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Original Article

Chemical quality and bioactive compounds of sweet potatoes under phosphate fertilization[1]

Qualidade química e compostos bioativos de batata-doce sob adubação fosfatada

Pablo H. de A. Oliveira[2], Anna K. S. de Oliveira[2], Ester dos S. Coêlho[2], Valécia N. S. e Silva[2], Welder de A. R. Lopes[2], Gisele L. dos Santos[2], João E. da S. Ribeiro[2*], Antonio G. C. da Silva[2], José T. dos Santos Júnior[2], Aurélio P. Barros Júnior[2] & Lindomar M. da Silveira[2]

[1] Research developed at Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brazil
[2] Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brazil

HIGHLIGHTS:

P dose of 60 kg ha^{-1} promoted increase in carotenoid content in the sweet potato cultivar Paraná.
Cultivar Paraná showed an increase in the contents of anthocyanins and flavonoids at the maximum P dose of 240 kg ha^{-1}.
The pH, SS, TA and SS/TA ratio increased in the BRS Cuia cultivar at the phosphate dose of 120 kg ha^{-1}.

ABSTRACT: Sweet potato is among the most important food crops in the world. Due to its high genetic diversity, this species has cultivars that can respond in different ways depending on mineral fertilization. Among the nutrients, phosphorus is related to physiological and biochemical processes that can influence the final quality of the product. This study aimed to assess the influence of P doses on the quality and bioactive compounds of sweet potato cultivars - Paraná, BRS Amélia, and BRS Cuia. The pH, soluble solids (SS), titratable acidity (TA), SS/TA ratio, soluble sugars, and the bioactive compounds - flavonoids, anthocyanins, and carotenoids - were evaluated. The P doses influenced sweet potato cultivars. The dose of 120 kg ha^{-1} promoted increments in the parameters pH, SS, TA, and SS/TA ratio for the cultivar BRS Cuia. The same dose promoted an increase in total soluble sugars for the cultivar BRS Amélia. P dose of 240 kg ha^{-1} promoted higher levels of flavonoids and anthocyanins in the cultivar Paraná, and there was an increase in carotenoid content at the dose of 60 kg ha^{-1}.

Key words: *Ipomoea batatas* (L.) Lam, post-harvest, antioxidants, cultivars, tuberous roots

RESUMO: A batata-doce está entre as culturas alimentícias mais importantes do mundo. Por apresentar alta diversidade genética, essa espécie possui cultivares que podem responder de maneiras diferentes em função da adubação mineral. Dentre os nutrientes, o fósforo está relacionado com processos fisiológicos e bioquímicos que podem influenciar na qualidade final do produto. Este estudo teve como objetivo avaliar a influência de doses de P na qualidade e compostos bioativos de cultivares de batata-doce - Paraná, BRS Amélia e BRS Cuia. Foram avaliados o pH, sólidos solúveis (SS), acidez titulável (AT), relação SS/AT, açúcares solúveis e os compostos bioativos - flavonoides, antocianinas e carotenoides. As doses de P influenciaram as cultivares de batata-doce. A dose de 120 kg ha^{-1} promoveu incrementos nos parâmetros pH, SS, AT e relação SS/AT para a cultivar BRS Cuia. A mesma dose promoveu incrementos nos açúcares solúveis totais para a cultivar BRS Amélia. A dose de 240 kg ha^{-1} promoveu maiores teores de flavonoides e antocianinas na cultivar Paraná, e houve aumento no teor de carotenoides na dose de 60 kg ha^{-1}.

Palavras-chave: *Ipomoea batatas* (L.) Lam, pós-colheita, antioxidantes, cultivares, raízes tuberosas

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* Corresponding author - E-mail: j.everthon@hotmail.com
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Introduction

The quality of vegetables is a primary parameter due to the evolution of consumer demands (Natalini et al., 2021). Moreover, those which have been gaining attention not only from consumers but also from the industry are bioactive compounds, which are essential pigments in human health, due to their antioxidant potential (Giaconia et al., 2020). These pigments can be carotenoids, anthocyanins and phenolic compounds that are present in several vegetables, such as sweet potato (Frond et al., 2019).

Sweet potato [*Ipomoea batatas* (L.) Lam] is a vegetable with economic and social importance and has wide climatic adaptation and high energy production capacity; moreover, it shows high genetic diversity among cultivars and local varieties in the various producing regions (Oliveira et al., 2015). Different responses have been observed in sweet potato cultivars in producing regions, mainly in terms of fertilization management, so this differentiated response has required localized research to determine the best way to use nutrients for the crop (Minemba et al., 2019).

Among nutrients, phosphorus (P) is important for photosynthesis, respiration, energy transfer and essential metabolic functions for plant growth and maturity (Basavegowda & Baek, 2021). As for the absorption of this nutrient, sweet potato is efficient, being responsive to fertilization in soils with low P content (Minemba et al., 2019). Several studies have shown that P is paramount and its deficiency limits plant growth and crop yield.

Thus, it is important to understand the responses of sweet potato cultivars to P use for the conditions under which the genotype is being evaluated, as management can interfere, becoming important and significant. This study aimed to assess the influence of P doses on the quality and bioactive compounds of sweet potato cultivars.

Material and Methods

The field experiment was conducted from December/2021 to April/2022 at the Rafael Fernandes Experimental Farm, located in Mossoró-RN, Brazil (5° 03' 37" South latitude, 37° 23' 50" West longitude, and 72 m altitude). The Experimental Farm belongs to the Universidade Federal Rural do Semi-Árido (UFERSA). The region's climate is BSh according to Köppen's classification, that is, a dry climate; in addition, it has a rainy season in the summer that extends until autumn, so it is very hot (Alvares et al., 2013). It has an average temperature of around 27.8 °C, irregular annual rainfall of approximately 555 mm, and relative humidity of 68.9% (CLIMATE-DATA, 2021).

Daily data on air temperature, relative humidity of air, total precipitation, incident global solar radiation, and wind speed were collected at the Automatic Weather Station installed at the experimental farm. The mean data were calculated by the arithmetic mean of each variable's minimum and maximum values (Figure 1).

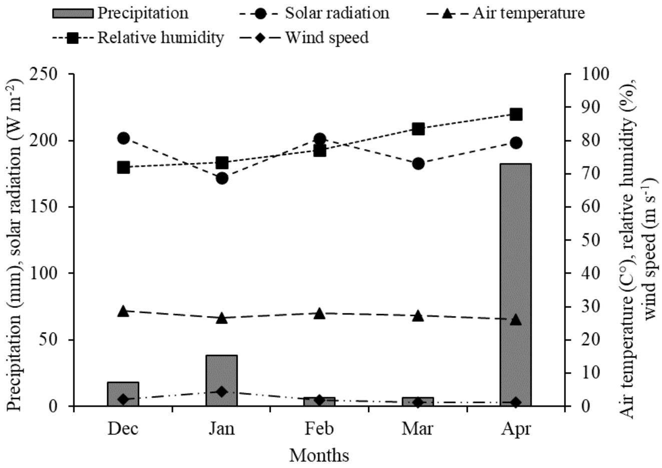


Figure 1. Average of the meteorological data at the Rafael Fernandes Experimental Farm during the experimental period

The experimental design was randomized blocks arranged in split plots with four replications. The plots were composed of P doses (0, 60, 120, 180, and 240 kg ha^{-1}) and application was split and applied at planting (IPA, 2008), while the subplots were formed by the cultivars (Paraná, BRS Amélia, and BRS Cuia). Monoammonium phosphate (MAP) (61% P_2O_5 and 12% N) was used as a source of P. Nitrogen (N) and potassium (K) were applied according to IPA (2008). 80% of N was applied 15 days after planting (DAP), being the equivalent of 1.677 kg per experimental plot, while the remaining 20%, referring to topdressing fertilization, was not applied in order not to favor shoot growth. The total N was applied taking into account the P doses; when the P doses were increased, the N doses were reduced, and this value was leveled and completed with urea. K was applied 50% at 20 DAP and 50% at 45 DAP, with an equivalent amount of 0.804 kg per plot being applied, referring respectively to planting and top dressing fertilization. The total N and K applied in the five experimental plots was 8.38 and 8.04 kg, respectively. Applied nutrients were distributed by fertigation using different pressure tanks. In all, four fertigation operations were performed. Fertilization with micronutrients was not applied.

The cultivar Paraná has branched leaves with hasted base and acute apex and rounded roots with periderm and orange pulp (Moreira et al., 2011) (Figure 2A). The cultivar BRS

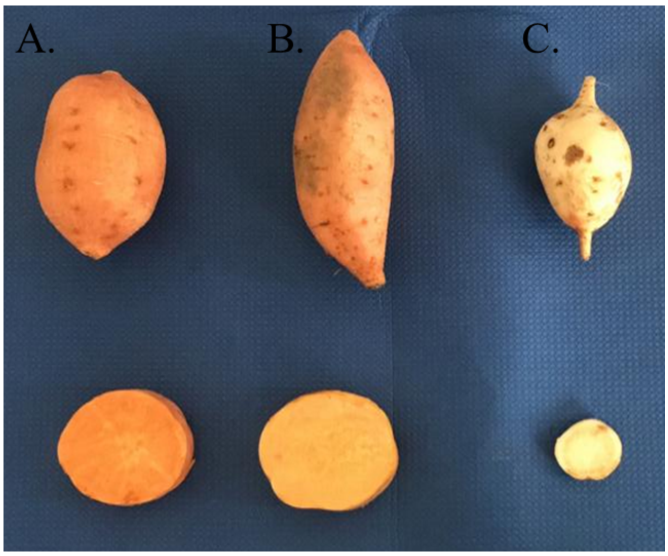


Figure 2. Tuberous roots of sweet potato cultivars - Paraná (A), BRS Amélia (B) and BRS Cuia (C)

Amélia has differentiated nutritional qualities and is rich in provitamin A, proteins, and anthocyanins. It has a long elliptical shape with pinkish periderm and orange pulp. It is used as an ornamental species, has applications for processing (flour), and use in diets for athletes (Castro & Becker, 2011) (Figure 2B). The cultivar BRS Cuia has periderm and cream pulp. It is recommended for domestic consumption; however, due to its size, it is suitable for the industrial process and can be used to produce ethanol and medical alcohol. It has rounded shape and has applications for processing and diets for athletes (Castro et al., 2011) (Figure 2C). The plant materials used came from the didactic collection of germplasm of the Universidade Federal Rural do Semi-Árido.

In the experimental area, before setting up the experiments, soil samples were collected at depths of 0-0.20 and 0.20-0.40 m to evaluate the chemical properties of the soil (Table 1). The irrigation system was drip irrigation, with emitters spaced 0.30 m apart, applying an average depth of 11 mm. Tensiometers were installed to monitor soil moisture. Irrigation was performed daily until 30 days after planting (DAP) (EMBRAPA, 2021). From 30 to 75 DAP, irrigation was performed when the tensiometers marked -20 kPa. From 75 to 90 DAP, irrigation was suspended, and thereafter performed once a week until harvest, always considering soil moisture.

Each plot consisted of four rows measuring 2.4 m in length and spaced 1.00 m apart, with a observation area of 3.6 m^2 and total area of 9.6 m^2. Apical branches with five to six buds were used, with two branches planted per hole, spaced 0.30 m apart. Manual weeding was carried out, in a total of four operations for each season. Defensives were not applied in the area, since the occurrence of pests and/or diseases in the crop indicating a level of economic damage was not observed. At 153 days, harvest was carried out manually with the aid of hoes, and the material was later sent to the Plant and Sample Reception Laboratory of the Semi-Arid Plant Research Center (LABRPA/CPVSA), Department of Agrarian and Forest Sciences (DCAF), Center for Agrarian Sciences (CCA), where the roots with damage by cuts, pathogens, insects and animals were discarded. After washing, they were taken to the Postharvest Physiology and Technology Laboratory of DCAF/CCA, processed, and the pulp was stored in plastic containers and taken to the freezer for further analysis.

The characteristics evaluated were: hydrogen potential (pH) determined by direct reading in a pH meter (Model mPA-210 Tecnal®, Brazil), expressed in pH values (AOAC, 2002). Titratable acidity (TA) was expressed in % (IAL, 2008). Soluble solids (SS) were expressed in °Brix (AOAC, 2002). SS/TA ratio was determined by the ratio of soluble solids to titratable acidity. Total soluble sugars (TSS) are expressed as % (Yemn & Willis, 1954). Anthocyanins and flavonoids are expressed in mg $100g^{-1}$ of fresh weight (FW) (Francis, 1982). Total carotenoids are expressed in mg $100g^{-1}$ FW (Higby, 1962).

The data obtained were checked for normal distribution by the Shapiro-Wilk test. They were subjected to analysis of variance followed by polynomial regression for P doses, and Tukey's test was used to compare the means between cultivars up to at 0.05 probability level. Sisvar 5.6 software (Ferreira, 2014) was used for the statistical analyses.

Results and Discussion

The pH, titratable acidity (TA), soluble solids (SS), soluble solids/titratable acidity ratio (SS/TA), and total soluble sugars (TSS) of sweet potato cultivars were affected by the interaction between P doses and sweet potato cultivars.

The pH of the cultivar BRS Cuia was reduced up to the P_2O_5 dose of 180 kg ha^{-1}, while the cultivar Paraná showed an increase in pH ranging from 9 to 10% compared to the treatment that did not receive doses of P. The doses of P did not influence the pH of the cultivar BRS Amélia (Figure 3A). Oliveira et al. (2019) mention that factors such as climate, soil and fertilizers, as well as pre- and postharvest conditions and types of storage, have little influence, since the evaluated sweet potato genotypes received the same methodological treatments, and that, in addition, the differences observed are mainly due to the intrinsic characteristics of each cultivar.

The pH is an important parameter because it influences the enzymatic activity, besides helping identify the maturation of fruits and vegetables; it can be observed in sweet potatoes that pH above 6.0 provides good maturation and conservation, while pH with variations between 4.7 and 5.5 may favor the action of deteriorating enzymes, compromising the integrity of the product (Oliveira et al., 2019).

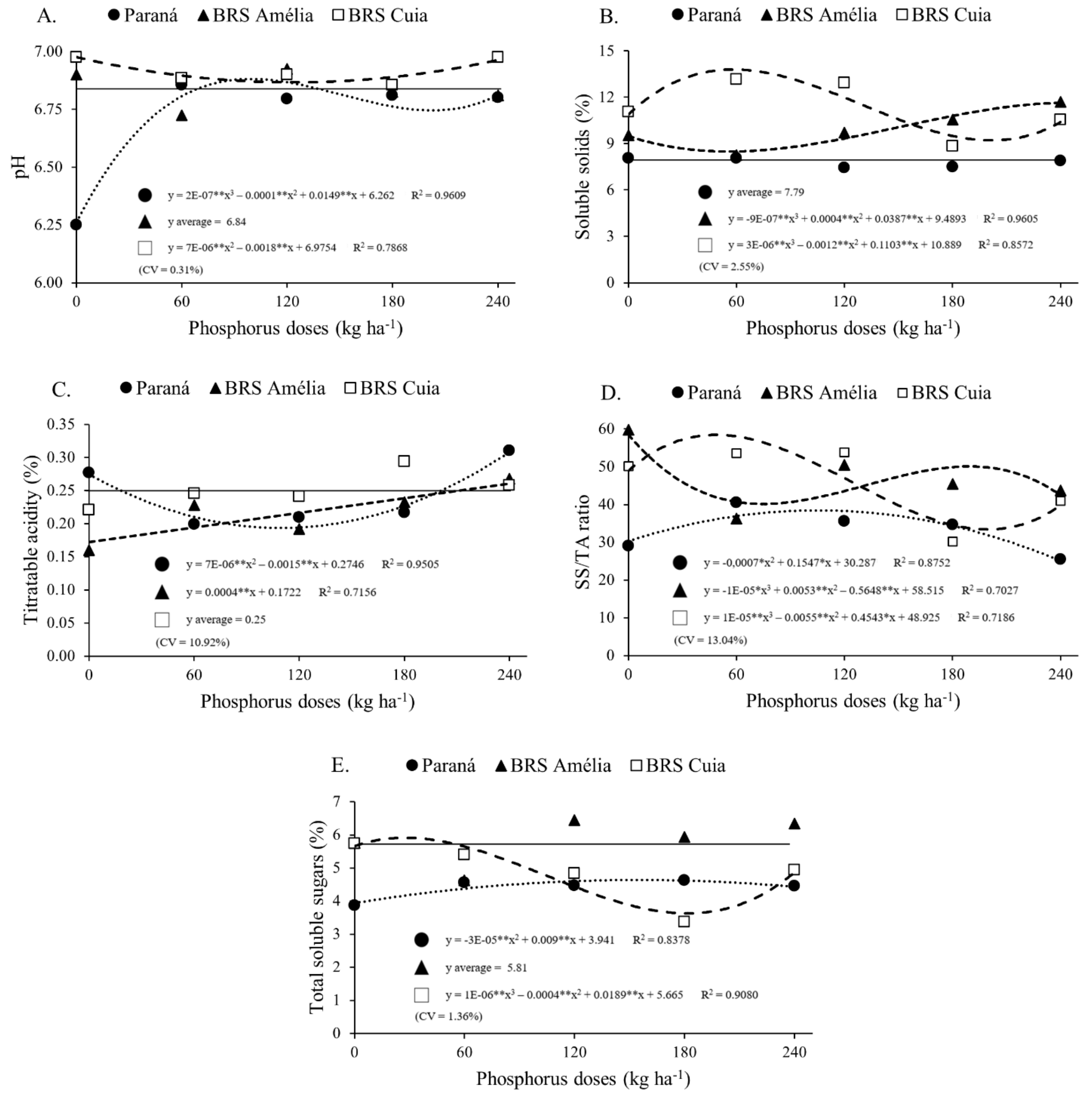
The cultivar BRS Amélia showed an increase in SS from the P_2O_5 dose of 60 kg ha^{-1}; as the doses were increased, the SS content was increased from 2 to 22%. For the cultivar BRS Cuia, the SS content was increased up to 120 kg ha^{-1} of P_2O_5. The P doses did not influence the SS of the Paraná cultivar (Figure 3B). The SS content is an indirect measure of the sugar content since other substances are dissolved in the vacuolar sap (i.e., vitamins, phenolics, pectins, and organic acids). Its values vary according to species, cultivars, maturation stages, and climate, ranging from 2 to 25% (Chitarra & Chitarra, 2005). Silveira et al. (2021) observed a reduction in SS content with increasing P doses (0, 60, 120, 180 and 240 kg ha^{-1} of P_2O_5) in table cassava.

The TA increased linearly for the cultivar BRS Amélia with the increase of the doses of P. The cultivar Paraná suffered a reduction in titratable acidity up to the P_2O_5 dose of 180 kg ha^{-1}, increasing 11% at the P_2O_5 dose of 240 kg ha^{-1} compared to the treatment that did not receive P. The cultivar BRS Cuia showed no significant difference in titratable acidity under the P doses (Figure 3C). Chitarra & Chitarra (2005) mention that acidity is attributed to the dissolution of organic acids found in cellular vacuoles, in free forms, or combined with

Table 1. Chemical analysis of the soil of the experimental area before the application of treatments

Soil depth (m)	pH (water)	EC (dS m^{-1})	P*	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	SB	ECEC	CEC
			(mg dm^{-3})			($cmol_c$ dm^{-3})					
0-0.20	5.10	1.00	4.20	59.00	0.70	1.06	0.49	0.00	1.70	1.70	1.70
0.20-0.40	5.37	0.8	2.37	50.96	14.01	0.79	0.23	0.00	1.21	1.21	1.21

*Extractant: $Mehlich^{-1}$; EC - Electrical conductivity of soil saturation extract; SB - Sum of bases; ECEC - Effective cation exchange capacity; CEC - Cation exchange capacity



* and ** respectively significant at 0.05 and 0.01 probability levels by F test; CV - coefficient of variation

Figure 3. pH (A), soluble solids - SS (B), titratable acidity - TA (C), SS/TA ratio (D), and total soluble sugars (E) of the roots of sweet potato cultivars as a function of phosphate fertilization

salts, esters, and glycosides. In addition, these acids are used as substrates in the respiratory process during ripening and may suffer variation by environmental factors and factors related to the plant. Truong et al. (2019) mention that the increase in TA may be related to the system of active enzymes, such as anthocyanins, polyphenol oxidases, and peroxidases.

The Paraná cultivar showed SS/TA ratio with a maximum point at the P_2O_5 dose of 60 kg ha^{-1}, with an increase of 39%, followed by a reduction between P_2O_5 doses 120 and 240 kg ha^{-1}. There was a reduction in the SS/TA ratio of the cultivar BRS Amélia ranging from 16 to 40%. The cultivar BRS Cuia showed an increase up to the P_2O_5 dose of 120 kg ha^{-1} ranging from 7 to 8%; in addition, it showed a minimum point at the dose of 180 kg ha^{-1} with a 40% reduction in the SS/TA ratio (Figure 3D). The SS/TA ratio is one of the best ways to evaluate the flavor and is more efficient than the separate measurements of soluble solids and titratable acidity, showing a balance between these two components (Chitarra & Chitarra, 2005).

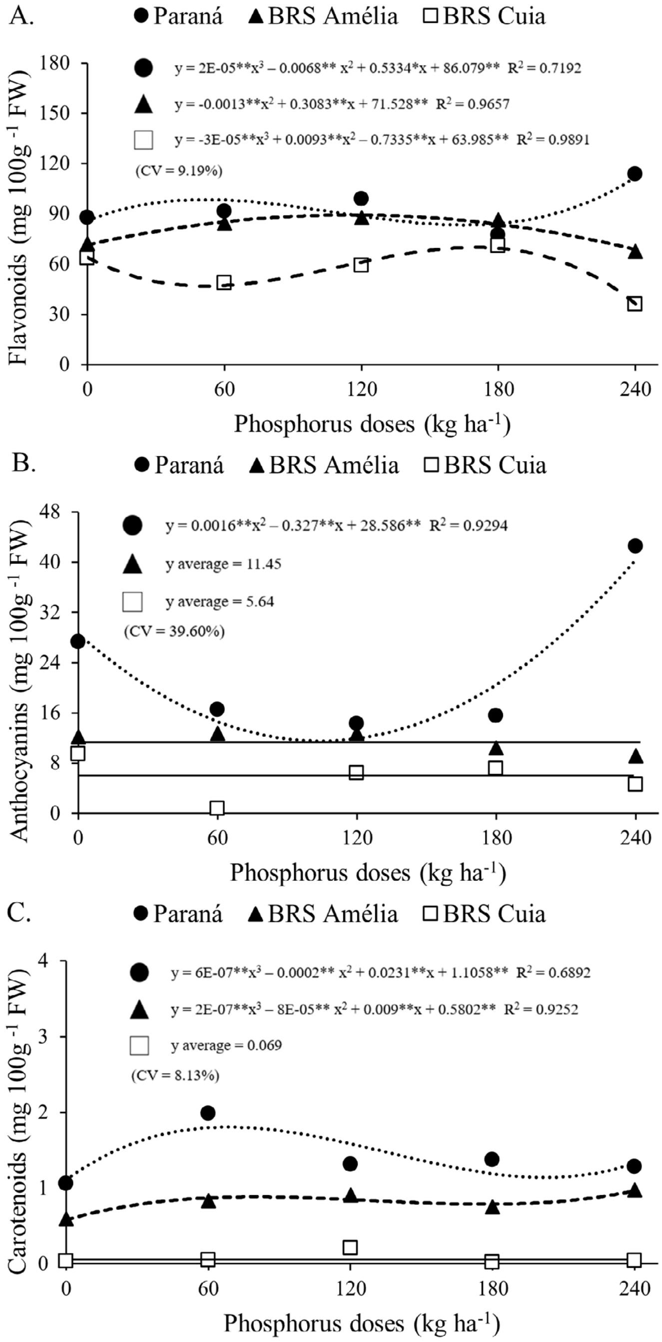
The TSS increased with the increment of P doses in the cultivar Paraná, ranging from 15 to 19%. The BRS Cuia showed the opposite result, suffering a reduction in TSS content ranging from 6 to 41%. The BRS Amélia was not influenced by P doses (Figure 3E). The accumulation of TSS is associated with greater translocation of sucrose during the development of tuberous roots of sweet potatoes since it is the main form of translocated carbohydrate in the plant. Furthermore, P is involved in the formation of sucrose, which is important in determining the TSS content of many species. During the process of sucrose synthesis, sucrose phosphate synthase (SPS) is one of the main enzymes that regulate the accumulation of sucrose in plants (Iqbal et al., 2023). Silveira et al. (2021) did not observe any effect of P doses on TSS in table cassava, with a maximum content of 6.97 with a P_2O_5 dose of 35.80 kg ha^{-1}.

P as phosphate (PO_4^{3-}) is an integral component of important compounds in plant cells, as well as phosphate sugars, intermediates of photosynthesis and respiration, and composing plant membranes through phospholipids (Taiz et al., 2017). Fruits and vegetables respond in different ways to the supply or deficiency of P. Chitarra & Chitarra (2005) mentioned that citrus plants are not very demanding of P, but its excess and lack significantly influence yield and quality. The application of P decreases peel thickness, increasing the percentage of juice. In addition, it reduces the SS content and increases the SS/TA ratio. These findings were similar to the results of the cultivar BRS Cuia, largely demonstrating that the quality attributes differ among the cultivars of the same species treated with phosphorus doses. This may occur because the cultivars used have different responses to soil phosphorus fertilization (Li et al., 2020).

The P doses did not influence the flavonoid content, but there was significance between the cultivars and the interaction of the doses with the cultivars (Figure 4A). The cultivar Paraná showed a significant increase only at the P_2O_5 dose of 240 kg ha^{-1}, of approximately 30%, compared to the treatment that did not receive the phosphate dose. Moreover, the cultivar Paraná had higher and statistically different means at the P_2O_5 doses 0 and 240 kg ha^{-1} compared to the other cultivars and averages similar to those of BRS Amélia between the P_2O_5 doses of 60 and 180 kg ha^{-1}. The cultivar BRS Cuia showed low levels of flavonoids compared to the other cultivars at P_2O_5 doses 60, 120, and 240 kg ha^{-1}. Although not significant, up to the P_2O_5 dose of 120 kg ha^{-1}, the cultivars Paraná and BRS Amélia had increasing levels of flavonoids (Figure 4A).

For anthocyanins, there was significance for the interaction of factors and for the individual factors doses and cultivars. The P doses reduced the anthocyanin contents of the cultivars Paraná up to the dose of 180 kg ha^{-1} and BRS Cuia up to the maximum dose of phosphorus. However, the maximum dose (240 kg ha^{-1} of P_2O_5) increased by 56% the anthocyanin content for the cultivar Paraná. The cultivar BRS Amélia showed an increase of 4% in the anthocyanin content up to the P_2O_5 dose of 120 kg ha^{-1} (Figure 4B). The observed increments of flavonoids and anthocyanins can be justified by the fact that phosphorus is a constituent of fundamental structures of intermediate molecules of secondary metabolism, being interconnected, mainly in chemical energy availability. In addition, P makes up the structure of precursors and enzymes primordial for the biosynthesis of phenolic compounds using pentose phosphate, shikimate, and phenylpropanoid. P deficiency may result in the reduction of secondary metabolites (Taiz et al., 2017).

Carotenoids are important bioactive compounds that act as antioxidants (Amengual, 2019). The P doses influenced the carotenoids of sweet potato cultivars. The cultivar Paraná had higher levels of carotenoids than the cultivars BRS Amélia



* and ** respectively significant at 0.05 and 0.01 probability levels by F test; CV - coefficient of variation; FW - fresh weight

Figure 4. Flavonoids (A), anthocyanins (B), and carotenoids (C) of the roots of sweet potato cultivars as a function of phosphate fertilization

and BRS Cuia at all doses of P. In addition, the P_2O_5 dose of 60 kg ha^{-1} promoted the highest content of carotenoids for the cultivar Paraná, causing an increase of 87% in this pigment compared to the treatment that did not receive any dose of P. For the cultivar BRS Amélia, the doses of P promoted increments that varied from 27 to 55% in the carotenoid content. BRS Cuia showed no significant difference between the P doses (Figure 4C).

The influence of P doses can be explained by the fact that phosphorus is a component of pyrophosphates, which are essential intermediate constituents in the biosynthesis of carotenoids important for the color of fruits, causing an increase in carotenoid content (Li et al., 2022). Nascimento et al. (2019)

observed that P influenced the content of total carotenoids in the Beauregard sweet potato cultivar, with a recommended P_2O_5 dose of 174.09 kg ha^{-1}. Cordeiro et al. (2023) mentioned that soils with P concentration < 5.0 mg dm^{-3} require 68 kg ha^{-1} of P for maximum production of sweet potato, showing similarity for some variables in the present study, since the P concentrations here were 4.20 and 2.37 mg dm^{-3}, respectively, for depths of 0-0.20 m and 0.20-0.40 m, that is, P < 5.0 mg dm^{-3}. Furthermore, the carotenoid content for the P_2O_5 dose of 60 kg ha^{-1} was increased for the Paraná cultivar, highlighting that some sweet potato cultivars are responsive to this dose.

Conclusions

1. The P_2O_5 dose of 120 kg ha^{-1} promoted increments in pH, SS, TA, and SS/TA ratio parameters, mainly for the cultivar BRS Cuia. For the same dose, the cultivar BRS Amélia showed increases in total soluble sugars.

2. The P_2O_5 dose of 240 kg ha^{-1} promoted higher levels of flavonoids and anthocyanins in the cultivar Paraná compared to the others. In addition, its carotenoid content was increased at all phosphorus doses, mainly at the P_2O_5 dose of 60 kg ha^{-1}, showing that the cultivar has great antioxidant potential.

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