ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.27, n.5, p.415-421, 2023
agriambi
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v27n5p415-421

Nutritional status and quality of table grapes cultivated in Submédio São Francisco Valley[1]

Estado nutricional e qualidade da uva de mesa cultivada no Vale do Submédio São Francisco

Suellen R. V. da Silva[2*], Fernando J. Freire[3], Jefrejan S. Rezende[4], Renato L. dos Santos[5] & Jailson C. Cunha[6]

[1] Research developed at São Francisco Valley, Brazil
[2] Universidade Federal Rural de Pernambuco/Programa de Pós-Graduação em Ciência do Solo, Recife, PE, Brazil
[3] Univerdidade Federal Rural de Pernambuco/Departamento de Agronomia, Recife, PE, Brazil
[4] Universidade Estadual do Piauí/Departamento de Agronomia, Recife, PE, Brazil
[5] Instituto Federal de Educação, Ciência e Tecnologia/Departamento de Desenvolvimento Educacional, Vitória de Santo Antão, PE, Brazil
[6] PlantSoil Laboratórios, Petrolina, PE, Brazil

HIGHLIGHTS:

The nutritional diagnosis shows excess Ca in table grape orchards in the Submédio São Francisco Valley.
The nutritional balance in table grape orchards correlates negatively with the Ca-pectate concentration in the fruit.
The Ca-pectate concentration did not correlate with Ca-total concentration in fruit and with berry firmness.

ABSTRACT: The cultivation of fruit trees is influenced by abiotic factors such as nutritional management. However, fertilizers are used in large amounts in vineyards, resulting in excess nutrients that can cause stress and reduce fruit quality. Calcium (Ca) is one of the most used nutrients in vineyards due to its effects on fruit quality. However, excess of Ca interferes with the distribution of Ca compounds in fruits, being a form of abiotic stress. The aim of this study was to evaluate the influence of the nutritional balance of table grape orchards on calcium nutrition and fruit quality. Nineteen table grape orchards were selected in the Submédio São Francisco Valley in 2019 and 2020 crops. The nutritional diagnosis was performed using the integrated diagnosis and recommendation system (DRIS) and the average nutritional balance index (NBIm) was calculated. The concentration of Ca-pectate, Ca-total, berry firmness, soluble solids, titratable acidity, soluble solids/titratable acidity ratio and dry matter were determined in the fruits. The nutritional diagnosis identified excess Ca in the orchards. The correlation between Ca-pectate and the average NBIm was negative, indicating that the Ca-pectate concentration is higher in vines that are more nutritionally unbalanced. However, the Ca-total in the fruit was not correlated with Ca-pectate. Ca-total and Ca-pectate were not correlated with berry firmness. Calcium nutrition is complex and highlights the importance of associating the assessment of nutritional balance with Ca in fruit quality to optimize the nutritional management of the grapevine.

Key words: *Vitis vinifera* L., integrated diagnosis and recommendation system, nutritional balance, calcium in grapevine fruits

RESUMO: O cultivo de fruteiras é influenciado por fatores abióticos como o manejo nutricional. Contudo, os fertilizantes são usados em grandes quantidades em vinhedos, resultando no excesso de nutrientes que podem causar estresse e reduzir a qualidade dos frutos. O Ca é um dos nutrientes mais utilizados nos vinhedos devido aos seus efeitos na qualidade dos frutos. Entretanto, o excesso de Ca interfere na distribuição das suas frações nos frutos, sendo uma forma de estresse abiótico. O objetivo desse estudo foi avaliar a influência do balanço nutricional da uva de mesa na nutrição cálcica e qualidade dos frutos. Foram selecionados 19 pomares de uvas de mesa no Vale do Submédio São Francisco nas safras de 2019 e 2020. Foi realizado o diagnóstico nutricional utilizando o sistema integrado de diagnose e recomendação (DRIS) e calculado o índice do balanço nutricional médio (IBNm) médio. O teor de Ca-pectato, Ca-total, firmeza da baga, sólidos solúveis, acidez titulável, razão sólidos solúveis/acidez titulável e matéria seca foram determinados nos frutos. O diagnóstico nutricional identificou excesso de Ca. A correlação entre Ca-pectato e o IBNm médio foi negativa, indicando que o teor de Ca-pectato é maior em videiras mais desbalanceadas nutricionalmente. Contudo, o Ca-total no fruto não teve correlação com Ca-pectato. O Ca-total e o Ca-pectato não se correlacionaram com a firmeza da baga. A nutrição cálcica é complexa e evidencia a importância de associar a avaliação do balanço nutricional com o Ca na qualidade dos frutos para otimizar o manejo nutricional da videira.

Palavras-chave: *Vitis vinifera* L., sistema integrado de diagnose e recomendação, balanço nutricional, cálcio em frutos de uva

• Ref. 267901 – Received 15 Sept, 2022
* Corresponding author - E-mail: suellenrv1@gmail.com
• Accepted 03 Feb, 2023 • Published 07 Feb, 2023
Editors: Geovani Soares de Lima & Walter Esfrain Pereira

Introduction

Fruit crop cultivation is influenced by many abiotic factors that interfere with yield and fruit quality such as soil type, climatic conditions, and nutritional management (Brunetto et al., 2020). Grapes (*Vitis* sp.) are nutritionally demanding crops that have been adapted to tropical regions as the Brazilian semi-arid. The Submédio São Francisco Valley stands out in the production of seedless table grape in Brazil, where is produced two annual grape crops. Intense cultivation presents high nutritional demand from the plant to keep high yield and fruit quality (Oliosi et al., 2020).

Thus, the fertilization management is fundamental in grapes cultivation. However, fertilizers are overused in vineyards (Brunetto et al., 2020). Nutrient excess or deficiency are a form of abiotic stress and trigger physiological and morphological responses that can decrease yield and fruit quality (Gao et al., 2019).

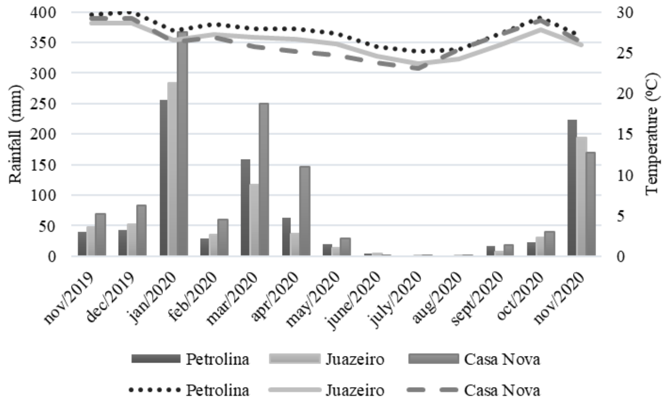
Ca is often overused in grapes cultivation (Brunetto et al., 2020; Sotiropoulos et al., 2021) because it plays important functions in fruit formation, development, and quality (Sinha et al., 2019). Most of Ca is present in the cell wall as Ca-pectate which is related to fruit firmness, prevention of physiological disorders related to cell wall integrity, and quality variables (Gao et al., 2019; Sinha et al., 2019). As high Ca concentration is toxic to cells, grapevines use mechanisms to control it such as forming Ca-oxalate crystals. These Ca fractions are influenced by the concentration of other nutrients as P, K, and Fe (Bonomelli et al., 2018).

Therefore, nutritional balance methods can be great tools to predict the nutritional status of the plant and avoid nutrient excess or deficiency and their consequences in yield and fruit quality. The objective in this study was to evaluate the influence of the nutritional balance of table grape orchards on calcium nutrition and fruit quality.

Material and Methods

The study was carried out in the Submédio São Francisco Valley, Brazil, from November 2019 to November 2020. The data were collected from three table grapes commercial farms located in Casa Nova/BA (NQ1) (9.1753439 S; 40.9765494 W; elevation 380 m), Juazeiro/BA (NF1) (9.4312149 S; 40.5100556 W; 371 m of altitude), and Petrolina/PE (NQ2) (9.4311232 S; 40.5428867 W; 376 m of altitude). The climate is classified as tropical semi-arid Bsh type in Köeppen classification (Alvarez et al., 2013). The monthly temperature and rainfall are represented in Figure 1. The soils are classified as Quartzipsamments (United States, 2014) that correspond to a Neossolo Quartzarênico distrófico textura arenosa in the Brazilian Soil Classification System (EMBRAPA, 2018) in Petrolina and Casa Nova farms. The soil is classified as Fluvent (United States, 2014) that corresponds to a Neossolo Flúvico eutrófico in the Brazilian Soil Classification System (EMBRAPA, 2018) in Juazeiro farm.

The database consisted of 19 orchards harvested in the first (seven orchards) and second (12 orchards) 2020 semesters. The orchards had 1.85 ha area cultivated with BRS Vitória, Sweet



Source: Agritempo (2020)

Figure 1. Monthly air temperature and rainfall in Petrolina (PE), Juazeiro (BA), and Casa Nova (BA) during the study

Jubilee, and Sugar Crisp cultivars grafted to SO4 rootstock. The database had one to four-year grapevines.

The orchards had a varied bud dormancy time according to the commercialization schedule. It was performed the dormant pruning only in the one-year planting orchards. The soil was sampled 15 days before the production pruning. It was realized two soil samples per plant (one in the plant line and the other in the interline), about 0.15 m from the plant, at 0.0-0.30 m depth. It was collected 60 simple samples to form one composite sample in each orchard. The soil chemical attributes were determined according to Silva (2009) (Table 1).

There was no need to perform liming on any of the farms. The base fertilization consisted in the application of P (simple superphosphate), Ca (lithothamnium), and Mg (Mg oxide). It was also applied goat manure (10 L per plant).

The pruning was made 15 days after the soil sampling and was applied hidrogen cyanamide (CH_2N_2) to induce budbreak. The surface fertilization was performed weekly after the pruning with all macronutrients and Fe, Cu, Zn, Mn, and B by fertigation.

The fertilizer sources were the same among the farms, but the rates applied were different according to the soil attributes values. NQ1 soil was applied: 50 kg ha^{-1} of Mg_2SO_4; 35 kg ha^{-1} of K_2SO^4; 6 kg ha^{-1} of Fe_2SO_4; 6 kg ha^{-1} of Zn_2SO_4; 50 kg ha^{-1}

Table 1. Soil chemical attributes in the study areas

Attributes	NQ1	NQ2	NF1
pH (H_2O)	6.57	6.61	6.95
Ca^{2+} (cmol$_c$ dm^3)	6.46	5.78	10.48
Mg^{2+} (cmol$_c$ dm^3)	2.58	1.67	2.51
Ca^{2+}/Mg^{2+} ratio	2.50	3.46	4.17
K^+ (cmol$_c$ dm^3)	0.38	0.30	0.52
Na^+ (cmol$_c$ dm^3)	0.09	0.07	0.11
P (mg dm^{-3})	227.03	95.80	197.08
Fe^{2+} (mg dm^{-3})	79.45	49.96	145.13
Cu^{2+} (mg dm^{-3})	3.71	1.44	2.03
Mn^{2+} (mg dm^{-3})	71.87	28.74	104.28
Zn^{2+} (mg dm^{-3})	75.24	33.39	119.48
B (mg dm^{-3})	2.19	1.31	1.38
CEC (cmol$_c$ dm^3)	10.11	8.18	14.15
V (%)	93.63	94.37	96.86
ESP (%)	1.00	0.96	0.70
OM (g kg^{-1})	18.10	10.31	25.28

NQ1 - Neossolo Quatzarênico, Casa Nova/BA; NQ2 - Neossolo Quatzarênico, Petrolina/PE; NF1 - Neossolo Flúvico, Juazeiro/BA; CEC – Cation exchange capacity; V – Base saturation; ESP – Exchangeable sodium percentage; OM – Organic matter of $CaNO_3$; 1 kg ha^{-1} of H_3BO_3; 63 kg ha^{-1} of $CaCl_2$; 30 kg ha^{-1} of MAP; 30 kg ha^{-1} of urea. NQ2 soil was applied: 26 kg ha^{-1} of Mg_2SO_4; 47 kg ha^{-1} of K_2SO^4; 17 kg ha^{-1} of Fe_2SO_4; 7 kg ha^{-1} of Zn_2SO_4; 52 kg ha^{-1} of $CaNO_3$; 4 kg ha^{-1} of H_3BO_3; 36 kg ha^{-1} of MAP; 25 kg ha^{-1} of urea. NF1 soil was applied: 25 kg ha^{-1} of Mg_2SO_4; 43 kg ha^{-1} of K_2SO^4; 2 kg ha^{-1} of Zn_2SO_4; 28 kg ha^{-1} of $CaNO_3$; 2 kg ha^{-1} of H_3BO_3; 22 kg ha^{-1} of KCl; 12 kg ha^{-1} of MAP; 20 kg ha^{-1} of urea.

The leaf sampling was done at full bloom, 30 days after the pruning. It was collected the leaf (petiole and blade) opposite to the first bunch from the bottom of the shoot. It was sampled 30 plants chosen randomly in every orchard and collected two leaves per plant, resulting in 60 leaves to form a composite sample. The leaves were washed, dried, and ground. It was determined N, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn, and B according to Silva (2009). The N was extracted by nitropercloric digestion and determined by Kjeldahl; K and Na were determined by flame photometry; Ca, Mg, Mn, Zn, Fe, and Cu by atomic absorption spectrometry; S by turbidimetry method; P was extracted by anion exchange resin and determined by UV-V is spectrophotometry.

The integrated diagnosis and recommendation system (DRIS) norms were stablished from a database of 19 orchards. DRIS norms were calculated using the arithmetic mean and standard deviation of the direct and indirect nutrient concentration ratios from the high-yielding population (Partelli et al., 2014). We separated the database into two populations: high and low-yielding. The selection of the high-yielding population was based on the mean yield + 0.5 standard deviation, resulting in 18.89 Mg ha^{-1} (Urano et al., 2007). The DRIS indexes were calculated by Jones (1981) nutrient binary relationships function. Then, it was calculated the mean nutritional balance index (NBIm) to each orchard.

The fruit were sampled randomly at harvest. The evaluations were performed in three bunches and ten berries per bunch. It was determined: Ca-pectate concentration (Bonomelli et al., 2018); Ca-total concentration and dry matter (MS) (Silva, 2009); Titratable acidity (TA) by titration and soluble solids (SS) using a refractometer (Instituto Adolfo Lutz, 2008); SS/TA ratio; Mean of berry firmness in the longitudinal and transverse directions (FB) using a digital penetrometer; Bunch length (CC) and berry diameter (DB) using a pachymeter; and berry weight (PB).

Spearman correlation (ρ) was performed between the following variables: Ca-pectate concentration and NBIm; Ca-pectate concentration and Ca-total concentration in the fruit; Ca-pectate and MS, TA, SS, FB, SS/TA, CC, PB, ad DB.

Results and Discussion

Nutritional diagnoses showed that Ca, B, Mg, K, and N were the most recurrent nutrients in excess, especially Ca and B (Table 2). The excess of N may be associated with the use of various sources of fertilizers, some of which are quite soluble, used not only to supply the demand for N, but also for other nutrients. Urea, monoammonium phosphate (MAP), $CaNO_3$, $MgNO_3$, and KNO_3 were used in the nutritional management of the orchards and all of them contain N. The same happens for Ca and K that are applied weekly with highly soluble sources ($CaCl_2$, $CaNO_3$, KCl and K_2SO_4).

Rozane et al. (2020) reported Ca, Mg, K, and S excess and N, Fe, and Zn deficiency and Zn, Cu, and Mn excess in grapevines cultivated in Rio Grande do Sul, Brazil. In general, the number of our orchards with micronutrients deficiency were similar to the excess diagnoses (Table 2). Although Zn was deficient in 63% of our orchards.

The excess of K decreases the Ca uptake by the grapevine, but in this study, it was verified excess of both nutrients in all three environments where the grapevine was cultivated (NQ1, NQ2, and NF1) (Table 2). The K excess influences on fruit

Table 2. Yield, DRIS index, and mean nutritional balance index (NBIm) of the grape orchards in Submédio São Francisco Valley

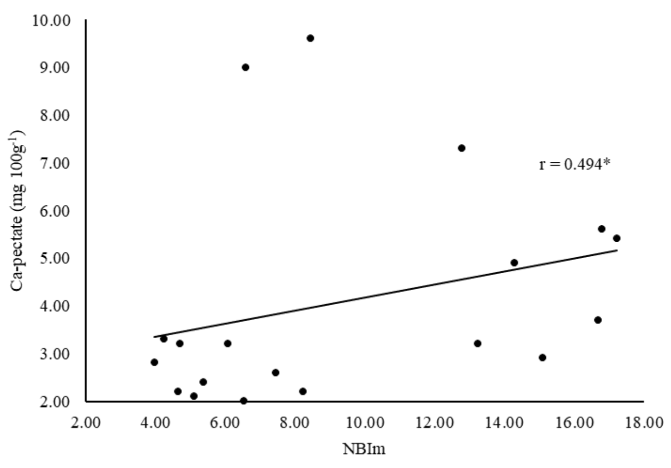
Orchard	Yield (Mg ha^{-1})	DRIS Index											
		IN	IP	IK	ICa	IMg	IS	IFe	ICu	IMn	IZn	IB	NBIm
Neossolo Quartzarênico – Petrolina (NQ2)													
1	22.74	-1.29	2.76	2.53	-4.92	-1.44	-2.87	9.89	10.40	-6.06	-5.55	-3.46	4.65
2	11.01	7.01	4.35	11.11	14.81	-0.12	0.22	0.81	-24.43	-45.76	15.63	16.37	12.79
3	18.63	-0.20	-10.33	-11.98	5.00	7.80	-0.88	-1.42	3.82	-8.68	12.63	4.22	6.09
4	17.87	-1.55	-7.59	1.04	20.16	-4.27	-6.65	0.01	0.50	-0.07	-1.74	0.16	3.98
5	18.41	23.51	-0.46	26.51	22.19	-11.66	0.13	-9.80	-3.45	-67.00	8.79	11.23	16.79
6	17.34	9.92	-7.70	-0.91	19.27	12.26	2.37	-0.24	-16.03	-48.01	10.12	18.93	13.25
7	10.78	11.02	-27.84	12.22	11.65	7.41	9.99	-10.11	-3.84	-11.46	-41.48	42.42	17.22
8	10.45	17.65	-0.49	5.25	-4.33	3.67	-5.10	-3.45	-1.86	-27.31	-4.03	19.98	8.46
9	14.93	-5.16	-0.38	13.24	-8.42	5.46	-6.59	-4.55	-0.55	-2.22	5.64	3.54	5.07
Neossolo Quartzarênico – Casa Nova (NQ1)													
10	14.31	2.68	3.10	2.81	-4.61	7.42	5.05	14.97	-1.39	-10.11	-13.88	-6.05	6.55
11	21.00	0.57	-2.72	7.10	-8.44	-2.30	-4.44	-7.40	-10.99	8.66	7.91	12.05	6.60
12	24.11	2.29	-0.07	7.03	-2.69	-3.28	5.16	-9.17	-8.85	7.58	-4.05	6.07	5.11
13	23.98	-6.88	-1.30	2.69	7.17	-4.67	4.84	-7.07	10.21	-1.22	0.99	-4.76	4.71
14	11.71	2.79	-7.08	9.43	47.29	-9.30	8.50	13.69	3.24	-44.59	-30.78	6.81	16.68
15	15.00	2.10	-8.93	5.54	23.19	18.72	8.88	11.56	-6.10	-23.48	-40.20	8.71	14.31
16	20.31	1.23	2.68	4.99	-3.58	5.06	-0.43	14.15	-6.24	1.51	-6.85	-12.53	5.39
Neossolo Flúvico – Juazeiro (NF1)													
17	19.93	4.27	8.98	-12.37	7.45	-1.18	-1.37	1.01	1.67	-1.79	-5.08	-1.59	4.25
18	11.42	16.19	2.99	12.11	36.02	0.00	-3.62	-0.28	-7.80	-52.75	-18.56	15.71	15.09
19	9.07	-0.69	-1.54	6.53	14.26	8.30	-28.07	1.71	4.23	-3.58	-11.46	10.30	8.24

quality by increasing the titratable acidity and SS/AT ratio which affects the flavor (Brunetto et al., 2020). Concerning the N, Thompson et al. (2019) also found increase in the N concentration in the leaves of apple trees treated with Ca $(NO_3)_2$ via fertigation as Ca and N have a synergistic relationship.

In this study, 63% of the orchards had excess Ca in the leaves (Table 2). Ca-pectate showed a positive correlation with NBIm in grapevine orchards (Figure 2). However, this relationship is in the same direction, suggesting that a more nutritionally balanced orchard does not necessarily have a higher Ca-pectate concentration in the fruit than a less balanced orchard. Therefore, when Ca supply is high, the plant absorbs and translocates it to other plant tissues, including the fruit, and stores it as Ca-pectate which is one of the mechanisms to controlling cytoplasm Ca concentration (Bonomelli et al., 2018; Gao et al., 2019).

Wang et al. (2019) applied increasing Ca rates (0, 15, 30, 45, 60, and 75 kg ha^{-1}) via drip irrigation in grapevines and observed an increase in Ca content in the leaves and a decrease in the berries. The authors discussed that Ca is not easily transferred in plants and can precipitate as Ca-oxalate, which may result in a decrease in Ca content in berries. In contrast, Sinha et al. (2019) studied the effect of pre-harvest foliar application of Ca on plum fruit quality. The authors found an increase in the concentration of Ca content in the fruit with the maximum value in the plants treated with the highest $CaCl_2$ concentration (2%). Depending on the fertilization management and the plant's transpiration rate, the Ca application can result in the increase of Ca-total concentration and its other factions in the fruit and also influence the nutritional balance of the plant.

In this study, Ca fertilizers were applied through fertigation. Ca uptake occurs at a higher rate in apical meristems than in older root regions (Bonomelli & Ruiz, 2010). The tissue cells of the root apical meristem present discontinuities of the Caspary band which facilitates Ca uptake and its translocation through the xylem. As Ca is not very mobile in the plant, its transport to other plant organs, including the fruit, occurs through the xylem (Bonomelli & Ruiz, 2010; Sotiropoulos et al., 2021). The xylem is crucial to Ca distribution in the plant until the beginning of berry maturation and can be very important in warm regions, where leaf and fruit transpiration is high, as is the case in the Submédio São Francisco Valley. Thus, when Ca availability is optimum, there are no limitations for Ca uptake and translocation which stimulates plant growth (Bonomelli & Ruiz, 2010).



* - Significant at $p \leq 0.05$ by t-test

Figure 2. Correlation between Ca-pectate concentration in the fruit and mean nutritional balance index (NBIm) in grapevine orchards

The positive correlation between the Ca-pectate concentration and the NBIm suggests that nutritional balance does not always result in a higher Ca-pectate concentration, as well as nutritional balance is not always related to high yields (Brunetto et al., 2020). This is because the concentration of nutrients in the tissues may not be in active forms. This can occur when the nutrient concentration is greater than the plant's demand. The excess of Ca in the tissues induces the plant to use mechanisms to control its cellular concentration. Some of these mechanisms are the storage of Ca in the vacuole and in idioblasts, specialized cells where Ca is precipitated as Ca-oxalate.

In this study, it was verified that more than half of the orchards had excess Ca in the leaves (Table 2) which causes nutritional imbalances and alters Ca fractioning in the plant. The DRIS norms and indexes were calculated with data collected at full bloom phase. However, Ca fertilizers were applied until the veraison. So it is possible that the nutritional imbalance of the orchards at the end of the cycle might have been at a even higher scale. So DRIS norms and indexes calculated with leaves data collected at veraison or even DRIS norms and indexes of fruit can be more suitable for evaluating the correlation between Ca-pectate and NBIm.

It was not verified significant correlation between the Ca-pectate concentration and Ca-total concentration in the fruit (Table 3). The determination of Ca-total in the fruit occurred at harvest and a study by Michailidis et al. (2017) showed that the effect of Ca application does not change the Ca-pectate concentration at harvest. Michailidis et al. (2017) compared cherry trees treated with $CaCl_2$ and the control treatment and did not find differences in the Ca-pectate content determined at harvest. Although it is important to evaluate the Ca fractioning in the fruit at harvest and post-harvest to understand the effect of Ca application on Ca-pectate content as some studies show that Ca application increases fruit firmness at post-harvest as shown by Martins et al. (2020). The authors found that the firmness of grapes at harvest increased after application of $CaCl_2$ at pre-harvest, which is related to the Ca-pectate.

Only part of the Ca-total in the fruit is as Ca-pectate with part being stored in the vacuole and idioblasts as Ca-oxalate. Ca-oxalate is formed when there is an excess of Ca in the cell and can act as a reserve for when the plant needs Ca. Bonomelli et al. (2018) found values of 1.85 mg $100g^{-1}$ of Ca-pectate at harvest and post-harvest, as well as 0 and 0.17 mg $100g^{-1}$ of Ca-oxalate at harvest and post-harvest, respectively, in Thompson Seedless fruit. Thus, future work is needed to assess whether this lack of correlation at harvest found in most studies is due to high Ca-oxalate concentration in grapevines with excess Ca fertilization and this Ca fraction can benefit post-harvest quality by providing Ca during storage.

The Ca-pectate concentration was not correlated with berry firmness, despite Ca being the nutrient most associated with fruit quality and, in particular, pulp firmness (Zhang et al., 2019) (Table 3). According to Siddiqui & Bangerth (1995), the application of Ca in pre-harvest does not always result

Table 3. Spearman correlation between Ca-pectate concentration, Ca-total concentration in the fruit, berry weight (PB), berry diameter (DB), bunch length (CC), berry firmness (FB), titratable acidity (TA), soluble solids (SS), SS/TA ratio (SS/TA), and dry matter (MS) in berries of grapevine cultivated in Submédio São Francisco Valley

	Ca-pectate	Ca-total	PB	DB	CC	FB	TA	SS	SS/TA	MS
Ca-pectate	-	0.32	-0.48*	-0.18	-0.22	-0.25	0.51*	-0.20	-0.57**	0.41
Ca-total	-	-	-0.50*	-0.18	-0.23	0.05	0.34	0.04	-0.29	0.37
PB	-	-	-	0.65**	0.41	0.53*	-0.39	0.06	0.46*	-0.65**
DB	-	-	-	-	0.33	0.57**	-0.19	0.19	0.28	-0.38
CC	-	-	-	-	-	0.41	-0.52*	-0.15	0.23	-0.38
FB	-	-	-	-	-	-	-0.27	0.24	0.47*	-0.21
TA	-	-	-	-	-	-	-	0.25	-0.44*	0.60**
SS	-	-	-	-	-	-	-	-	0.66**	0.42
SS/TA	-	-	-	-	-	-	-	-	-	-0.04
MS	-	-	-	-	-	-	-	-	-	-

* - Significant at $p \leq 0.05$ and ** - Significant at $p \leq 0.01$ by t-test

in greater fruit firmness at harvest. However, it can promote the prolongation of the pulp firmness during its storage. The authors found that this occurred after the storage of apple in plants treated with $CaCl_2$ application because the pectin concentration was only altered in the post-harvest.

Jain et al. (2019) observed the effect of $CaCl_2$ application in *Ziziphus mauritiana* Lamk. fruit at postharvest. The authors found a decrease in fruit softening over storage time. The authors attributed this decrease to Ca that preserves the integrity of the cell wall and delays the activity of enzymes responsible for degradation such as polygalacturonase and pectinmethylesterase. Thus, the effect of Ca on fruit firmness was observed only in fruit storage.

In this study, the Ca-pectate concentration may not have correlation with berry firmness due to the interference of other nutrients such as excess B, K, Mg, N, and Ca, as observed in the nutritional diagnosis of the orchards (Table 2). The excess of K and N can reduce the fruit quality, mainly in relation to its texture (Brunetto et al., 2020), while B presents synergism with Ca, being able to replace it in the cell wall. Thus, other factors may have influenced the berry firmness more than the Ca-pectate concentration.

The Ca-pectate concentration was positively correlated with the titratable acidity (TA) (Table 3). Some authors have reported an increase in TA with Ca application which can influence the Ca concentration in fruit (El-Masri et al., 2021; Santhosh et al., 2021; Khakpour et al., 2022). El-Masri et al. (2021) observed an increase in TA in table grapes berries after Ca application with different sources of fertilizers. Khakpour et al. (2022) suggested that the increase in TA in Ca-treated fruit was due to the preservation of acids because Ca decreases the consumption of organic acids as a respiratory substrate. In contrast, Wang et al. (2019) found that the TA and SS decreased in grape berries treated with water-soluble Ca fertilizer. The authors suggested that the SS decreased due to a decrease in Ca/N ratio in the fruit, which reduced the sugar metabolism.

The SS/TA ratio showed a negative correlation with the Ca-pectate concentration, possibly due to the fact that Ca has influence on TA because of the reduction of acid oxidation. Thus, this result suggests that higher Ca-pectate concentration result in high TA values and, consequently, lower SS values at harvest. As TA is part of the denominator of the SS/TA ratio, the relationship between SS/TA and Ca-pectate is negative. Moradinezhad & Dorostkar (2021) found an increase in the TA and a decrease in the SS/TA ratio in apricot fruit treated with $CaCl_2$ at pre-harvest. A proper SS/TA ratio is essential for the table grapes market because it is related to the fruit taste.

The SS/TA ratio also correlated with TA and SS, as they are components of this measure of fruit quality and flavor. In addition, the SS/TA ratio still showed a positive correlation with PB and berry firmness. The accumulation of solutes and soluble solids influences the water concentration of the fruit which is related to berry weight (Bonomelli & Ruiz, 2010). The berry water concentration influences the turgidity of the cells which makes the fruit more or less firm, depending on its degree of turgidity.

Ca-pectate concentration was negatively correlated with berry weight (Table 3). Eboibi et al. (2021) found a decrease in the weight, length, and width of tomato fruits after foliar application of $CaCl_2$. Bonomelli & Ruiz (2010) did not find difference in the bunch weight of grapevines treated with Ca compared to the control. However, the authors found low dry matter value and attributed this effect to the increase in Cl^- concentration, which can increase the water flow to the berries.

However, berry firmness showed a positive correlation with berry weight and diameter (Table 3). Bonomelli & Ruiz (2010) observed an increase in the size of the berry and associated it with the water concentration in the berry, which causes greater turgidity in the cells. The Submédio São Francisco Valley has high temperatures during most of the year and high evaporation rate, about 2600 to 3000 mm per year (Costa et al., 2021). This condition stimulates plant transpiration and water consumption, which may have influenced the turgidity of the cells and, consequently, the berry diameter and weight. Berry diameter may have influenced dry matter accumulation in agreement with Bonomelli & Ruiz (2010).

Ca metabolism is complex regarding its effects on fruit quality at harvest and post-harvest and it is not fully understood. Ca excessive application in vineyards result in nutritional imbalances that influence Ca fractioning and fruit quality. Thus, it is important to evaluate the nutritional balance of grapevines and connect with fruit quality variables to improve the nutritional management.

Conclusions

1. DRIS indexes indicated the excesses of Ca, B, Mg, K, and N in grapevine leaves.

2. The orchards had Ca excess, that interferes in the other nutrients in the plant tissue and also in some fruit quality variables.

3. Ca-pectate showed positive correlation with the mean nutritional balance index.

4. Ca-pectate showed a positive correlation with titratable acidity but does not correlate with berry firmness.

Acknowledgments

The authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Agrobras Agrícola Tropical do Brasil SA, and PlantSoil Laboratórios for the support with our research.

Literature Cited

Agritempo. Sistema de Monitoramento Agrometeorológico. Available on: <https://www.agritempo.gov.br/agritempo/index.jsp>. Accessed on: Dec. 2020.

Alvarez, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. L. de M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

Bonomelli, C.; Ariaas, M. I.; Villalobos, L. Adaptation and validation of a methodology for the measurement of calcium fractions in fruits. Communications in Soil Science and Plant Analysis, v.49, p.735-744, 2018. https://doi.org/10.1080/00103624.2018.1435681

Bonomelli, C.; Ruiz, R. Effects of foliar and soil calcium application on yield and quality of table grape cv. 'Thompson Seedless'. Journal of Plant Nutrition, v.33, p.299-314, 2010. https://doi.org/10.1080/01904160903470364

Brunetto, G.; Ricachenevsky, F. K.; Stefanello, L. O.; Paula, B. V. de; Kulmann, M. S. de S.; Tainari, A.; Melo, G. W. B. de; Natale, W.; Rozne, D. E.; Ciotta, M. N.; Brighenti, A. F.; Comin, J. J.; Lourenzi, C. R.; Loss, A.; Schmitt, D. E.; Zalamena, J.; De Conti, L.; Tiecher, T. L.; Souza, A. L. K. de; Bem, B. P. de. Diagnosis and management of nutrient constraints in grape. In: Srivastava, A. K.; Hu, C. (Eds.). Fruit Crops: Diagnosis and Management of Nutrient Constraints. Elsevier, Cap.47, 2020. p.693-710. https://doi.org/10.1016/B978-0-12-818732-6.00047-2

Costa, R. R. da; Ferreira, T. de O.; Lima, M. A. C. de. Trellis systems and rootstocks affect the quality and antioxidant potential of 'BRS Cora' grapes in rainy seasons under semiarid conditions. Bragantia, v.80, p.1-12, 2021. https://doi.org/10.1590/1678-4499.2020020

Eboibi, O.; Akpokodje, O. I.; Nyorere, O.; Oghenerukevwe, P.; Uguru, H. Effect of pre-harvest applications of organic manure and calcium chloride on the storability of tomato fruits. Annals of Agricultural Sciences, v.66, p.142-151, 2021. https://doi.org/10.1016/j.aoas.2021.10.001

El-Masri, I. Y.; Al-Akiki, M.; Eldin, N. J.; Ghantous, G.; El-Sebaaly, Z.; Hammound, M.; Khoury, E.; AlTurki, S. M.; Sassine, Y. N. Conventional vs. nano-Ca fertilizers effects on traditional table grape Tfiefihi. Journal of Plant Nutrition, v.44, p.3020-3033, 2021. https://doi.org/10.1080/01904167.2021.1936032

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. Sistema Brasileiro de Classificação de Solos, 5.ed. Rio de Janeiro: Embrapa, 2018. 356p.

Gao, Q.; Xiong, T.; Li, X.; Chen, W.; Zhu, X. Calcium and calcium sensors in fruit development and ripening. Scientia Horticulturae, v.253, p.412-421, 2019. https://doi.org/10.1016/j.scienta.2019.04.069

Instituto Adolfo Lutz. Métodos físico-químicos para análise de alimentos. 4.ed. São Paulo: Instituto Adolfo Lutz, 2008. 1020p.

Jain, V.; Chawla, S.; Choudhary, P.; Jain, S. Post-harvest calcium chloride treatments influence fruit firmness, cell wall components and cell wall hydrolyzing enzymes of Ber (*Ziziphus mauritiana* Lamk.) fruits during storage. Journal of Food Science and Technology, v.56, p.4535-4545, 2019. https://doi.org/10.1007/s13197-019-03934-z

Jones, C. A. Proposed modifications of the Diagnosis and Recommendation Integrated System (DRIS) for interpreting plant analyses. Communications in Soil Science and Plant Analysis, v.12, p.785-794, 1981. https://doi.org/10.1080/00103628109367194

Khakpour, S.; Hajizadeh, H. S.; Hemati, A.; Bayanati, M.; Nobaharan, K.; Chelan, E. M.; Lajayer, B. A.; Dell, N. The effect of pre-harvest treatment of calcium nitrate and iron chelate on post-harvest quality of apple (*Malus domestica* Borkh cv. Red Delicious). Scientia Horticulturae, v.304, p.1-10, 2022. https://doi.org/10.1016/j.scienta.2022.111351

Martins, V.; Garcia, A.; Alhinho, A. T.; Costa, P.; Lanceros-Méndez, S.; Costa, M. M. R.; Gerós, H. Vineyard calcium sprays induce changes in grape berry skin, firmness, cell wall composition and expression of cell wall-related genes. Plant Physiology and Biochemistry, v.150, p.49-55, 2020. https://doi.org/10.1016/j.plaphy.2020.02.033

Michailidis, M.; Karagiannis, E.; Tanou, G.; Karamanoli, K.; Lazaridou, A.; Matsi, T.; Molassiotis, A. Metabolomic and physico-chemical approach unravel dynamic regulation of calcium in sweet cherry fruit physiology. Plant Physiology and Biochemistry, v.116, p.68-79, 2017. https://doi.org/10.1016/j.plaphy.2017.05.005

Moradinezhad, F.; Dorostkar, M. Pre-harvest foliar application of calcium chloride and potassium nitrate influences growth and quality of apricot (*Prunus armeniaca* L.) fruit cv. 'Shahroudi'. Journal of Soil Science and Plant Nutrition, v.21, p.1642-1652, 2021. https://doi.org/10.1007/s42729-021-00468-2

Oliosi, G.; Partelli, F. L.; Silva, C. A. da; Dubberstein, D.; Gontijo, I.; Tomaz, M. A. Seasonal variation in leaf nutrient concentration of conilon coffee genotypes. Journal of Plant Nutrition, v.44, p.74-85, 2020. https://doi.org/10.1080/01904167.2020.1792492

Partelli, F. L.; Dias, J. F. M.; Vieira, H. D.; Wadt, P. G. S.; Paiva Junior, E. Avaliação nutricional de feijoeiro irrigado pelos métodos CND, DRIS e faixas de suficiência. Revista Brasileira Ciência do Solo, v.38, p.858-866, 2014. https://doi.org/10.1590/S0100-06832014000300017

Rozane, D. E.; Paula, B. V.; Melo, G. W. B. de; Santos, E. M. H. dos; Trentin, E.; Marchezan, C.; Silva, L. O. S. da; Tassinari, A.; Dotto, L.; Oliveira, F. N. de; Natale, W.; Baldi, E.; Toselli, M.; Brunetto, G. Compositional Nutrient Diagnosis (CND) Applied to grapevines grown in subtropical climate region. Horticulturae, v.6, p.2-13, 2020. https://doi.org/10.3390/horticulturae6030056

Santhosh, S. S.; Chitdeshwari, T.; Jegadeeswari, D.; Kavitha, C. Effect of different levels and sources of calcium on post harvest physiology of hybrid tomatoes (*Solanum lycopersicum*). Journal of Applied and Natural Science, v.13, p.1357-1364, 2021. https://doi.org/10.31018/jans.v13i4.3058

Siddiqui, S.; Bangerth, F. Differential effect of calcium and strontium on flesh firmness and properties of cell walls in apples. Journal of Horticultural Science, v.70, p.949-953, 1995. https://doi.org/10.1080/14620316.1995.11515370

Silva, F. C. da. Manual de análises químicas de solos, plantas e fertilizantes. 2.ed. Brasília/Rio de Janeiro: Embrapa Informação Tecnológica/Embrapa Solos, 2009. 627p.

Sinha, A.; Jawandha, S. K.; Gill, P. P. S.; Singh, H. Influence of pre-harvest sprays of calcium nitrate on storability and quality attributes of plum fruits. Journal of Food Science and Technology, v.56, p.1427-1437, 2019. https://doi.org/10.1007/s13197-019-03621-z

Sotiropoulos, T.; Vougarakis, A.; Karaiskos, D.; Chatzistathis, T.; Manthos, I.; Dichala, O.; Mpouuntla, A. Foliar Calcium Fertilizers Impact on Several Fruit Quality Characteristics and Leaf and Fruit Nutritional Status of the 'Hayward' Kiwifruit Cultivar. Agronomy, v.11, p.1-8, 2021. https://doi.org/10.3390/agronomy11020235

Thompson, A. A.; Williams, M. A.; Peck, G. M. Compost and Geneva® series rootstocks increase young 'Gala' apple tree growth and change root-zone microbial communities. Scientia Horticulturae, v.256, p.1-11, 2019. https://doi.org/10.1016/j.scienta.2019.108573

United States. Soil Survey Staff. Keys to Soil Taxonomy (12th ed.) USDA NRCS. 2014. Available on: <http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/>. Accessed on: Jan. 2023.

Urano, E. O. M.; Kurihara, C. H.; Maeda, S.; Vitorino, A. C. T.; Gonçalves, M. C.; Marchetti, M. E. Determinação de teores ótimos de nutrientes em soja pelos métodos Chance Matemática, Sistema Integrado de Diagnose e Recomendação e Diagnose da Composição Nutricional. Revista Brasileira de Ciência do Solo, v.31, p.63-72, 2007. https://doi.org/10.1590/S0100-06832007000100007

Wang, R.; Qi, Y.; Shukla, M. K.; Sun, Q. Influence of the application of irrigated water-soluble calcium fertilizer on wine grape properties. PLoS ONE, v.14, p.1-11, 2019. https://doi.org/10.1371/journal.pone.0222104

Zhang, L.; Wang, J.; Chen, J.; Song, T.; Jiang, Y.; Zhang, Y.; Wang, L.; Li, F. Preharvest spraying calcium ameliorated aroma weakening and kept higher aroma-related genes expression level in postharvest 'Nanguo' pears after long-term refrigerated storage. Scientia Horticulturae, v.247, p.287-295, 2019. https://doi.org/10.1016/j.scienta.2018.12.038