.5	0.4	38.1	14.9	1.8	2.1	0.4	38.3	13.6	11.1	12.5	0.2	38.1	6.2
4	17.5	20.0	0.3	40.3	8.2	2.1	2.4	0.5	39.9	16.4	12.5	13.9	0.3	41.1	11.0
5	20.0	22.6	0.3	43.9	6.7	2.4	2.7	0.0	0.0	0.0	13.9	15.3	0.4	38.5	10.5
6	22.6	25.1	0.3	40.6	4.7	2.7	3.0	0.0	0.0	0.0	15.3	16.7	0.7	37.9	8.9
7	25.1	27.7	0.0	0.0	0.0	3.0	3.3	1.0	39.12	7.9	16.7	18.1	0.8	40.1	12.3
8	27.7	30.2	0.0	0.0	0.0	3.3	3.6	1.0	38.43	7.8	18.1	19.5	0.5	39.1	5.6

Class	Ca					Mg					S				
	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	----- g kg^{-1} -----			--- Mg ha^{-1} ---		--- g kg^{-1} ---			-- Mg ha^{-1} --		----- g kg^{-1} -----			-- Mg ha^{-1} --	
1	17.5	23.4	0.2	38.7	4.6	0.9	1.4	0.8	37.9	11.6	0.1	0.4	0.3	38.4	4.5
2	23.4	29.4	0.5	37.3	17.9	1.4	1.9	0.5	40.4	15.4	0.4	0.7	0.3	37.3	7.6
3	29.4	35.3	0.3	42.6	13.9	1.9	2.4	0.4	39.0	18.1	0.7	1.1	0.2	39.3	6.2
4	35.3	41.3	0.5	38.4	5.5	2.4	2.9	0.1	42.7	2.3	1.1	1.4	0.3	36.5	10.2
5	41.3	47.2	0.0	0.0	0.0	2.9	3.3	0.3	39.7	4.7	1.4	1.8	0.4	41.5	11.3
6	47.2	53.1	0.0	0.0	0.0	3.3	3.8	0.0	0.0	0.0	1.8	2.1	0.6	42.3	11.6
7	53.1	59.1	0.0	0.0	0.0	3.8	4.3	0.0	0.0	0.0	2.1	2.4	0.5	39.7	5.7
8	59.1	65.0	1.0	43.4	8.8	4.3	4.8	0.0	0.0	0.0	2.4	2.8	0.8	42.7	13.1

Class	B					Cu					Fe				
	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	----- g kg^{-1} -----			--- Mg ha^{-1} ---		-- mg kg^{-1} --			-- Mg ha^{-1} --		---- mg kg^{-1} ----			-- Mg ha^{-1} --	
1	55.8	90.9	0.6	42.9	13.2	1.3	5.0	0.0	0.0	0.0	57.6	281.7	0.3	39.8	20.1
2	90.9	126.0	0.3	40.5	5.8	5.0	8.6	0.3	39.4	9.2	281.7	505.7	0.4	38.5	10.5
3	126.0	161.1	0.3	38.2	8.7	8.6	12.3	0.4	38.9	16.5	505.7	729.8	0.5	43.4	6.3
4	161.1	196.2	0.4	37.1	13.9	12.3	15.9	0.5	41.6	13.4	729.8	953.8	0.0	0.0	0.0
5	196.2	231.3	0.5	40.4	12.4	15.9	19.6	0.3	43.4	5.1	953.8	1177.9	0.0	0.0	0.0
6	231.3	266.4	0.0	0.0	0.0	19.6	23.2	0.0	0.0	0.0	1177.9	1401.9	1.0	34.2	7.0
7	266.4	301.5	0.0	0.0	0.0	23.2	26.9	0.5	34.7	5.0	1401.9	1626.0	0.0	0.0	0.0
8	301.5	336.6	0.3	42.7	4.4	26.9	30.5	1.0	36.3	7.4	1626.0	1850.0	0.0	0.0	0.0

Class	Mn					Zn					Mo				
	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	---- mg kg^{-1} ----			--- Mg ha^{-1} ---		-- mg kg^{-1} --			-- Mg ha^{-1} --		----- g kg^{-1} -----			-- Mg ha^{-1} --	
1	106.9	243.5	0.2	35.0	5.1	24.0	73.5	0.3	38.7	15.0	0.0	0.7	0.3	40.0	8.4
2	243.5	380.2	0.2	37.0	4.2	73.5	123.0	0.4	41.6	10.7	0.7	1.4	0.3	37.7	10.1
3	380.2	516.8	0.4	39.9	12.6	123.0	172.5	0.4	41.0	10.1	1.4	2.1	0.5	38.5	13.6
4	516.8	653.4	1.0	40.5	23.4	172.5	222.0	0.7	37.6	8.9	2.1	2.8	0.3	34.2	4.0
5	653.4	790.1	0.5	37.7	5.4	222.0	271.5	0.0	0.0	0.0	2.8	3.5	0.5	42.6	8.7
6	790.1	926.7	0.0	0.0	0.0	271.5	321.0	1.0	34.2	7.0	3.5	4.2	0.5	39.6	9.9
7	926.7	1063.4	0.8	43.6	13.3	321.0	370.5	0.0	0.0	0.0	4.2	4.8	1.0	47.7	9.7
8	1063.4	1200.0	0.5	36.3	5.2	370.5	420.0	1.0	43.4	8.8	4.8	5.5	0.5	44.1	6.4

Class	Cl				
	Li	Ls	P(Ai/Ci)	Prod	ChM
	---- mg kg^{-1} ----			--- Mg ha^{-1} ---	
1	0.1	0.2	0.0	0.0	0.0
2	0.2	0.2	0.5	39.7	12.5
3	0.2	0.3	0.5	38.7	14.6
4	0.3	0.4	0.3	43.0	9.6
5	0.4	0.5	0.3	39.5	9.5
6	0.5	0.5	0.4	37.0	6.9
7	0.5	0.6	0.5	34.7	5.1
8	0.6	0.7	0.0	0.0	0.0

Note. [a]Number of classes defined by the square root of the number of samples, according to Wadt et al. (1998); [b]Lower limit of nutrient content in each class; [c]higher limit of nutrient content in each class; [d]Frequency of high productivity orchards in class i, in relation to the overall total of orchards in class i [e]Average productivity of high productivity orchards in each class; [f]Mathematical chance in class i. Average productivity 0 in the class indicates that there is no high productivity orchar.

The highest ChM for nutrients N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, Mo and Cl were obtained in classes 3, 4, 7, 2, 3, 8, 4, 3, 1, 4, 1, 3 and 3 respectively. These values correspond to nutritional ranges 14.9-17.5; 2.1-2.4; 16.7-18.1; 23.4-29.4; 1.9-2.4; 2.4-2.8; 161.1-196.2; 8.6-12.3; 57.6-281.7; 516.8-653.4; 24.0-73.5; 1.4-2.1; 0.2-0.3, respectively (Table 3).

However, the range of nutrient content with the highest ChM did not corresponded to the range with the highest percentage of plants of high productivity in relation to the total number of plants of the respective class, as was observed in the cultivar Tommy Atkins, except for Mn and Cl. This is because the ChM method takes into account the frequency of high productivity plants and the total number of plants in the same class. However, a class that has a higher percentage of high productivity plants may be less representative than a class that has a lower percentage (Almeida et al., 2016). For example, for P to class 8 has one plant, being has high productivity, which represents 100% of the plants. Class 4 (with the highest ChM) has 14 plantes, 7 have high productivity, which represents 50% of the plants. Class 4 is more representative than class 8 (Table 3).

Similar results were observed by Urano et al. (2007), De Deus et al. (2012) and Almeida et al. (2016) studying soybean, peanut and pitaya, respectively. These authors recommended analyzing the entire sampling set and not only interpreting the percentages of high productivity plants in isolation, considering only individual classes. Thus, the choice of sufficiency ranges based on the highest ChM value is more consistent.

The highest ChM in variety Kent for nutrients N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, Mo and Cl were obtained in classes 4, 5, 5, 4, 6, 3, 2, 2, 2, 2, 1, 1, 2 respectively. These values correspond to nutritional ranges 15.1-17.2; 2.1-2.3; 16.4-18.2; 21.4-26.6; 2.9-3.1; 1.8-2.7; 129.0-212.6; 7.3-12.1; 72.1-129,3; 387.1-689.3; 24,5-76,7; 0.0-1.4; 0.2-0.4, respectively (Table 4).

Table 4. Mathematical chance for different nutrient distribution classes of the cultivar Kent in commercial orchards of mango trees in Belém do São Francisco, Pernambuco, Brazil

Class[a]	N					P					K				
	Li[b]	Ls[c]	P(Ai/Ci)[d]	Prod[e]	ChM[f]	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	----- g kg^{-1} -----			--- Mg ha^{-1} ---		--- g kg^{-1} ---			-- Mg ha^{-1} --		----- g kg^{-1} -----			-- Mg ha^{-1} --	
1	8.9	11.0	0.2	33.6	3.8	1.3	1.5	0.3	37.3	0.0	9.3	11.0	0.2	33.6	3.8
2	11.0	13.0	0.2	41.1	4.7	1.5	1.7	0.3	44.5	8.7	11.0	12.8	0.2	36.1	6.7
3	13.0	15.1	0.2	45.3	10.1	1.7	1.9	0.3	39.2	10.9	12.8	14.6	0.0	0.0	0.0
4	15.1	17.2	0.4	38.5	16.5	1.9	2.1	0.1	40.5	4.2	14.6	16.4	0.3	39.6	11.3
5	17.2	19.2	0.4	37.5	9.3	2.1	2.3	0.3	38.9	13.5	16.4	18.2	0.5	39.9	15.7
6	19.2	21.3	0.0	0.0	0.0	2.3	2.5	0.0	0.0	0.0	18.2	20.0	0.5	41.1	8.1
7	21.3	23.3	0.0	0.0	0.0	2.5	2.7	0.0	0.0	0.0	20.0	21.7	0.5	51.3	10.1

Class	Ca					Mg					S				
	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	----- g kg^{-1} -----			--- Mg ha^{-1} ---		--- g kg^{-1} ---			-- Mg ha^{-1} --		----- g kg^{-1} -----			-- Mg ha^{-1} --	
1	5.5	10.8	1.0	41.1	11.4	1.7	1.9	0.3	39.3	5.4	0.1	1.0	0.2	43.4	8.8
2	10.8	16.1	0.0	0.0	0.0	1.9	2.2	0.3	34.1	7.2	1.0	1.8	0.2	37.0	8.6
3	16.1	21.4	0.3	40.6	9.2	2.2	2.4	0.2	42.4	7.1	1.8	2.7	0.6	40.9	18.9
4	21.4	26.6	0.3	37.3	12.0	2.4	2.6	0.2	47.4	7.3	2.7	3.6	0.5	33.6	6.6
5	26.6	31.9	0.1	43.7	7.9	2.6	2.9	0.3	42.9	8.4	3.6	4.4	0.0	0.0	0.0
6	31.9	37.2	0.2	40.0	7.0	2.9	3.1	0.4	35.3	11.1	4.4	5.3	0.0	0.0	0.0
7	37.2	42.5	0.5	33.6	6.6	3.1	3.3	0.5	37.5	7.4	5.3	6.1	0.0	0.0	0.0

Class	B					Cu					Fe				
	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	----- g kg^{-1} -----			--- Mg ha^{-1} ---		-- mg kg^{-1} --			-- Mg ha^{-1} --		---- mg kg^{-1} ----			-- Mg ha^{-1} --	
1	45.4	129.0	0.1	37.4	6.8	2.5	7.3	0.0	0.0	0.0	15.0	72.1	0.0	0.0	0.0
2	129.0	212.6	0.3	40.9	17.3	7.3	12.1	0.4	38.8	17.7	72.1	129.3	0.4	39.1	19.9
3	212.6	296.2	0.3	43.5	7.0	12.1	16.9	0.3	42.0	11.6	129.3	186.4	0.2	37.3	6.0
4	296.2	379.9	0.0	0.0	0.0	16.9	21.6	0.0	0.0	0.0	186.4	243.6	0.2	47.5	8.8
5	379.9	463.5	0.5	40.5	7.9	21.6	26.4	0.5	37.5	7.4	243.6	300.7	0.0	0.0	0.0
6	463.5	547.1	1.0	33.6	9.3	26.4	31.2	0.0	0.0	0.0	300.7	357.8	0.0	0.0	0.0
7	547.1	630.8	0.0	0.0	0.0	31.2	36.0	1.0	39.3	10.9	357.8	415.0	1.0	33.5	9.3

Class	Mn					Zn					Mo				
	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	---- mg kg^{-1} ----			--- Mg ha^{-1} ---		-- mg kg^{-1} --			-- Mg ha^{-1} --		----- g kg^{-1} -----			-- Mg ha^{-1} --	
1	85.0	387.1	0.1	37.5	3.7	24.5	76.7	0.2	39.1	15.8	0.0	1.4	0.4	37.9	19.5
2	387.1	689.3	0.3	41.6	16.3	76.7	128.9	0.3	43.0	8.4	1.4	2.9	0.0	0.0	0.0
3	689.3	991.4	0.3	38.9	12.7	128.9	181.1	1.0	45.3	12.6	2.9	4.3	1.0	33.5	10.1
4	991.4	1293.6	0.0	0.0	0.0	181.1	233.3	1.0	33.6	9.3	4.3	5.7	0.3	41.1	6.2
5	1293.6	1595.7	0.5	34.7	6.8	233.3	285.6	0.0	0.0	0.0	5.7	7.1	0.0	0.0	0.0
6	1595.7	1897.8	0.0	0.0	0.0	285.6	337.8	0.0	0.0	0.0	7.1	8.5	0.5	51.3	10.9
7	1897.8	2200.0	0.0	0.0	0.0	337.8	390.0	0.0	0.0	0.0	0.0	1.4	0.4	37.9	19.5

Class	Cl				
	Li	Ls	P(Ai/Ci)	Prod	ChM
	---- mg kg^{-1} ----			--- Mg ha^{-1} ---	
1	0.1	0.2	0.2	42.4	6.8
2	0.2	0.4	0.3	40.2	17.8
3	0.4	0.6	0.3	36.5	9.6
4	0.6	0.8	0.0	0.0	0.0
5	0.8	0.9	0.0	0.0	0.0
6	0.9	1.1	0.0	0.0	0.0
7	1.1	1.3	0.0	0.0	0.0

Note. [a]Number of classes defined by the square root of the number of samples, according to Wadt et al. (1998); [b]Lower limit of nutrient content in each class; [c]higher limit of nutrient content in each class; [d]Frequency of high productivity orchards in class i, in relation to the overall total of orchards in class i [e]Average productivity of high productivity orchards in each class; [f]Mathematical chance in class i. Average productivity 0 in the class indicates that there is no high productivity orchar.

The nutritional ranges for Ca, Mg, B, Cu, Fe, Mn, Zn and Mo with the highest percentage of plants estimated to have high productivity in relation to the total number of plants in the respective class differed from the ranges with the highest ChM value. These values corresponded to 5.5-10.8; 3.1-3.3; 463.5-547.1; 31.2-36.0; 357.8-415.0; 1293.6-1595.7; 128.9-181.1 and 2.9-4.3, respectively. However, these nutritional ranges corresponded to unrepresentative classes, which suggests the choice of the optimal ranges based on the highest value of ChM (Table 4).

The highest ChM in variety Keitt for nutrients N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, Mo and Cl were estimated in classes 6, 4, 1, 5, 2, 3, 1, 3, 1, 5, 1, 1 and 3 respectively. These values correspond to nutritional ranges 22.6-25.0; 2.0-2.4; 9.0-15.4; 29.3-32.3; 2.1-2.6; 1.3-1.9; 49.8-115.7; 12.0-16.5; 42.2-285.2; 791.1-945.5; 32.9-103.3; 0.1-1.5 and 0.3-0.4, respectively (Table 5).

Table 5. Mathematical chance for different nutrient distribution classes of the cultivar Keitt in commercial orchards of mango trees in Belém do São Francisco, Pernambuco, Brazil

Class[a]	N					P					K				
	Li[b]	Ls[c]	P(Ai/Ci)[d]	Prod[e]	ChM[f]	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	----- g kg^{-1} -----			--- Mg ha^{-1} ---		--- g kg^{-1} ---			-- Mg ha^{-1} --		----- g kg^{-1} -----			-- Mg ha^{-1} --	
1	10.7	13.1	0.3	52.3	11.1	0.8	1.2	0.0	0.0	0.0	9.0	15.4	0.3	52.5	24.4
2	13.1	15.5	0.2	53.7	13.5	1.2	1.6	0.3	49.4	12.2	15.4	21.8	0.3	49.7	10.6
3	15.5	17.9	0.3	49.0	10.5	1.6	2.0	0.2	57.3	9.6	21.8	28.2	0.0	0.0	0.0
4	17.9	20.2	0.0	0.0	0.0	2.0	2.4	0.4	49.9	21.7	28.2	34.7	0.0	0.0	0.0
5	20.2	22.6	0.0	0.0	0.0	2.4	2.8	0.3	57.2	10.0	34.7	41.1	0.0	0.0	0.0
6	22.6	25.0	1.0	50.8	30.6	2.8	3.2	0.5	46.4	9.9	41.1	47.5	1.0	47.3	14.3

Class	Ca					Mg					S				
	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	----- g kg^{-1} -----			--- Mg ha^{-1} ---		--- g kg^{-1} ---			-- Mg ha^{-1} --		----- g kg^{-1} -----			-- Mg ha^{-1} --	
1	17.3	20.3	0.3	47.3	8.2	1.6	2.1	0.3	52.0	16.8	0.1	0.7	0.0	0.0	0.0
2	20.3	23.3	0.3	56.2	12.8	2.1	2.6	0.3	52.6	17.6	0.7	1.3	0.3	49.4	12.2
3	23.3	26.3	0.3	52.2	15.7	2.6	3.1	0.4	49.5	15.8	1.3	1.9	0.4	52.7	22.9
4	26.3	29.3	0.0	0.0	0.0	3.1	3.5	0.0	0.0	0.0	1.9	2.4	0.4	51.2	16.4
5	29.3	32.3	0.6	50.7	20.5	3.5	4.0	0.0	0.0	0.0	2.4	3.0	0.0	0.0	0.0
6	32.3	35.3	0.4	49.0	13.2	4.0	4.5	0.0	0.0	0.0	3.0	3.6	0.3	50.4	8.8

Class	B					Cu					Fe				
	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	----- g kg^{-1} -----			--- Mg ha^{-1} ---		-- mg kg^{-1} --			-- Mg ha^{-1} --		---- mg kg^{-1} ----			-- Mg ha^{-1} --	
1	49.8	115.7	0.4	52.0	21.0	3.0	7.5	0.2	50.4	6.8	42.2	285.2	0.3	51.5	29.7
2	115.7	181.7	0.3	50.7	17.0	7.5	12.0	0.3	49.1	13.4	285.2	528.1	0.0	0.0	0.0
3	181.7	247.7	0.4	51.8	14.0	12.0	16.5	0.4	53.8	19.6	528.1	771.1	0.0	0.0	0.0
4	247.7	313.7	0.0	0.0	0.0	16.5	21.0	0.5	53.1	16.0	771.1	1014.1	0.0	0.0	0.0
5	313.7	379.6	0.0	0.0	0.0	21.0	25.5	0.0	0.0	0.0	1014.1	1257.0	0.0	0.0	0.0
6	379.6	445.6	0.0	0.0	0.0	25.5	30.0	0.2	47.2	6.4	1257.0	1500.0	0.0	0.0	0.0

Class	Mn					Zn					Mo				
	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM	Li	Ls	P(Ai/Ci)	Prod	ChM
	---- mg kg^{-1} ----			--- Mg ha^{-1} ---		-- mg kg^{-1} --			-- Mg ha^{-1} --		----- g kg^{-1} -----			-- Mg ha^{-1} --	
1	173.3	327.7	0.0	0.0	0.0	32.9	103.3	0.3	51.3	23.1	0.1	1.5	0.3	52.6	21.3
2	327.7	482.2	0.4	48.8	19.7	103.3	173.6	0.3	55.8	12.7	1.5	3.0	0.3	54.0	12.3
3	482.2	636.6	0.2	52.3	9.5	173.6	244.0	0.0	0.0	0.0	3.0	4.4	0.4	47.9	12.9
4	636.6	791.1	0.3	43.3	10.7	244.0	314.3	0.3	48.6	8.5	4.4	5.9	0.3	47.3	7.1
5	791.1	945.5	1.0	60.7	25.9	314.3	384.7	0.0	0.0	0.0	5.9	7.3	0.0	0.0	0.0
6	945.5	1100.0	0.0	0.0	0.0	384.7	455.0	0.5	47.3	10.1	7.3	8.7	0.0	0.0	0.0

Class	Cl				
	Li	Ls	P(Ai/Ci)	Prod	ChM
	---- mg kg^{-1} ----			--- Mg ha^{-1} ---	
1	0.1	0.2	0.3	48.4	13.9
2	0.2	0.3	0.3	56.9	16.3
3	0.3	0.4	0.5	50.8	21.7
4	0.4	0.5	0.0	0.0	0.0
5	0.5	0.6	0.0	0.0	0.0
6	0.6	0.7	0.5	47.3	10.1

Note. [a]Number of classes defined by the square root of the number of samples, according to Wadt et al. (1998); [b]Lower limit of nutrient content in each class; [c]higher limit of nutrient content in each class; [d]Frequency of high productivity orchards in class i, in relation to the overall total of orchards in class I; [e]Average productivity of high productivity orchards in each class; [f]Mathematical chance in class i. Average productivity 0 in the class indicates that there is no high productivity orchar.

The nutritional ranges for P, K, Mg, Cu, Zn and Mo with the highest percentage of plants estimated to have high productivity in relation to the total number of plants in the respective class differed from the ranges with higher value of ChM. These values corresponded to 2.8-3.2; 41.1-47.5; 2.6-3.1; 16.5-21.0; 384.7-455.0; and 3.0-4.4, respectively (Table 5).

The classes 3, 5 and 4 of Tommy Atkins for Ca, B and Cu, respectively; the class 3 of Kent for Cu, Mn and Zn; and the classes 3, 4, 2 and 4 of Keitt for Mg, S, B and Cu, respectively have significant ChM value. The nutritional contents corresponding to these classes are above the established optimal ranges for these nutrients (Tables 3, 4 and 5). This suggests that these nutritional contents are in a range corresponding to luxury consumption, which can cause toxicity or nutritional disorders. These results showed the importance of nutritional monitoring of mango tree, especially in relation to micronutrients, in which the difference between the levels of deficiency and toxicity is very narrow. Monitored crops avoids toxic nutritional effects and productivity losses (Zanão Júnior, Lana, & Guimarães, 2007; Almeida et al., 2016).

The optimal nutrient contents estimated for all mango tree cultivars by the BL and ChM methods (Table 6) were, in general, close to the mean contents of the high productivity population (Table 1). However, the optimal contents recommended by the literature (Table 6) distanced from the mean contents of the high productivity population (Table 1), except for Ca and S contents. This suggests that the methods applied in this study proved to be more consistent. Optimum contents estimated in this study were derived from samples of mango tree leaves collected in the region and were correlated with the productivity. Therefore, it is expected that it express better the regional management of mango tree cultivation (Teixeira, Tecchio, Moura, Terra, & Pires, 2015).

Table 6. Content and optimum range of nutrients of the cultivars Tommy Atkins, Kent and Keitt obtained by the Boundary Line and Mathematical Chance methods, as well as content and optimal range of nutrients referenced in the literature by Malavolta et al. (1997), Quaggio (1996), Medeiros et al. (2004) and Winston (2007) in commercial orchards of mango trees in Belém do São Francisco, Pernambuco, Brazil

Nutrient	Diagnostic method	Optimal content	Optimal range
Tommy Atkins			
		---------- $g\ kg^{-1}$ ----------	
N	Boundary Line	14.9	11.9-17.9
	Mathematical Chance	16.2	14.9-17.5
	Malavolta et al. (1997)	11.0	10.0-12.0
	Quaggio (1996)	13.0	12.0-14.0
	Medeiros et al. (2004)	11.6	10,4-12,9
	Winston (2007)	12.5	10.0-15.0
P	Boundary Line	2.0	**1.5-2.4**
	Mathematical Chance	2.2	**2.1-2.4**
	Malavolta et al. (1997)	1.0	0.8-1.2
	Quaggio (1996)	1.2	0.8-1.6
	Medeiros et al. (2004)	1.0	**0.9-1.2**
	Winston (2007)	-	-
K	Boundary Line	13.0	10.2-15.9
	Mathematical Chance	17.4	16.7-18.1
	Malavolta et al. (1997)	4.5	4.0-5.0
	Quaggio (1996)	7.5	5.0-10.0
	Medeiros et al. (2004)	7.7	5.3-10.2
	Winston (2007)	9.5	7.0-12.0
Ca	Boundary Line	28.2	24.3-32.1
	Mathematical Chance	26.4	23.4-29.4
	Malavolta et al. (1997)	31.0	28.0-34.0
	Quaggio (1996)	27.5	20.0-35.0
	Medeiros et al. (2004)	25.4	9.4-41.4
	Winston (2007)	27.5	20.0-35.0
Mg	Boundary Line	2.0	1.6-2.4
	Mathematical Chance	2.1	1.9-2.4
	Malavolta et al. (1997)	6.5	5.0-8.0
	Quaggio (1996)	3.7	2.5-5.0
	Medeiros et al. (2004)	3.1	2.1-4.0
	Winston (2007)	-	-

S	Boundary Line	-	-
	Mathematical Chance	1.9	1.7-2.1
	Malavolta et al. (1997)	1.6	1.5-1.8
	Quaggio (1996)	1.3	0.8-1.8
	Medeiros et al. (2004)	-	-
	Winston (2007)	-	-
		---------------------- mg kg^{-1} ---------------------	
B	Boundary Line	163.1	101.1-225.1
	Mathematical Chance	178.6	161.1-196.2
	Malavolta et al. (1997)	30.0	-
	Quaggio (1996)	75.0	50.0-100.0
	Medeiros et al. (2004)	-	-
	Winston (2007)	60.0	50.0-70.0
Cu	Boundary Line	5.1	0.2-10.0
	Mathematical Chance	10.4	8.6-12.2
	Malavolta et al. (1997)	30.0	-
	Quaggio (1996)	30.0	10.0-50.0
	Medeiros et al. (2004)	215.0	78.0-352.0
	Winston (2007)	15.0	10.0-20.0
Fe	Boundary Line	159.0	100.8-217.2
	Mathematical Chance	169.6	57.6-281.6
	Malavolta et al. (1997)	70.0	-
	Quaggio (1996)	125.0	50.0-200.0
	Medeiros et al. (2004)	183.0	114.0-252.0
	Winston (2007)	135.0	70.0-200.0
Mn	Boundary Line	564.7	345.5-783.9
	Mathematical Chance	585.1	516.8-653.4
	Malavolta et al. (1997)	120.0	-
	Quaggio (1996)	75.0	50.0-100.0
	Medeiros et al. (2004)	478.5	69.0-888.0
	Winston (2007)	280.0	60.0-500.0
Zn	Boundary Line	90.2	33.3-147.2
	Mathematical Chance	48.7	24.0-73.5
	Malavolta et al. (1997)	90.0	-
	Quaggio (1996)	30.0	20.0-40.0
	Medeiros et al. (2004)	57.0	18.0-96.0
	Winston (2007)	85.0	20.0-150.0
Mo	Boundary Line	-	-
	Mathematical Chance	1.7	1.4-2.1
	Malavolta et al. (1997)	-	-
	Quaggio (1996)	-	-
	Medeiros et al. (2004)	-	-
	Winston (2007)	0.5	0.05-1.0
Cl	Boundary Line	0.3	0.2-0.4
	Mathematical Chance	0.25	0.2-0.3
	Malavolta et al. (1997)	-	-
	Quaggio (1996)	-	-
	Medeiros et al. (2004)	-	-
	Winston (2007)	-	-
Kent			
		----------------------- g kg^{-1} ----------------------	
N	Boundary Line	15.7	13.5-17.9
	Mathematical Chance	16.1	15.1-17.1
	Malavolta et al. (1997)	11.0	10.0-12.0
	Quaggio (1996)	13.0	12.0-14.0
	Medeiros et al. (2004)	11.6	10.4-12.9
	Winston (2007)	12.5	10.0-15.0

P	Boundary Line	2.0	**1.5-2.5**
	Mathematical Chance	2.2	**2.1-2.3**
	Malavolta et al. (1997)	1.0	0.8-1.2
	Quaggio (1996)	1.2	0.8-1.6
	Medeiros et al. (2004)	1.0	**0.9-1.2**
	Winston (2007)	-	-
K	Boundary Line	13.1	9.4-16.8
	Mathematical Chance	17.3	16.4-18.2
	Malavolta et al. (1997)	4.5	4.0-5.0
	Quaggio (1996)	7.5	5.0-10.0
	Medeiros et al. (2004)	7.7	5.3-10.2
	Winston (2007)	9.5	7.0-12.0
Ca	Boundary Line	28.4	21.2-35.6
	Mathematical Chance	23.9	21.3-26.6
	Malavolta et al. (1997)	31.0	28.0-34.0
	Quaggio (1996)	27.5	20.0-35.0
	Medeiros et al. (2004)	25.4	9.4-41.4
	Winston (2007)	27.5	20.0-30.0
Mg	Boundary Line	2.1	1.7-2.6
	Mathematical Chance	2.9	2.8-3.1
	Malavolta et al. (1997)	6.5	5.0-8.0
	Quaggio (1996)	3.7	2.5-5.0
	Medeiros et al. (2004)	3.1	2.1-4.0
	Winston (2007)	-	-
S	Boundary Line	-	-
	Mathematical Chance	2.2	1.8-2.7
	Malavolta et al. (1997)	1.6	1.5-1.8
	Quaggio (1996)	1.3	0.8-1.8
	Medeiros et al. (2004)	-	-
	Winston (2007)	-	-
		---------------------- mg kg^{-1}	----------------------
B	Boundary Line	141.0	77.3-204.7
	Mathematical Chance	170.8	129.0-212.6
	Malavolta et al. (1997)	30.0	-
	Quaggio (1996)	75.0	50.0-100.0
	Medeiros et al. (2004)	-	-
	Winston (2007)	60.0	50.0-70.0
Cu	Boundary Line	10.9	7.5-14.3
	Mathematical Chance	9.7	7.3-12.1
	Malavolta et al. (1997)	30.0	-
	Quaggio (1996)	30.0	10.0-50.0
	Medeiros et al. (2004)	215.0	78.0-352.0
	Winston (2007)	15.0	10.0-20.0
Fe	Boundary Line	131.7	59.2-204.2
	Mathematical Chance	100.7	72.1-129.3
	Malavolta et al. (1997)	70.0	-
	Quaggio (1996)	125.0	50.0-200.0
	Medeiros et al. (2004)	183.0	114.0-252.0
	Winston (2007)	135.0	70.0-200.0
Mn	Boundary Line	820.0	481.1-1158.9
	Mathematical Chance	538.2	387.1-689.3
	Malavolta et al. (1997)	120.0	-
	Quaggio (1996)	75.0	50.0-100.0
	Medeiros et al. (2004)	478.5	69.0-888.0
	Winston (2007)	280.0	60.0-500.0

Zn	Boundary Line	66.5	47.0-86.0
	Mathematical Chance	50.6	24.5-76.7
	Malavolta et al. (1997)	90.0	-
	Quaggio (1996)	30.0	20.0-40.0
	Medeiros et al. (2004)	57.0	18.0-96.0
	Winston (2007)	85.0	20.0-150.0
Mo	Boundary Line	-	-
	Mathematical Chance	0.7	0.03-1.4
	Malavolta et al. (1997)	-	-
	Quaggio (1996)	-	-
	Medeiros et al. (2004)	-	-
	Winston (2007)	0.5	0.05-1.0
Cl	Boundary Line	0.27	0.14-0.40
	Mathematical Chance	0.3	0.25-0.41
	Malavolta et al. (1997)	-	-
	Quaggio (1996)	-	-
	Medeiros et al. (2004)	-	-
	Winston (2007)	-	-
Keitt			
		----------------------- $g\ kg^{-1}$ -----------------------	
N	Boundary Line	14.7	10.5-19.0
	Mathematical Chance	23.8	22.6-25.0
	Malavolta et al. (1997)	11.0	10.0-12.0
	Quaggio (1996)	13.0	12.0-14.0
	Medeiros et al. (2004)	11.6	10.4-12.9
	Winston (2007)	12.5	10.0-15.0
P	Boundary Line	1.9	**1.5-2.3**
	Mathematical Chance	2.2	2.0-2.4
	Malavolta et al. (1997)	1.0	0.8-1.2
	Quaggio (1996)	1.2	0.8-1.6
	Medeiros et al. (2004)	1.0	**0.9-1.2**
	Winston (2007)	-	-
K	Boundary Line	14.8	11.2-18.4
	Mathematical Chance	12.2	9.0-15.4
	Malavolta et al. (1997)	4.5	4.0-5.0
	Quaggio (1996)	7.5	5.0-10.0
	Medeiros et al. (2004)	7.7	5.3-10.2
	Winston (2007)	9.5	7.0-12.0
Ca	Boundary Line	28.1	22.7-33.5
	Mathematical Chance	30.7	29.2-32.2
	Malavolta et al. (1997)	31.0	28.0-34.0
	Quaggio (1996)	27.5	20.0-35.0
	Medeiros et al. (2004)	25.4	9.4-41.4
	Winston (2007)	27.5	20.0-35.0
Mg	Boundary Line	2.3	2.0-2.6
	Mathematical Chance	2.3	2.1-2.6
	Malavolta et al. (1997)	6.5	5.0-8.0
	Quaggio (1996)	3.7	2.5-5.0
	Medeiros et al. (2004)	3.1	2.1-4.0
	Winston (2007)	-	-
S	Boundary Line	6.7	3.9-9.4
	Mathematical Chance	1.6	1.3-1.9
	Malavolta et al. (1997)	1.6	1.5-1.8
	Quaggio (1996)	1.3	0.8-1.8
	Medeiros et al. (2004)	-	-
	Winston (2007)	-	-

		---------------------- mg kg^{-1} ---------------------	
B	Boundary Line	120.0	57,0-183,0
	Mathematical Chance	82.7	49.8-115.7
	Malavolta et al. (1997)	30.0	-
	Quaggio (1996)	75.0	50.0-100.0
	Medeiros et al. (2004)	-	-
	Winston (2007)	60.0	50.0-70.0
Cu	Boundary Line	13.6	7.2-20.0
	Mathematical Chance	14.2	12.0-16.5
	Malavolta et al. (1997)	30.0	-
	Quaggio (1996)	30.0	10.0-50.0
	Medeiros et al. (2004)	215.0	78.0-352.0
	Winston (2007)	15.0	10.0-20.0
Fe	Boundary Line	151.4	136.1-166.7
	Mathematical Chance	163.7	42.2-285.2
	Malavolta et al. (1997)	70.0	-
	Quaggio (1996)	125.0	50.0-200.0
	Medeiros et al. (2004)	183.0	114.0-252.0
	Winston (2007)	135.0	70.0-200.0
Mn	Boundary Line	409.8	249.7-570.0
	Mathematical Chance	868.3	791.1-945.5
	Malavolta et al. (1997)	120.0	-
	Quaggio (1996)	75.0	50.0-100.0
	Medeiros et al. (2004)	478.5	69.0-888.0
	Winston (2007)	280.0	60.0-500.0
Zn	Boundary Line	65.1	8.4-121,8
	Mathematical Chance	68.0	32.9-103.2
	Malavolta et al. (1997)	90.0	-
	Quaggio (1996)	30.0	20.0-40.0
	Medeiros et al. (2004)	57.0	18.0-96.0
	Winston (2007)	85.0	20.0-150.0
Mo	Boundary Line	-	-
	Mathematical Chance	0.80	0.1-1.5
	Malavolta et al. (1997)	-	-
	Quaggio (1996)	-	-
	Medeiros et al. (2004)	-	-
	Winston (2007)	0.5	0.05-1.0
Cl	Boundary Line	0.25	0.1-0.4
	Chance Matemática	0.35	0.3-0.4
	Malavolta et al. (1997)	-	-
	Quaggio (1996)	-	-
	Medeiros et al. (2004)	-	-
	Winston (2007)	-	-

The nutrients optimal ranges estimated by the BL and ChM methods for all cultivars presented minimum and maximum values above those recommended in the literature, except for Ca, Mg, Cu, Zn and Cl (Table 6). This difference showed importance of developing new methods based on specific cultivars, such as the cultivars in this study. These mango tree cultivars are more demanding than cultivars used in the development of traditional methods of nutritional diagnosis (Quaggio, 1996; Malavolta et al., 1997; Medeiros et al., 2004; Winston, 2007). According to Lafond (2013), the nutritional ranges developed by the critical level and critical range methods in the literature are not adapted to the conditions of climate, soil and cultivation practices from different production areas, making their use limited.

The Mo sufficiency range developed by the BL and ChM methods (Table 6) made it possible to assess the nutritional status of this nutrient in the Sub-Middle São Francisco Valley, facilitating its recommendation in mango fertilization programs. Winston (2007) developed in Australia an optimal range for Mo for various mango cultivars. However, these cultivars have different nutritional requirements than those used in the Sub-Médio São Francisco Valley. These results show the importance of creating and validating specific nutritional standards for the edapho-climatic conditions of the Valley, taking into account the production management and nutritional requirement of the cultivars.

The nutritional diagnoses established by the BL and ChM methods were disagreed, and also disagreed with the diagnoses of the authors Quaggio (1996), Malavolta et al. (1997), Medeiros et al. (2004) and Winston (2007) for the orchards of all cultivars (Tables 7, 8 and 9), except K, Mg and Zn for cultivar Keitt (Table 9), in which the BL and ChM methods were concordant.

Table 7. Chi-square likelihood ratio test of the Fertilizer Response Potential (FRP) of the cultivar Tommy Atkins with nutritional diagnosis of deficiency (P), adequate (Z) and excess (N) by the Boundary Line (BL) and Mathematical Chance (ChM) methods, as well as of the diagnosis referenced in the literature by Malavolta et al. (1997), Quaggio (1996), Medeiros et al. (2004) and Winston (2007) in commercial orchards of mango trees in Belém do São Francisco, Pernambuco, Brazil

Diagnostic method	FRP			Chi-square					
	P	Z	N	BL	ChM	Malavolta et al. (1997)	Quaggio (1996)	Medeiros et al. (2004)	Winston (2007)
N									
BL	2	42	22	-	17.73^{**}	59.94^{**}	37.94^{**}	50.05^{**}	22.25^{**}
ChM	17	23	26		-	58.74^{**}	32.35^{**}	46.49^{**}	22.53^{**}
Malavolta et al. (1997)	1	1	64			-	7.07^{*}	1.99^{ns}	15.22^{**}
Quaggio (1996)	2	8	56				-	1.91^{ns}	3.46^{ns}
Medeiros et al. (2004)	1	4	61					-	8.50^{*}
Winston (2007)	1	16	49						-
P									
BL	12	51	3	-	43.54^{**}	116.61^{**}	61.25^{**}	116.61^{**}	-
ChM	49	14	3		-	151.02^{**}	113.43^{**}	151.02^{**}	-
Malavolta et al. (1997)	0	1	65			-	19.69^{**}	0.00^{ns}	-
Quaggio (1996)	0	21	45				-	19.69^{**}	-
Medeiros et al. (2004)	0	1	65					-	-
Winston (2007)	-	-	-						-
K									
BL	6	52	8	-	88.92^{**}	103.46^{**}	82.25^{**}	82.25^{**}	36.00^{**}
ChM	60	4	2		-	164.94^{**}	151.86^{**}	151.86^{**}	110.51^{**}
Malavolta et al. (1997)	0	0	66			-	8.60^{**}	8.60^{**}	32.37^{**}
Quaggio (1996)	0	6	60				-	0.00^{ns}	16.50^{**}
Medeiros et al. (2004)	0	6	60					-	16.50^{**}
Winston (2007)	0	26	40						-
Ca									
BL	16	38	12	-	9.22^{**}	10.73^{**}	15.36^{**}	32.38^{**}	17.44^{**}
ChM	12	26	28		-	26.41^{**}	36.93^{**}	65.40^{**}	36.21^{**}
Malavolta et al. (1997)	34	26	6			-	40.01^{**}	68.36^{**}	39.18^{**}
Quaggio (1996)	4	58	4				-	7.87^{*}	0.15^{ns}
Medeiros et al. (2004)	0	65	1					-	5.09^{ns}
Winston (2007)	3	59	4						-
Mg									
BL	8	38	20	-	7.39^{*}	103.46^{**}	65.45^{**}	$28,31^{**}$	-
ChM	20	26	20		-	89.70^{**}	47.61^{**}	24.34^{**}	-
Malavolta et al. (1997)	66	0	0			-	12.28^{**}	68.48^{**}	-
Quaggio (1996)	53	13	0				-	21.23^{**}	-
Medeiros et al. (2004)	28	37	1					-	-
Winston (2007)	-	-	-						-
S									
BL	-	-	-	-	-	-	-	-	-
ChM	53	7	6		-	1.17^{ns}	50.18^{**}	-	-
Malavolta et al. (1997)	50	6	10			-	49.13^{**}	-	-
Quaggio (1996)	15	41	10				-	-	-
Medeiros et al. (2004)	-	-	-					-	-
Winston (2007)	-	-	-						-

B									
BL	8	46	12	-	23.90^{**}	-	64.97^{**}	-	83.91^{**}
ChM	28	19	19		-	-	64.12^{**}	-	66.15^{**}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	0	8	58				-	-	3.89^{ns}
Medeiros et al. (2004)	-	-	-					-	-
Winston (2007)	0	2	64						-
Cu									
BL	0	39	27	-	$26,62^{**}$	-	68.18^{**}	132.00^{**}	54.67^{**}
ChM	22	28	16		-	-	27.00^{**}	84.02^{**}	11.48^{**}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	39	27	0				-	44.45^{**}	3.41^{ns}
Medeiros et al. (2004)	66	0	0					-	42.24^{**}
Winston (2007)	34	29	3						-
Fe									
BL	7	39	20	-	10.61^{**}	-	7.39^{*}	1.61^{ns}	2.98^{ns}
ChM	0	53	13		-	-	2.48^{ns}	17.21^{**}	5.58^{ns}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	0	44	22				-	16.77^{**}	2.04^{ns}
Medeiros et al. (2004)	11	40	15					-	7.60^{*}
Winston (2007)	2	42	22						-
Mn									
BL	29	27	10	-	14.35^{**}	-	97.26^{**}	40.53^{**}	37.57^{**}
ChM	46	8	12		-	-	116.01^{**}	107.31^{**}	73.86^{**}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	0	0	66				-	132.29^{**}	66.00^{**}
Medeiros et al. (2004)	0	58	8					-	8.45^{**}
Winston (2007)	0	44	22						-
Zn									
BL	5	52	9	-	$12,78^{**}$	-	64.74^{**}	8.82^{*}	5.23^{ns}
ChM	1	39	26		-	-	28.62^{**}	3.22^{ns}	12.63^{**}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	0	11	55				-	37.67^{**}	64.18^{**}
Medeiros et al. (2004)	0	47	19						4.53^{ns}
Winston (2007)	0	57	9						-
Mo									
BL	-	-	-	-	-	-	-	-	
ChM	36	14	16	-	-	-	-	46.70^{**}	
Malavolta et al. (1997)	-	-			-	-	-	-	
Quaggio (1996)	-	-				-	-	-	
Medeiros et al. (2004)	-	-					-	-	
Winston (2007)	1	24	41					-	
Cl									
BL	13	34	19	-	14.02^{**}	-	-	-	
ChM	13	15	38	-	-	-	-	-	
Malavolta et al. (1997)	-	-	-	-	-	-	-	-	
Quaggio (1996)	-	-	-	-	-	-	-	-	
Medeiros et al. (2004)	-	-	-	-	-	-	-	-	
Winston (2007)	-	-	-	-	-	-	-	-	

Note. ** and * Significant at 1 and 5% probability, respectively by the Chi-square likelihood ratio test (G). ^{ns} non-significant.

Table 8. Chi-square likelihood ratio test of the Fertilizer Response Potential (FRP) of the cultivar Kent with nutritional diagnosis of deficiency (P), adequate (Z) and excess (N) by the Boundary Line (BL) and Mathematical Chance (ChM) methods, as well as of the diagnosis referenced in the literature by Malavolta et al. (1997), Quaggio (1996), Medeiros et al. (2004) and Winston (2007) in commercial orchards of mango trees in Belém do São Francisco, Pernambuco, Brazil

Diagnostic method	FRP			Chi-square					
	P	Z	N	BL	ChM	Malavolta et al. (1997)	Quaggio (1996)	Medeiros et al. (2004)	Winston (2007)
N									
BL	15	30	7	-	8.84^{*}	53.93^{**}	24.00^{**}	42.46^{**}	17.53^{**}
ChM	26	15	11		-	45.51^{**}	20.09^{**}	36.07^{**}	21.30^{**}
Malavolta et al. (1997)	5	3	44			-	9.70^{**}	1.83^{ns}	18.12^{**}
Quaggio (1996)	8	13	31				-	3.67^{ns}	3.01^{ns}
Medeiros et al. (2004)	5	7	40					-	9.96^{**}
Winston (2007)	5	21	26						-
P									
BL	4	46	2	-	34.52^{**}	96.29^{**}	63.50^{**}	96.29^{**}	-
ChM	30	17	5		-	110.29^{**}	76.72^{**}	110.29^{**}	-
Malavolta et al. (1997)	0	0	52			-	14.92^{**}	0.00^{ns}	-
Quaggio (1996)	0	10	42				-	14.92^{**}	-
Medeiros et al. (2004)	0	0	52					-	-
Winston (2007)	-	-	-						-
K									
BL	1	45	6	-	63.33^{**}	82.48^{**}	67.97^{**}	67.97^{**}	50.27^{**}
ChM	40	8	4		-	115.35^{**}	100.69^{**}	100.69^{**}	71.61^{**}
Malavolta et al. (1997)	0	0	52			-	5.70^{*}	5.70^{*}	11.06^{**}
Quaggio (1996)	0	4	48				-	0.00^{ns}	2.97^{ns}
Medeiros et al. (2004)	0	4	48					-	2.97^{ns}
Winston (2007)	0	10	42						-
Ca									
BL	6	42	4	-	40.35^{**}	21.39^{**}	0.44^{ns}	6.07^{*}	0.44^{ns}
ChM	6	12	34		-	28.64^{**}	46.94^{**}	68.42^{**}	46.94^{**}
Malavolta et al. (1997)	24	19	9			-	28.02^{**}	48.06^{**}	28.02^{**}
Quaggio (1996)	4	44	4				-	4.23^{ns}	0.00^{ns}
Medeiros et al. (2004)	1	50	1					-	4.23^{ns}
Winston (2007)	4	44	4						-
Mg									
BL	1	32	19	-	62.38^{**}	100.08^{**}	46.60^{**}	27.01^{**}	-
ChM	40	10	2		-	18.20^{**}	9.79^{**}	46.10^{**}	-
Malavolta et al. (1997)	52	0	0			-	38.50^{**}	69.94^{**}	-
Quaggio (1996)	29	23	0				-	17.23^{**}	-
Medeiros et al. (2004)	9	43	0					-	-
Winston (2007)	-	-	-						-
S									
BL	-	-	-	-	-	-	-	-	-
ChM	39	10	3		-	7.96^{*}	29.90^{**}	-	-
Malavolta et al. (1997)	30	9	13			-	17.30^{**}	-	-
Quaggio (1996)	12	27	13				-	-	-
Medeiros et al. (2004)	-	-	-					-	-
Winston (2007)	-	-	-						-
B									
BL	5	34	13	-	13.31^{**}	-	28.17^{**}	-	45.62^{**}
ChM	21	21	10		-	-	44.81^{**}	-	53.75^{**}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	1	11	40				-	-	3.82^{ns}
Medeiros et al. (2004)	-	-	-					-	-
Winston (2007)	1	4	47						-

Cu									
BL	11	32	9	-	10.04^{**}	-	12.73^{**}	67.68^{**}	5.47^{ns}
ChM	11	18	23		-	-	38.65^{**}	85.82^{**}	18.29^{**}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	22	30	0				-	54.10^{**}	4.18^{ns}
Medeiros et al. (2004)	52	0	0					-	44.16^{**}
Winston (2007)	21	27	4						-
Fe									
BL	6	37	9	-	14.12^{**}	-	0.45^{nz}	11.82^{**}	0.00^{ns}
ChM	7	19	26		-	-	16.48^{**}	26.75^{**}	14.12^{**}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	4	39	9				-	16.84^{**}	0.45^{ns}
Medeiros et al. (2004)	21	27	4					-	11.81^{**}
Winston (2007)	6	37	9						-
Mn									
BL	13	33	6	-	18.10^{**}	-	75.03^{**}	16.55^{**}	45.89^{**}
ChM	8	18	26		-	-	33.52^{**}	15.08^{**}	11.40^{**}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	0	2	50				-	49.76^{**}	9.42^{**}
Medeiros et al. (2004)	0	38	14					-	24.04^{**}
Winston (2007)	0	13	39						-
Zn									
BL	11	31	10	-	12.37^{**}	-	45.97^{**}	13.47^{**}	14.92^{**}
ChM	0	38	14		-	-	32.78^{**}	2.09^{ns}	3.96^{ns}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	0	8	44				-	54.87^{**}	55.62^{**}
Medeiros et al. (2004)	0	44	8					-	0.33^{ns}
Winston (2007)	0	46	6						
Mo									
BL	-	-	-	-	-	-	-	-	-
ChM	1	21	30		-	-	-	-	0.37^{ns}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	-	-	-				-	-	-
Medeiros et al. (2004)	-	-	-					-	-
Winston (2007)	1	18	33						-
Cl									
BL	6	31	11	39.78^{**}	-	78.45^{**}	-	-	
ChM	5	4	43	-	-	85.75^{**}	-	-	
Malavolta et al. (1997)	-	-			-	-	-	-	
Quaggio (1996)	52	0	0			-	-	-	
Medeiros et al. (2004)	-	-					-	-	
Winston (2007)	-	-						-	

Note. ** and * Significant at 1 and 5% probability, respectively by the Chi-square likelihood ratio test (G). ^{ns} non-significant.

Table 9. Chi-square likelihood ratio test of the Fertilizer Response Potential (FRP) of the cultivar Keitt with nutritional diagnosis of deficiency (P), adequate (Z) and excess (N) by the Boundary Line (BL) and Mathematical Chance (ChM) methods, as well as of the diagnosis referenced in the literature by Malavolta et al. (1997), Quaggio (1996), Medeiros et al. (2004) and Winston (2007) in commercial orchards of mango trees in Belém do São Francisco, Pernambuco, Brazil.

Diagnostic method	FRP			Chi-square					
	P	Z	N	BL	ChM	Malavolta et al. (1997)	Quaggio (1996)	Medeiros et al. (2004)	Winston (2007)
N									
BL	0	32	6	-	61.78^{**}	35.58^{**}	33.67^{**}	30.40^{**}	0.00^{ns}
ChM	34	4	0		-	91.89^{**}	57.12^{**}	90.08^{**}	61.77^{**}
Malavolta et al. (1997)	0	6	32			-	9.25^{*}	0.08^{ns}	35.57^{**}
Quaggio (1996)	6	7	25				-	8.84^{*}	33.67^{**}
Medeiros et al. (2004)	0	8	30					-	30.40^{**}
Winston (2007)	0	32	6						-
P									
BL	6	27	5	-	14.10^{**}	51.15^{**}	33.19^{**}	51.15^{**}	-
ChM	21	12	5		-	59.76^{**}	43.50^{**}	59.76^{**}	-
Malavolta et al. (1997)	1	1	36			-	5.60^{ns}	0.00^{ns}	-
Quaggio (1996)	1	7	30				-	5.60^{ns}	-
Medeiros et al. (2004)	1	1	36					-	-
Winston (2007)	-	-	-						-
K									
BL	6	26	6	-	5.04^{ns}	55.27^{**}	38.92^{**}	38.92^{**}	31.53^{**}
ChM	1	26	11		-	53.17^{**}	28.48^{**}	28.48^{**}	19.33^{**}
Malavolta et al. (1997)	0	0	38			-	7.28^{**}	7.28^{**}	8.94^{**}
Quaggio (1996)	0	5	33				-	$0,00^{ns}$	0.83^{ns}
Medeiros et al. (2004)	0	5	33					-	0.83^{ns}
Winston (2007)	0	8	30						-
Ca									
BL	10	24	4	-	23.21^{**}	13.54^{**}	11.56^{**}	17.16^{**}	11.56^{**}
ChM	28	4	6		-	4.82^{ns}	64.91^{**}	78.94^{**}	64.91^{**}
Malavolta et al. (1997)	26	10	2			-	44.81^{**}	56.23^{**}	44.81^{**}
Quaggio (1996)	1	36	1				-	2.82^{ns}	0.00^{ns}
Medeiros et al. (2004)	0	38	0					-	2.82^{ns}
Winston (2007)	1	36	1						-
Mg									
BL	9	19	10	-	1.61^{ns}	46.89^{**}	21.13^{**}	8.83^{*}	-
ChM	14	15	9		-	42.20^{**}	16.31^{**}	9.60^{**}	-
Malavolta et al. (1997)	38	0	0			-	17.12^{**}	44.77^{**}	-
Quaggio (1996)	27	11	0				-	9.90^{**}	-
Medeiros et al. (2004)	14	23	1					-	-
Winston (2007)	-	-	-						-
S									
BL	-	-	-	-	-	-	-	-	-
ChM	13	12	13		-	1.78^{ns}	1.67^{ns}	-	-
Malavolta et al. (1997)	16	7	15			-	5.69^{ns}	-	-
Quaggio (1996)	8	15	15				-	-	-
Medeiros et al. (2004)	-	-	-					-	-
Winston (2007)	-	-	-						-
B									
BL	1	27	10	-	10.66^{**}	-	15.62^{**}	-	35.44^{**}
ChM	1	13	24		-	-	0.56^{ns}	-	10.11^{**}
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	1	10	27				-	-	6.36^{*}
Medeiros et al. (2004)	-	-	-					-	-
Winston (2007)	1	2	35						-

Cu									
BL	3	28	7	-	15.29**	-	11.59**	64.88**	4.77ns
ChM	15	12	11		-	-	21.78**	42.20**	4.34ns
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	11	27	0				-	38.83**	7.79*
Medeiros et al. (2004)	38	0	0					-	44.33**
Winston (2007)	10	21	7						-
Fe									
BL	15	13	10	-	25.36**	-	15.65**	6.40*	15.65**
ChM	0	33	5		-	-	3.88ns	12.60**	3.88ns
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	2	28	8				-	4.45ns	0.00ns
Medeiros et al. (2004)	8	24	6					-	4.45ns
Winston (2007)	2	28	8						-
Mn									
BL	2	23	13	-	48.10**	-	37.25**	10.73**	3.50 ns
ChM	32	3	3		-	-	83.89**	76.05**	55.27**
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	0	0	38				-	61.22**	25.33**
Medeiros et al. (2004)	0	35	3					-	16.37**
Winston (2007)	0	19	19						-
Zn									
BL	0	25	13	-	0.50ns	-	33.67**	2.62ns	1.02ns
ChM	0	22	16		-	-	24.93**	0.47ns	2.92ns
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	0	1	37				-	23.65**	43.17**
Medeiros et al. (2004)	0	18	20					-	6.74*
Winston (2007)	0	29	9						-
Mo									
BL	-	-	-	-	-	-	-	-	-
ChM	0	20	18		-	-	-	-	2.62ns
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	-	-	-				-	-	-
Medeiros et al. (2004)	-	-	-					-	-
Winston (2007)	0	13	25						-
Cl									
BL	5	25	8	-	15.43**	-	58.32**	-	-
ChM	20	10	8		-	-	23.58**	-	-
Malavolta et al. (1997)	-	-	-			-	-	-	-
Quaggio (1996)	38	0	0				-	-	-
Medeiros et al. (2004)	-	-	-					-	-
Winston (2007)	-	-	-						-

Note. ** and * Significant at 1 and 5% probability, respectively by the Chi-square likelihood ratio test (G). ns non-significant.

The BL and ChM methods estimated sufficiency ranges for most nutrients wider than the sufficiency ranges established in the literature (Quaggio, 1996; Malavolta et al., 1997; Medeiros et al., 2004; Winston, 2007) (Table 6). This greater range provided balanced nutritional diagnoses when the BL and ChM methods were used, contrary to diagnoses of deficiency or excess, when the methods reported in the literature were used (Tables 7, 8 and 9).

BL method for the cultivar Tommy Atkins agreed with Quaggio (1996) and Medeiros et al. (2004) in the Fe diagnosis; and Winston (2007) in the Zn diagnosis. BL method for the cultivar Kent agreed with Quaggio (1996) and Winston (2007) in the Ca and Fe diagnosis; and Winston (2007) in the Cu diagnosis. BL method for the cultivar Keitt agreed with Winston (2007) in the N, Cu, Mn and Zn diagnosis (Tables 7, 8 and 9).

ChM method for the cultivar Tommy Atkins agreed with Quaggio (1996), Malavolta et al. (1997) and Medeiros et al. (2004) in the S, Fe and Zn diagnosis, respectively. ChM method for the cultivar Kent agreed with Medeiros et al. (2004) and Winston (2007) in the Zn diagnosis. ChM method for the cultivar keitt agreed with Winston (2007) in the Cu, Fe, Zn and Mo diagnosis; Malavolta et al. (1997) in the Ca and S diagnosis; and Quaggio (1996) in the S, B and Fe diagnosis (Tables 7, 8 and 9).

The sufficiency ranges established by the ChM method were slightly narrower than the ranges established by the BL method, except for Fe in the Tommy Atkins and Keitt mango trees, and Zn in the Kent mango tree (Table 6). This indicated that ChM values were more rigorous for diagnosing the nutritional status of the cultivars Tommy Atkins, Kent and Keitt (Tables 7, 8 and 9).

Despite the disagreement of nutritional diagnoses between the BL and ChM methods (Tables 7, 8 and 9), it was observed that the sufficiency ranges corresponding to nutrients N, P, Mg, B, Mn and Cl for the cultivar Tommy Atkins; N, P, K, Ca, Mg, Fe and Cl for cultivar Kent; and Ca, Mg, Cu, Mn and Cl for cultivar Keitt obtained by the ChM method are within the ranges established by the BL method (Table 6).

4. Conclusions

The optimal nutrient contents for mango tree cultivars by the Boundary Line and Mathematical Chance methods were close to the mean contents of the high productivity population, as well as the nutrients optimal ranges presented values above those recommended in the literature, suggesting that these methods were more consistent and expressed better the regional management of mango tree cultivation in the Sub-Middle São Francisco Valley.

The nutritional diagnoses established by the Boundary Line and Mathematical Chance methods were disagreed, and also disagreed of the diagnoses of the methods commonly used in the literature, main in the mango cultivars Tommy Atkins and Kent, suggesting that orchards are nutritionally more balanced than diagnoses of deficiency or excess reported by methods commonly used in the literature.

The sufficiency ranges established by the Mathematical Chance method were smaller than the ranges established by the Boundary Line method, indicating that the Mathematical Chance method was more rigorous for diagnosing the nutritional status of the cultivars Tommy Atkins, Kent and Keitt.

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