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Nutritional diagnosis of soursop according to the Kenworthy balance index and deviation from optimum percentage, Nayarit, Mexico

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RESUMEN

La guanábana es una fruta tropical de importancia económica en México, sin embargo, existen escasas investigaciones sobre su nutrición. El objetivo de este estudio fue evaluar la concentración de nutrientes foliares en estado vegetativo y comparar el diagnóstico nutricional entre el Índice de Balance de Kenworthy (KBI) y la Desviación del Porcentaje Óptimo (DOP) en el cultivo de guanábana. La concentración foliar de N, P, K, Ca, Mg, Mn y B presentó valores inferiores al estándar de referencia. Se encontró concordancia entre los índices KBI y DOP para el diagnóstico en el 91% de los huertos; los nutrientes N, P, K, Ca, Mn y B fueron deficientes en todos los huertos y excesivos Cu (en el 33% de los huertos), Fe y Zn (en el 8% de los huertos, respectivamente). Sin embargo, el diagnóstico de Mg, Fe, Cu y Zn en algunos huertos fue contradictorio debido a que existen rangos adecuados con el KBI y deficientes con el DOP. En general, con los dos índices el 25% de los huertos coinciden con el orden decreciente de los nutrientes P<K<Ca<N<Mg<Mn<B <Zn<Fe<Cu. Aunque hubo algunas similitudes y diferencias en el diagnóstico nutricional entre KBI y DOP, se deben cubrir las necesidades nutricionales específicas de cada huerto de guanábana.

Palabras clave: *Annona muricata*; análisis foliar, macronutrientes; micronutrientes; requerimiento nutricional.

ABSTRACT

Soursop is a tropical fruit of economic importance in Mexico, however, there is scarce research on its nutrition. The aim of this study was to evaluate the foliar nutrient concentration in the vegetative state and to compare the nutritional diagnosis between the Kenworthy Balance Index (KBI) and Deviation from Optimum Percentage (DOP) in the soursop crop. The foliar concentration of N, P, K, Ca, Mg, Mn and B presented lower values than the reference standard. It was found concordance between KBI and DOP indices for the diagnosis in 91% of the orchards; the nutrients N, P, K, Ca, Mn and B were deficient in all orchards and excessive Cu (in 33% of the orchards), Fe and Zn (in 8% of the orchards respectively). However, the diagnosis of Mg, Fe, Cu and Zn in some orchards was contradictory due their adequate ranges with the KBI and deficient with the DOP. In general, with the two indices 25% of the orchards coincide with the decreasing order of the nutrients P<K<Ca<N<Mg<Mn<B<Zn<Fe<Cu. Although there were some similarities and differences in the nutritional diagnosis among KBI and DOP, the specific nutritional needs of each soursop orchard must be supply.

Keywords: *Annona muricata*; foliar analysis; macronutrients; micronutrients; nutritional requirement.

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1. Introduction

Mexico is the main producer of soursop (*Annona muricata* L.) worldwide with 3.612 hectare planted for the year 2019; Nayarit represents 68% of the cultivated area (2.456 ha), becoming a fruit tree of economic importance, the average price per ton was 8.400 Mexican pesos, so the production value for this crop was 195.153 Mexican pesos (SIAP, 2023).

Fruit tree nutrition is responsible for various functions in plants; energy processes, enzymatic activation and osmotic regulation of membranes (Vasconcelos-Botelho & Lopes-Müller, 2020), therefore, to guarantee optimal nutrition it is necessary to know the nutrient levels of the crop, these can be determined by nutritional diagnosis. The interpretation of the results of the foliar analyzes allows diagnosing the nutritional level and evaluating the availability of reserves or existing imbalances in the fruit tree (Rodríguez-Polanco et al., 2018). The nutrient content can be interpreted from the foliar analysis with a scientific basis through indices, different methods have been proposed; the Kenworthy Balance Index (KBI) normalizes the concentration of nutrients sampled in a particular state of the plant, based on a reference standard value and the coefficient of variation (Kenworthy, 1961). Another index used to interpret the nutritional values is the Deviation from the Optimum Percentage (DOP) index, defined as the percentage deviation of the concentration of an element with respect to the reference standard value (Montañés et al., 1991). These diagnostic methods address the aspect of nutritional balance by analyzing each nutrient in isolation from the others, giving an idea of the balance between what was absorbed and what the plant needs, based on the values obtained, the needs and excesses of nutrients are determined, as well as the type of fertilization to apply (Kenworthy, 1961; Montañés et al., 1991).

According to the reviewed literature, there is little information available on the optimal nutritional values of the soursop crop at a specific phenological moment, the studies carried out by Avilán (1975), Gazel-Filho et al. (1994) and Fernández-Batista et al. (2003) provide macronutrient reference values in juvenile plants (up to 1 year old); Yamarte-Chirinos et al. (2009) evaluated macronutrients (N, K, Ca, Mg and Na) in grafted and free-standing plants; Silva de Lima et al. (2007) studied macro and micronutrients (with the exception of N and B) in 2.5-year-old plants; Marques et al. (2018) report the concentration of macro and micronutrients in the reproductive stage of the plant. For this study, it is considered that Andrade (2004) provides the most complete and indicative information on nutritional standards in soursop, these correspond to minimum and maximum concentrations, regardless of the variety or cultivar.

Nutrition studies in fruit trees vary, as different indices have been used. IBK has been used in cocoa (*Theobroma cacao*) (Bahia et al., 2021) and avocado (*Persea americana* cv. Hass) (Maldonado-Torres et al., 2007). DOP has been used in guava (*Psidium guajava*) (Nava et al., 2006), avocado (Persea americana cv. Hass) (Sotelo-Nava et al., 2017) and tahiti acid lime (*Citrus latifolia*) (Rodríguez-Polanco et al., 2018). Although it is infrequent to find studies where comparisons were made with the KBI and DOP indices, these have been carried out in coffee cultivation (*Coffea sp.*) associated with tree species, the two diagnostic indices coincided in 70% with deficient or low nutrients; N, K, Ca and B in the four agroforestry systems, high P and low Fe in three systems, low Zn in two systems, low Mg and Mn in one system, and high Cu and Mn in one agroforestry system (Garza-Lau et al., 2020). Taking into account that the diagnosis establishes alterations and/or balances or predicts future nutrient limitations in the crops, the objective of this study was to evaluate the foliar nutrient concentration in the vegetative state and compare the nutritional diagnosis between KBI and DOP in the crop of soursop.

2. Methodology

Study zone

The municipality of Compostela is located on the southern coast of the state of Nayarit (21º 22' to 20º 52' north latitude and 104º 49' to 105º 22' west longitude). The climate is semi-warm (Köppen's Aw2) with an average annual temperature of 22.9°C and relative humidity of 79% on average. The average annual precipitation is 1.140 mm with seasonal rain between the months of July to October (301 mm of average monthly precipitation) (CONAGUA, 2023).

The predominant crop is soursop under rainfed conditions, on average the pH of the soils is moderately acid (5.7), high organic matter content (6.8%), medium texture (sandy clay loam and clay loam) and low cation exchange capacity (10.6 Cmol+kg^{-1}). The N content is high (57.4 mg kg^{-1}) and medium content of P (23 mg kg^{-1}), K (23.1 mg kg^{-1}), Ca (103 mg kg^{-1}) and Mg (35.1 mg kg^{-1}).

Regarding micronutrients, very high content of B (4.97 mg kg^{-1}), high Mn (31.8 mg kg^{-1}), moderately low Fe (8.66 mg kg^{-1}) and Zn (0.98 mg kg^{-1}) and, low Cu (0.40 mg kg^{-1}) (Martínez-Mera et al., 2023).

Nutritional diagnosis

In the month of March 2019, in the municipality of Compostela, 12 orchards were sampled in the vegetative stage with ages between 15 and 33 years, seven trees were randomly chosen for each hectare of surface area (Martínez-Mera et al., 2023), from the middle part of the tree crown (approximately 1.8 m high), in each of the four cardinal points a branch was chosen and complete leaves (without damage, mature and physiologically active) were taken from the third and fourth position. The samples were stored in paper bags and kept cold (5±2 °C). Subsequently, in the soil analysis laboratory of the Autonomous University of Nayarit, the leaves were washed with distilled water and dried in an oven at 70 °C until reaching constant weight. Finally, they were processed in a stainless-steel mill (General Electric 5XBG015D®), with 40 mesh (0.45 mm opening between threads) (Silva de Lima et al., 2007; Yamarte-Chirinos et al., 2009).

Sample analyzes were performed in triplicate. Wet digestion was performed with mixed acids (sulfuric:perchloric); the extract obtained was measured with deionized water to analyze macronutrients, N by Kjeldahl; P by the vanadate-molybdate yellow method; K by flame emission spectrophotometry (Cole Parker 360®); Ca, Mg and micronutrients (Cu, Zn, Fe and Mn) with atomic absorption spectrophotometry (Agilent 240FS AA®) and B by the Azometina-H method (Alcántar-Gónzalez & Sandoval-Villa, 1999). The foliar analyzes were interpreted with the equations of the KBI and DOP to compare the nutrient concentration with the reference standard value proposed.

Kenworthy Balance Index (Kenworthy, 1961)

If C is less than the reference standard value:

$$P = (C/(Cref))*100$$
$$I = (100-P)*(CV/100)$$
$$IBK = P + I \quad (1)$$

If C is greater than the reference standard value:

$$P = (C/(C\ ref))*100$$
$$I = (P-100)*(CV/100)$$
$$IBK = P - I \quad (2)$$

Where C: foliar concentration of the sample; Cref: standard reference value; I: influence of the variation; P: percentage of the standard; CV: coefficient of variation of each nutrient; KBI: Kenworthy balance index.

Nutrient concentrations were adjusted by the coefficient of variation obtained from the data. The KBI of each nutrient were interpreted considering the analytical values according to their concentrations and were classified as: deficient (17-49%), low (50-82%), adequate (83-116%), high (117 -150%) and excessive (151-183%) (Kenworthy, 1961).

Deviation from optimum percentage (Montañés et al., 1991)

$$DOP = (C \times 100)/(Cref)-100$$

Where C: foliar concentration of the sample; Cref: standard reference value.

Negative DOP values for a certain element indicate a deficit, positive values reflect an excess of the element and when the index is zero the nutrient is in an optimal concentration (Montañés et al., 1991).

Due to the difference in the categorization of the ranges, to make the comparison between the KBI and the DOP indices, it was considered that the low range of the KBI would be categorized as deficient. Additionally, to calculate the indices, the average of the reference standard values proposed by Andrade (2004) was used (Table 1).

Table 1

Standard values used in the calculation of the KBI and DOP for soursop crop in the municipality of Compostela, Nayarit (Andrade, 2004)

Nutrient	Standard	Average
Nitrogen (%)	1.7-2.8	2.25
Phosphorus (%)	0.1-0.9	0.5
Potassium (%)	1.8-2.6	2.2
Calcium (%)	1.2-1.8	1.5
Magnesium (%)	0.2-0.4	0.3
Copper (mg kg^{-1})	100	100
Iron (mg kg^{-1})	100	100
Manganese (mg kg^{-1})	130	130
Zinc (mg kg^{-1})	16	16
Boron (mg kg^{-1})	41-49	45

3. Results and discussion

Nutritional diagnosis

The nutritional diagnosis results to determine the KBI and DOP come from a previously developed investigation where a nutritional characterization of the orchard was carried out (Martínez-Mera et al., 2023). The nutritional status of the soursop crop for the 12 orchards presented similarity in the macronutrients; the foliar nutrient concentration of N, P, K, Ca and Mg was lower than the reference standard in 100% of the orchards, with the exception of orchard 3; in which the Mg content was equal to the reference standard. The coefficient of variation (CV%) was low for N (6.65%), K (4.42%), Ca (9.46%) and Mg (6.70%). Regarding the variation in the nutritional concentration of P (13.2%), it was acceptable found in the range of 10% to 33% (Table 2).

The nutritional status of the soursop crop for the 12 orchards presented similarity in the micronutrients Mn and B since the foliar nutrient concentration was lower than the reference standard in 100 % of the orchards. However, Cu obtained values higher than the reference standard in 91 % of the orchards, with the exception of orchards 6 and 10. The micronutrients Fe, Cu and Zn showed variability in the nutrient concentration; orchards 2, 4, 6, 9 and 10 exhibited lower values than the reference standard for Fe and Zn; contrary to this, orchards 3, 7 and 11 showed values higher than the reference standard of Fe and Zn. The CV was low for Fe (5.51%) and Mn (2.27%). Unlike the variation in the nutritional concentration of Cu (10.5%), Zn (15.1%) and B (23.3%), which was acceptable since it was found in the range of 10 to 33% (Table 3).

The foliar macro and micronutrients that were deficient did not manifest visual symptoms, which are possibly associated with hidden hunger, generating a nutritional imbalance that does not reach the level to generate the manifestation of the characteristic symptoms according to the deficient nutrient (Hajiboland, 2011). Although it can also be associated with the phenological moment of the fruit tree; perennial crops are nutritionally efficient, nutrient reserves and their subsequent translocation are influenced by the phenological stage that guarantee the nutritional balance of plant tissues (Vasconcelos-Botelho & Lopes-Müller, 2020; Gentile et al., 2022).

Table 2

Foliar macronutrient content (%) of the soursop crop in the municipality of Compostela, Nayarit

Orchard	N	P	K	Ca	Mg
	% ± SD				
1	1.26±0.13	0.006±0.001	0.38±0.01	0.43±0.02	0.23±0.05
2	1.19±0.05	0.011±0.002	0.16±0.01	0.29±0.03	0.24±0.02
3	1.17±0.11	0.008±0.002	0.17±0.001	0.44±0.01	0.30±0.01
4	1.41±0.10	0.015±0.001	0.17±0.001	0.35±0.01	0.22±0.01
5	0.90±0.03	0.016±0.001	0.17±0.001	0.52±0.01	0.26±0.01
6	0.91±0.11	0.019±0.003	0.17±0.001	0.47±0.01	0.24±0.01
7	1.39±0.06	0.008±0.002	0.23±0.008	0.53±0.13	0.20±0.01
8	1.13±0.10	0.006±0.002	0.28±0.001	0.44±0.07	0.16±0.01
9	1.23±0.04	0.003±0.001	0.24±0.001	0.43±0.04	0.18±0.02
10	1.07±0.05	0.003±0.001	0.18±0.001	0.49±0.03	0.16±0.02
11	0.92±0.02	0.006±0.001	0.15±0.01	0.16±0.02	0.13±0.01
12	1.08±0.06	0.006±0.001	0.16±0.001	0.35±0.02	0.21±0.01
CV(%)	6.65	13.2	4.42	9.46	6.70

CV: Coefficient of Variation; S.D: Standard deviation.

Table 3

Foliar micronutrient content (mg kg^{-1}) of the soursop crop in the municipality of Compostela, Nayarit

Orchard	Cu	Fe	Mn	Zn	B
	mg kg^{-1} ± SD				
1	15.4±0.43	109±0.77	24.0±0.48	11.5±0.29	10.1±0.35
2	11.3±0.79	85.2±0.71	48.3±0.25	12.0±0.24	0
3	12.2±0.46	169±3.60	34.8±0.28	19.1±0.22	1.24±0.35
4	11.8±0.25	63.4±0.64	26.0±0.12	13.4±1.19	0
5	19.2±4.40	56.9±0.43	24.3±0.18	26.1±0.29	0
6	8.94±0.29	65.7±0.11	32.2±0.11	10.7±0.23	0
7	15.1±0.18	108±11.1	36.9±2.11	20.9±0.36	6.20±1.05
8	18.7±0.32	98.0±15.9	47.3±0.46	19.9±0.56	0
9	17.0±0.27	88.6±1.84	47.9±2.58	13.7±0.23	0
10	6.40±0.17	96.9±0.34	17.3±0.80	12.3±0.84	0
11	16.5±0.26	100±1.34	30.5±1.18	19.6±0.87	8.68±0.75
12	13.3±0.18	118±1.79	23.1±0.67	14.4±018	2.48±0.70
CV(%)	10.5	5.51	2.27	15.1	23.3

CV: Coefficient of Variation; S.D: Standard deviation.

On the other hand, the excess of Cu, Fe and Zn in some orchards can be related to foliar fertilization of micronutrients or applications of agrochemicals to control pathogens; high foliar concentrations can generate toxicity and alter metabolism, reduce growth and biomass production, in addition to the accumulation of metals (Kalaivanan & Ganeshamurthy, 2016).

Soil fertility is a determining factor in the availability of nutrients for plants. In cacao (*Theobroma cacao*), it has been reported that the high variability of the nutrient content of the leaves may be a consequence of the diversity of climatic and edaphic conditions with soils with wide variability of mineralogical, chemical and physical attributes (Arévalo-Hernández et al., 2019). Although there is a methodological limitation to determine the direct influence between soil fertility and nutrient remobilization, there are studies that have reported a positive correlation between these two factors. Other studies contradict this correlation, and it is possibly related to the fact that plants can restrict the availability of nutrient concentrations because the remobilization of nutrients in the leaf is a metabolic process regulated by environmental factors and physiological processes. Therefore, the main factor affecting the remobilization rate is the element itself (Achat et al., 2018). In accordance with the concentration of nutrients in the soil and foliar, in this study a positive correlation was not observed between them, since the nutrients N (57.4 mg kg^{-1}), Mn (31.8 mg kg^{-1}) and B (4.97 mg kg^{-1}), with high concentration in the soil, showed lower values (1.14 %N, 32.7 mg kg^{-1} Mn and 2.39 mg kg^{-1} B) than the foliar reference standards (1.7-2.8% N, 130 mg kg^{-1} Mn and 41-49 mg kg^{-1} B). There is few research on nutritional diagnosis of soursop that includes macro and micronutrients. In Colombia, Miranda-Lasprilla et al. (1996) evaluated the foliar concentration of five orchards, on average were reported 1.38% N, 0.18% P, 0.54% K, 3.04% Ca, 0.34% Mg, 7.62 mg kg^{-1} Cu, 81 mg kg^{-1} Fe, 40.8 mg kg^{-1} Mn, 35.4 mg kg^{-1}, Zn and 23.9 mg kg^{-1} B. Although the characteristics of the tree, phenology, sampling season and type of management are not reported, the foliar nutrient content shows values lower than the standards of N, P, K, Cu, Fe, Mn and B in 100% of the orchards, for Ca and Mg 60% of the orchards exhibit values higher than the standard and for the Zn, 100% of the orchard's present values higher than the standard. Similarly, in Mexico (Veracruz) Vidal-Hernández et al. (2014) diagnosed soursop crop in vegetative phenology in the dry season, the nutritional concentration was 2.53% N, 0.04% P, 3.05% K, 0.98% Ca, 0.15% Mg, 7.1 mg kg^{-1} Cu, 135 mg kg^{-1} Fe, 9.3 mg kg^{-1} Mn and 481 mg kg^{-1} Zn. Thus, the foliar nutrient content shows values higher than the standard for N, K, Fe and Zn. On the contrary, values below the standard are observed for Ca, Mg, Cu and Mn in the orchards of Mexico.

Fruit trees absorb nutrients throughout the year, however, variations in nutrient content are associated with edaphoclimatic aspects, plant age, yield, cultivar, genotype, and cultural practices (Silva de Lima et al., 2007). Regarding the temporary condition, it influences the absorption and transport of nutrients; The low availability of water in the soil combined with high temperatures reduce the absorption of nutrients, which can cause deficiency or imbalance of these and affect the distribution of photoassimilates, with consequence in physiological processes related to the formation of stems, roots, flowers and fruits (Aluko et al., 2021). Vidal-Hernandez et al. (2014) in soursop crop in Veracruz found differences in the foliar nutrient concentration between productive and non-productive trees during the dry season; this period includes six months with average monthly precipitation of 28.1 mm and the highest leaf content prevailed in non-productive trees. Unlike the study area in Nayarit, the dry period is eight months with 14.9 mm of average monthly precipitation, a situation that could influence the presence of deficiencies and probably explains the low leaf values.

Zhou & Melgar (2020) consider that nutrient reabsorption and remobilization become quantitatively more significant for older trees because they translocate more nutrients to permanent structures during leaf senescence, suggesting that they can recycle nutrients from more efficient way. However, this hypothesis needs to be confirmed by reuptake studies using labeled elements. The same way, orchard specific information should also be considered, such as the nutritional status of the trees from the previous year, annual yield, pruning intensity, as these differences can affect orchard productivity. In the case of soursop studies, crops have been developed in different regions, a possible cause that generates differences in nutritional ranges and due to the lack of agronomic information, it is difficult to determine the factors that influence these differences in nutritional diagnosis.

KBI and DOP indices

The nutritional diagnosis obtained showed excesses and deficiencies of nutrients. In general, the behavior of the limiting nutrients with the KBI and DOP diagnostic indices was the same for macro and micronutrients in 90% of the orchards. On the contrary, the differences between the indices occurred in 10% of the orchards; with the KBI the nutrient was adequate and with the DOP the nutrient was deficient. Only the nutrients Mg, Cu, Fe and Zn were adequate with the KBI in 35% of the orchards. The KBI and the DOP indicated that the diagnosis of the nutrients N, P, K, Ca, Mn and B, were the same because 100% of the orchards presented ranges of deficiency. On the contrary, the KBI and the DOP were excessive for the micronutrients Fe, Cu and Zn; in orchards 8, 9 and 11 with the Cu micronutrient, in orchard 5 with the Cu and Zn micronutrients and, in orchard 3 with Fe. The contrast cases where the KBI of the nutrient was adequate and with the DOP the nutrient was deficient were presented for orchards 1 and 5 with Mg; orchard 2 with Mg and Fe; orchards 4, 8 and 10 with Fe; orchard 6 with Mg and Cu, orchard 9 with Fe and Zn and orchard 12 with Fe (Table 4). Metabolic functions and crop yields can be affected by nutrient interactions in the uptake, distribution, or function of another nutrient. Therefore, the balanced nutrient approach is important for proper crop yield (Tiwari et al., 2020). In this study, the deficiency levels, although they were high, did not generate the manifestation of the characteristic symptoms according to the deficient nutrient since the difference with the standard nutrient concentration could be related to the phenological stage of the fruit tree and the amount of the nutrient is suitable for its function.

Table 4
Nutritional diagnosis of the soursop crop using the KBI and DOP indices in the municipality of Compostela, Nayarit

Indices	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn	B
					Orchard 1					
KBI	59	14	21	36	85	149	109	20	77	41
DOP	-44	-99	-83	-71	-21	55	9	-81	-28	-77
					Orchard 2					
KBI	56	15	11	28	86	112	86	39	79	23
DOP	-47	-98	-93	-80	-19	14	-15	-63	-25	-100
					Orchard 3					
KBI	55	15	12	37	108	120	165	28	121	25
DOP	-48	-98	-92	-71	2	23	69	-73	25	-97
					Orchard 4					
KBI	66	16	12	31	80	116	75	22	86	23
DOP	-37	-97	-92	-77	-27	18	-27	-80	-16	-100
					Orchard 5					
KBI	47	16	12	24	93	183	59	21	154	23
DOP	-56	-97	-92	-65	-13	93	-43	-81	63	-100
					Orchard 6					
KBI	45	17	12	39	87	91	68	26	72	23
DOP	-59	-96	-92	-68	-19	-11	-34	-75	-33	-100
					Orchard 7					
KBI	65	15	15	43	74	146	108	30	126	34
DOP	-38	-98	-89	-64	-32	51	8	-72	31	-86
					Orchard 8					
KBI	54	14	17	37	60	179	98	38	121	23
DOP	-50	-99	-87	-70	-46	88	-2	-64	24	-100
					Orchard 9					
KBI	58	14	15	37	69	163	89	38	88	23
DOP	-45	-99	-89	-71	-37	71	-11	-63	-14	-100
					Orchard 10					
KBI	51	14	12	40	61	68	97	15	81	23
DOP	-52	-99	-92	-67	-45	-36	-3	-87	-23	-100
					Orchard 11					
KBI	45	14	11	20	50	159	101	25	119	38
DOP	-59	-99	-93	-89	-56	66	1	-76	23	-81
					Orchard 12					
KBI	52	14	12	32	79	130	117	20	92	28
DOP	-52	-99	-93	-76	-27	33	18	-82	-10	-94

KBI: Kenwhorthy Balance Index; DOP: Deviation from Optimum Percentage.

Also, it should be considered that the anonas present overlapping phenophases where the vegetative and reproductive phases occur at the same time, these two simultaneous phenological processes generate competition between nutrients, physiologically there is a feedback control between the top and the roots to maintain balance, generating variation in the nutrient concentration (Paull & Duarte, 2012).

There are different indices to diagnose crops, in general the results obtained from the foliar sample are compared with another called reference pattern or reference standard value (Puentes-Páramo et al., 2016). The diagnoses using the KBI where coffee (Souza da Fonseca et al., 2018), avocado (Campos-Mariscal et al., 2020) and, diagnoses using DOP in hazelnut cultivation (Ajili-Lahiji, 2021) and mango (Yacomelo-Hernández et al., 2021), have proven to be effective in determining the nutritional status of plants, indicating the nutrient imbalances of the studied commercial orchards and proposing the order of nutritional requirements that serve as a guide to improve the nutritional status of the fruit tree in areas with similar edaphoclimatic conditions. In this study, the use of KBI and DOP evidence the nutritional status of the soursop crop, demonstrating that the nutrients N, P, K, Ca, B and Mn are the most limiting due to deficiency (in 100% of the orchards) and, by excess Cu (in 33% of the orchards), Fe and Zn (in 8% of the orchards respectively).

Although the same behavior was not presented in the decreasing order of the limiting nutrients, it is possible to consider a common deficiency pattern mainly with P, K, Mn and B. In general, with the two indices, 25% of the orchards coincide with the order decreasing the nutrients P<K<Ca<N<Mg<Mn<B<Zn<Fe<Cu (Table 5).

The nutritional diagnosis is an appropriate tool to know the nutritional limitations of the crop and determine the optimal concentration of nutrients in a phenological state of the crop, to obtain higher yields (Puentes-Páramo et al., 2016). Nutrient deficiency affects the physiological, biochemical and metabolic functions of plants. Tiwari et al. (2020) and De Bang et al. (2021) mention that N deficiency reduces the synthesis of biomolecules and photosynthetic activity, therefore, growth decreases; P deficiency affects regulation of protein synthesis, cell division, and root development; K deficiency limits osmotic regulation, stomatal opening, protein and starch synthesis; Ca deficiency impairs the structure of the cell wall reducing growth and; Mg deficiency affects activity as a cofactor, chlorophyll biosynthesis, and RuBisCo activation. Micronutrients participate as constituents of prosthetic groups in metalloproteins and activators of enzymatic reactions; Mn deficiency interferes with the regulation of protein, carbohydrate, lipid, and lignin biosynthesis; B deficiency hinders pollen germination, pollen tube growth, seed formation, and cell wall formation; Zn deficiency affects the structural composition of enzymes and proteins; Fe deficiency decreases the catalytic activity of chlorophyll synthesis and the formation of chelates and; Cu deficiency affects the formation of chlorophyll, regulation of cell metabolism and the structural composition of enzymes (Tiwari et al., 2020). The limiting nutrients, in addition to the phenological effect, can cause the interactions between them to be antagonistic due to excess or deficiency, in this way the absorption of another element could be reduced, inducing deficiency, therefore, this situation will not favor the adequate development of the crop, since the optimal nutritional level is not balanced (Tiwari et al., 2020).

Table 5
Decreasing order of the limiting nutrients due to deficiency in the soursop crop in the municipality of Compostela, Nayarit

Orchard	Concentration KBI		Concentration DOP	
	Macronutrients	Micronutrients	Macronutrients	Micronutrients
1	P<K<Ca<N<Mg	Mn<B<Zn<Fe<Cu	P<K<Ca<N<Mg	Mn<B<Zn<Fe<Cu
2	K<P<Ca<N<Mg	B<Mn<Zn<Fe<Cu	P<K<Ca<N<Mg	B<Mn<Zn<Fe<Cu
3	K<P<Ca<N<Mg	B<Mn<Cu<Zn<Fe	P<K<Ca<N<Mg	B<Mn<Cu<Zn<Fe
4	K<P<Ca<N<Mg	Mn<B<Fe<Zn<Cu	P<K<Ca<N<Mg	B<Mn<Fe<Zn<Cu
5	K<P<Ca<N<Mg	B<Mn<Fe<Zn<Cu	P<K<Ca<N<Mg	B<Mn<Fe<Zn<Cu
6	K<P<Ca<N<Mg	B<Mn<Fe<Zn<Cu	P<K<Ca<N<Mg	B<Mn<Fe<Zn<Cu
7	K=P<Ca<N<Mg	Mn<B<Fe<Zn<Cu	P<K<Ca<N<Mg	B<Mn<Fe<Zn<Cu
8	P<K<Ca<N<Mg	B<Mn<Fe<Zn<Cu	P<K<Ca<N<Mg	B<Mn<Fe<Zn<Cu
9	P<K<Ca<N<Mg	B<Mn<Zn<Fe<Cu	P<K<Ca<N<Mg	B<Mn<Zn<Fe<Cu
10	K<P<Ca<N<Mg	B<Mn<Cu<Zn<Fe	P<K<Ca<N<Mg	B<Mn<Cu<Zn<Fe
11	K<P<Ca<N<Mg	Mn<B<Fe<Zn<Cu	P<K<Ca<N<Mg	B<Mn<Fe<Zn<Cu
12	K<P<Ca<N<Mg	Mn<B<Zn<Fe<Cu	P<K<Ca<N<Mg	B<Mn<Zn<Fe<Cu

Finally, for decision-making on the nutritional management of the soursop crop, the use of tools that evaluate the nutritional balance is very important, especially for the diagnosis of deficiencies or excesses, which would indicate the need for adjustments in nutrient doses.

4. Conclusions

The foliar concentration of the nutrients N, P, K, Ca, Mg, Mn and B was lower than the reference standard in 100% of the soursop orchards in the state. Cu was excessive in 91% of the orchards, Zn in 98% of the orchards and Fe in 25% of the orchards. The KBI and DOP diagnoses coincided with 90 % in that the nutrients N, P, K, Ca, B and Mn are the most limiting due to deficiency and excessive Cu in 33% of the orchards, Fe and Zn in 8% of the orchards.

The order of the limiting nutrients in the orchards (P<K<Ca<N<Mg<Mn<B<Zn<Fe<Cu) indicate that nutritional management of the soursop crop should be implemented in the studied orchards.

References

Achat, D. L., Pousse, N., Nicolas, M., & Augusto, L. (2018). Nutrient remobilization in tree foliage as affected by soil nutrients and leaf life span. *Ecological Monographs, 88,* 408-428. https://doi.org/10.1002 /ecm.1300

Alcántar-Gónzalez, G., & Sandoval-Villa, M. (1999). Manual de análisis químico de tejido vegetal. Sociedad Mexicana de la Ciencia del Suelo. A.C. Chapingo, Estado de México, México.156 p.

Aluko, O.O., Li, C., Wang, Q., & Liu, H. (2021). Sucrose utilization for improved crop yields: a review article. International Journal of *Molecular Sciences, 22*(9), 4704. https://doi.org/10.3390/ijms22094704

Andrade, L. R. M. (2004). Corretivos e fertilizantes para culturas perenes e semiperenes. In: Cerrado: correção do solo e adubação. Sousa, D.M.G., & Lobato, E. (eds.). Embrapa Informação Tecnológica. Planaltina, Brasil. pp. 317-366.

Ajili-Lahiji, A. (2021). Study of nutritional status of hazelnut orchards of (*Corylus avellana* L.) Guilan Province by using with Deviation of Optimum Percentage (DOP). *Journal of Horticultural Science, 35*(49), 73-8. https://doi.org/10.22067/JHS.2021.61863.0

Arévalo-Hernández, C. O., Pinto, F. C., Souza-Júnior, J. O., Paiva, A. Q., & Baligar, V. C. (2019). Variability and correlation of physical attributes of soils cultivated with cacao trees in two climate zones in Southern Bahia, Brazil. *Agroforestry Systems, 93*, 793-802. https://doi.org/10.1007/s 10457-017-0176-4

Avilán, L. (1975). Efecto de la omisión de los macronutrientes en el desarrollo y composición química de la guanábana (*Annona muricata* L.) cultivada en soluciones nutritivas. *Agronomía Tropical, 25*(1), 73-79.

Bahia, B. L., Souza-Júnior, J. O., Fernandes, L. V., & Neves, J. C. L. (2021). Reference values and diagnostic ranges to assess the degree of nutritional balance for cacao plants. *Spanish Journal of Agricultural Research, 19*(1), e0801. https://doi.org/10.5424/sjar/2021191-17478

Campos-Mariscal, J. L., Álvarez Sánchez, M. E., Maldonado-Torres, R., & Almaguer-Vargas, G. (2020). Application of organic fertilizers in yield and root development in avocado cultivation. *Revista Mexicana de Ciencias Agrícolas, 11*(2), 263-274. https://doi.org/10.29312/remexca.v11i2.2301

CONAGUA. Comisión Nacional del Agua. (2023). Resúmenes mensuales de temperaturas y lluvia. Comisión Nacional del Agua. México.

De Bang, T. C., Husted, S., Laursen, K. H., Persson, D. P., & Schjoerring, J. K. (2021). The molecular-physiological functions of mineral macronutrients and their consequences for deficiency symptoms in plants. *New Phytologist, 229*(5), 2446-2469. https://doi.org/10.111 /nph.17074

Fernandes-Batista, M. M., Matos-Viégas, I. J., Capucho-Frazão, D. A., Alves-Thomaz, M. A., & Lemos da Silva, R. E. (2003). Efeito da omissão de macronutrientes no crescimento, nos sintomas de deficiências nutricionais e na composição mineral em gravioleiras (*Annona muricata*). *Revista Brasileira de Fruticultura, 25*(2), 315-318. http://dx.doi.org/10.1590/S0100-29452003000200033

Garza-Lau, R., Maldonado-Torres, R., Álvarez-Sánchez, M., & Torres-Rivera, J. (2020). Caracterización de especies arbóreas asociadas al cultivo de café. *Revista Mexicana de Ciencias Agrícolas, 11*(1), 25-32. https://doi.org/10.29312/remexca.v11i1.2210

Gazel-Filho, A.B., De Carvalho, A.C., & De Menezes, A.J. (1994). Teores de macronutrientes em folhas de gravioleiras. *Revista Brasileira de Fruticultura, 16*(2), 121-124.

Gentile, R. M., Boldingh, H. L., Campbell, R. E., Gee, M., Gould, N., Lo, P., McNally, S., Park, K., Richardson, A. C., Stringer, L.D., Vereijssen, J., & Walter, M. (2022). System nutrient dynamics in orchards: a research roadmap for nutrient management in apple and kiwifruit. A review. *Agronomy for Sustainable Development, 42*(64), 1-18. https://doi.org/10.1007/s13593-022-00798-0

Hajiboland, R. (2011). Effect of micronutrient deficiencies on plants stress responses. In: Abiotic stress responses in plants: metabolism, productivity and sustainability. Ahmad, P., & Prasad, M. (eds.). Springer. New York, United States. pp. 283-329.

Kenworthy, A. L. (1961). Interpreting the balance of nutrient elements in leaves of fruit trees. In: Plant analysis and fertilizer problems. Reuther. W. (ed.). American Institute of Biological Sciences. Washington, Estados Unidos. pp. 28-43.

Kalaivanan, D., & Ganeshamurthy, A. N. (2016). Mechanisms of heavy metal toxicity in plants. In: Abiotic stress physiology of horticultural crops. Rao, N.; Shivashankara, K., & Laxman, R. (eds.). Springer, New Delhi. pp. 85-102. https://doi.org/10.1007/978-81-322-2725-0_5

Maldonado-Torres, R., Álvarez-Sánchez, M. E., Almaguer-Vargas, G., Barrientos-Priego, A. F., & García-Mateos, R. (2007). Estándares nutrimentales para aguacatero Hass. *Revista Chapingo Serie Horticultura, 13*(1), 103-108. https://doi.org/10.5154/r.rchsh.2006.11.051

Marques, L. F., Souto, J. S., Ferreira-Cavalcante, L. F., Mesquita, E. F., & Medeiros do Nascimento, J. A. (2018). Composição mineral e redistribuição de nutrientes em gravioleira. *Pesquisa Agropecuária Pernambucana Recife, 23*(1), 1-5. http://dx.doi.org/10.12661/pap.2018.006

Martínez-Mera, E. A., García-Paredes, J. D., Can-Chulim, A., Martínez-Rodríguez, O. G., Luna-Esquivel, G., Cruz-Crespo, E., & Balois-Morales, R. (2023). Caracterización nutrimental edáfica y foliar de huertos con producción de guanábana en Nayarit, México. *Acta Agrícola y Pecuaria, 9*, E0091003. https://doi.org/10.30973/aap/2023.9.0091003

Miranda-Lasprilla, D., Barragán-Quijano, E., Barreto-Osorio, D., & Caicedo, A. (1996). Requerimientos nutricionales en el cultivo de guanábana. In: Manejo integrado del cultivo de guanábana. Norato-Forero, T. (ed.). Corpoica. Bogotá, Colombia. pp. 65-126.

Montañés, L., Heras, L., Abadía, J., & Sanz, M. (1991). Plant analysis interpretation based on a new index: Deviation from optimum percentage (DOP). *Journal of Plant Nutrition, 16*, 1289-1308.

Nava, A. D., Gónzalez-Hernández, V. A., Sánchez-García, P., Peña-Valdivia, C. B., & Livera-Muñoz, M. (2006). Dinámica y diagnóstico nutrimental del guayabo en Iguala, Guerrero, México. *Terra, 24*, 125-132.

Paull, R. E., & Duarte, O. (2012). Annonas: soursop and rollinia. Tropical fruits. Crop Production Science in Horticulture. CABI International. Second edition. pp. 1-24. https://doi.org/10.1079/9781845937 898.0001

Puentes-Páramo, Y. J., Menjivar-Flores, J. C., & Aranzazu-Hernández, F. (2016). Concentración de nutrientes en hojas, una herramienta para el diagnóstico nutricional en cacao. *Agronomía Mesoamericana, 27*(2), 329-336. https://doi.org/10.15517/am.v27i2.19728

Rodríguez-Polanco, E., Gutiérrez- Díaz, J.S., & Orduz-Rodríguez, J.O. (2018). Diagnostico nutricional del cultivo de la lima ácida Tahití [*Citrus latifolia* (Yu Tanaka) Tanaka] en el departamento del

Tolima (Colombia). *Temas Agrarios, 23*(2), v144-153. http://dx.doi.org/10.21897/rta.v23i2.1298

SIAP. Servicio de Información Agroalimentaria y Pesquera. (2023). Anuario estadístico de la producción agrícola del 2019. https://nube.siap.gob.mx/cierreagricola/

Silva de Lima, R. L., Barbosa-Ferreira, G., Baller-Weber, O., & Osvaldo-Cazetta, J. (2007). Diagnose foliar da gravioleira (*Annona muricata* L.): efeito da posição de ramos e folhas. *Ciência e Agrotecnologia, 31*(5), 1320-1325.

Sotelo-Nava, H., Hernández-Castro, E., Villegas-Torres, O. G., Nava, A. D., Sabino-López, J. E., Chino-Cantor, A., Cruz-Lagunas, B., & Álvarez- Vargas, D. (2017). Nutritional diagnosis of "Hass" avocado (*Persea americana* Mill.) soil fertility and water quality, in Tepoztlán, Morelos. International *Journal of Environmental and Agriculture Research, 3*(1), 152-159.

Souza da Fonseca, A., De Souza-Lima, J. S., & De Assis-Silva, S. (2018). Spacial variability of Balanced Indexes of Kenworthy (BIK) for macro and micronutrients on the Coffee Canephora. *Journal of Experimental Agriculture International, 23*(1), 1-10. https://doi.org/10.9734/JEAI/2018 /41211

Tiwari, S., Patel, A., Pandey, N., Raju, A., Singh, M., & Prasad, S.M. (2020). Deficiency of essential elements in crop plants. In: Sustainable solutions for elemental deficiency and excess in crop plants. Mishra, K., Tandon, P.K., & Srivastava, S. (eds.). Springer, Singapore. 19-52. https://doi.org/10.1007/978-981-15-8636-1_2

Vasconcelos-Botelho, R., & Lopes-Müller, M. M. (2020). Nutrient redistribution in fruit crops: Physiological implications. In: Fruit crops: diagnosis and management of nutrient constraints. Srivastava, A. K., & Chengxiao, H. (eds.). pp. 33-46. https://doi.org/10.1016/B978-0-12-818732-6.00003-4

Vidal-Hernández, L., Sánchez-Viveros, G., Vidal-Martínez, A.V., Castillo-Rocha, D. G., & Chiquito-Contreras, R. G. (2014). Análisis de suelo y foliar en guanábano (*Annona muricata* L.) en Blanca Espuma municipio de Alto Lucero, Veracruz. *Revista Brasileira de Fruticultura, 36*, 150-159. https://doi.org/10.1590/S0100-29452014000500019

Yamarte-Chirinos, M., Marín-Real, M., & Rendiles-Ollarves, E. (2009). Contenido foliar de algunos macronutrimentos en guanábana (*Annona muricata* L.). *Revista UDO Agrícola, 9*(2), 343-346.

Yacomelo-Hernández, M., Ramírez-Gómez, M.M., Perez, U., Arcila, A., Carrascal-Pérez, F., & Florez-Cordero, E. (2021). Análisis nutricional y niveles de extracción del mango azúcar en el departamento del Magdalena, Colombia. *Bioagro, 33*, 79-90. https://doi.org/10.51372/bioagro332.2.346

Zhou, Q., & Melgar, J. C. (2020). Tree age influences nutrient partitioning among annually removed aboveground organs of peach. *HortScience, 55*(4), 560-564. https://doi.org/10.21273/HORTSCI14731-19