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Scientific Article

Production and physical quality of sweet potatoes under phosphate fertilization

Produção e qualidade física de batata-doce sob adubação fosfatada

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ABSTRACT - Phosphorus (P) is a primordial mineral nutrient for plants, as it is directly linked to physiological and biochemical processes essential for plant maintenance, and can influence the production and final quality of the product. Furthermore, P favors good root development, which can benefit sweet potato crop. Thus, the objective of the work is to assess the influence of increasing doses of P on the production and physical quality of sweet potatoes in two growing seasons in a semi-arid environment. The experiments were carried out from April to August 2021 (season 1) and from December 2021 to April 2022 (season 2) at the Rafael Fernandes Experimental Farm - UFERSA, Mossoró, RN, BR. The design was randomized blocks, with four replications. The treatments consisted of five doses of P (0; 60; 120; 180 and 240 kg ha^{-1} of P_2O_5) via fertigation and tested on the sweet potato cultivar Paraná. After harvesting the roots, the number and yield of roots (commercial, non-commercial and total), the average mass and the percentage of commercial roots were evaluated. Commercial roots were evaluated for firmness, elasticity and cooking time. The P doses influenced the production characteristics, mainly at the dose of 60 kg ha^{-1} of P_2O_5, which promoted increases in the yield of commercial roots. The doses of P promoted the reduction of firmness for both growing seasons. A dose of 180 kg ha^{-1} of P_2O_5 led to the shortest cooking time for the second growing season.

Keywords: *Ipomoea batatas*. Growing seasons. Yield. Commercial roots.

RESUMO - O fósforo (P) é um nutriente mineral primordial para as plantas, pois está diretamente ligado a processos fisiológicos e bioquímicos essenciais para a manutenção das plantas, podendo influenciar na produção e na qualidade final do produto. Além disso, o P favorece o bom desenvolvimento radicular, o que pode beneficiar a cultura da batata-doce. Assim, o objetivo do trabalho foi avaliar a influência de doses crescentes de P na produção e qualidade física da batata-doce em duas épocas de cultivo em ambiente semiárido. Os experimentos foram realizados de abril a agosto de 2021 (época 1) e de dezembro de 2021 a abril de 2022 (época 2) na Fazenda Experimental Rafael Fernandes - UFERSA, Mossoró, RN, BR. O delineamento utilizado foi em blocos casualizados, com quatro repetições. Os tratamentos consistiram de cinco doses de P (0; 60; 120; 180 e 240 kg ha^{-1} de P_2O_5) via fertirrigação e testados em batata -doce cultivar Paraná. Após a colheita das raízes, foram avaliados o número e a produtividade de raízes (comerciais, não comerciais e totais), a massa média e a porcentagem de raízes comerciais. Raízes comerciais foram avaliadas quanto à firmeza, elasticidade e tempo de cozimento. As doses de P influenciaram as características de produção, principalmente na dose de 60 kg ha$_{-1}$ de P_2O_5, o que promoveu aumentos na produtividade de raízes comerciais. As doses de P promoveram a redução da firmeza nas duas épocas de cultivo. A dose de 180 kg ha^{-1} de P_2O_5 proporcionou menor tempo de cozimento para a segunda época de cultivo.

Palavras-chave: *Ipomoea batatas*. Épocas de cultivo. Produtividade. Raízes comerciais.

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INTRODUCTION

Sweet potato [*Ipomoea batatas* (L.) Lam] is an important species for human health and is rich in vitamins and minerals (ALAM et al., 2020). China has stood out as the world's largest producer of sweet potatoes, with a production of 88.86 million tons in 2021, while Brazil occupied at the same time the 14th position, with a production of 824,680 t (FAOSTAT, 2022) and average yield of 14.25 t ha^{-1} (IBGE, 2021). Among the Brazilian regions, the Northeast has stood out with an amount produced of 345,718 t in 2021, higher than those of the Southeast (269,949 t) and South (210,705 t) regions (IBGE, 2021).

Cultivated for a long time in Brazil as a secondary crop in areas unsuitable for other crops of economic value, sweet potato has emerged as a business crop due to its versatility, especially for the processing industry (EMBRAPA, 2021). In this segment, flour production can be highlighted, in addition to a good suitability of sweet potato for ethanol production (TEDESCO et al., 2021). In the food segment, it is among the foods preferred by those who practice sports due to its high nutritional composition (KEHOE et al., 2015), in addition to being an alternative for those who have gluten restriction, as it has characteristics that allow replacing wheat flour (PÉREZ et al., 2017).

Although considered a rustic crop and dependent on few management practices for its cultivation, research has shown that the species responds positively when subjected to technologies such as the use of cultivars adapted to the region of cultivation (TEDESCO et al., 2021) and the application of fertilizers

(CORDEIRO et al., 2023). When it comes to the nutritional requirements of sweet potatoes, the scientific literature has pointed out that the primary nutrients required by the crop are potassium (K), followed by nitrogen (N) and phosphorus (P) (EMBRAPA, 2021). P is one of the most limiting essential elements for plant growth in many soils, both in tropical and subtropical environments (SILVA et al., 2018).

In photosynthesis, P plays a central role in photophosphorylation and the exchange of triose phosphate between the chloroplast and the cytosol. This nutrient also controls the function of many proteins through their covalent binding and activation or inhibition of enzymes that regulate the central metabolism of plants (DISSANAYAKA et al., 2021). Findings in the literature highlight the importance of P fertilization in sweet potatoes, improving yield and quality (CORDEIRO et al., 2023) and quality in other crops, such as cassava (SILVEIRA et al., 2021). Silveira et al. (2021), who tested P doses (0, 60, 120, 180 and 240 kg ha^{-1} of P_2O_5), found that depending on the cultivars, the quality of the roots of table cassava varied according to the doses of P. In turn, Cordeiro et al. (2023) obtained higher yield when they used 68 kg ha^{-1} of P in sweet potato plants.

However, in the case of a crop in which wide genetic variability is observed for most characteristics (ALAM et al., 2020), it can be inferred that the studies that use phosphate fertilization in sweet potatoes are not enough to meet the need for information related to the theme, such as production and quality of the roots. On the other hand, the sweet potato production chain has several cultivars, improved and regional, all with importance for cultivation, and each cultivar may show varied responses when subjected to the same management. Thus, the variability for the species does not allow extrapolating results obtained for cultivars and specific conditions since the results obtained may not be replicated, making it necessary to study the conditions where the technology is intended to be applied.

Thus, this study aimed to evaluate the influence of phosphorus doses on the production and physical quality of the sweet potato cultivar Paraná in a semi-arid environment.

MATERIAL AND METHODS

Experiments were carried out in two seasons, from April to August 2021 (season 1) and from December 2021 to April 2022 (season 2) at the Rafael Fernandes Experimental Farm, belonging to the Federal Rural University of the Semi-Arid Region (UFERSA), located in Mossoró, RN, Brazil (5º03′37" South latitude, 37º23′50" West longitude and 72 m altitude). The region's climate is characterized as BSh, hot and dry, according to Köppen's classification (ALVARES et al., 2013). The average temperature is approximately 27.8 °C, with irregular annual rainfall around 555 mm of total average and relative humidity of 68.9% (CLIMATE, 2021). The average air temperature, relative humidity, rainfall, solar radiation and wind speed data were collected at the Automatic Meteorological Station installed at the Experimental Farm (Figure 1).

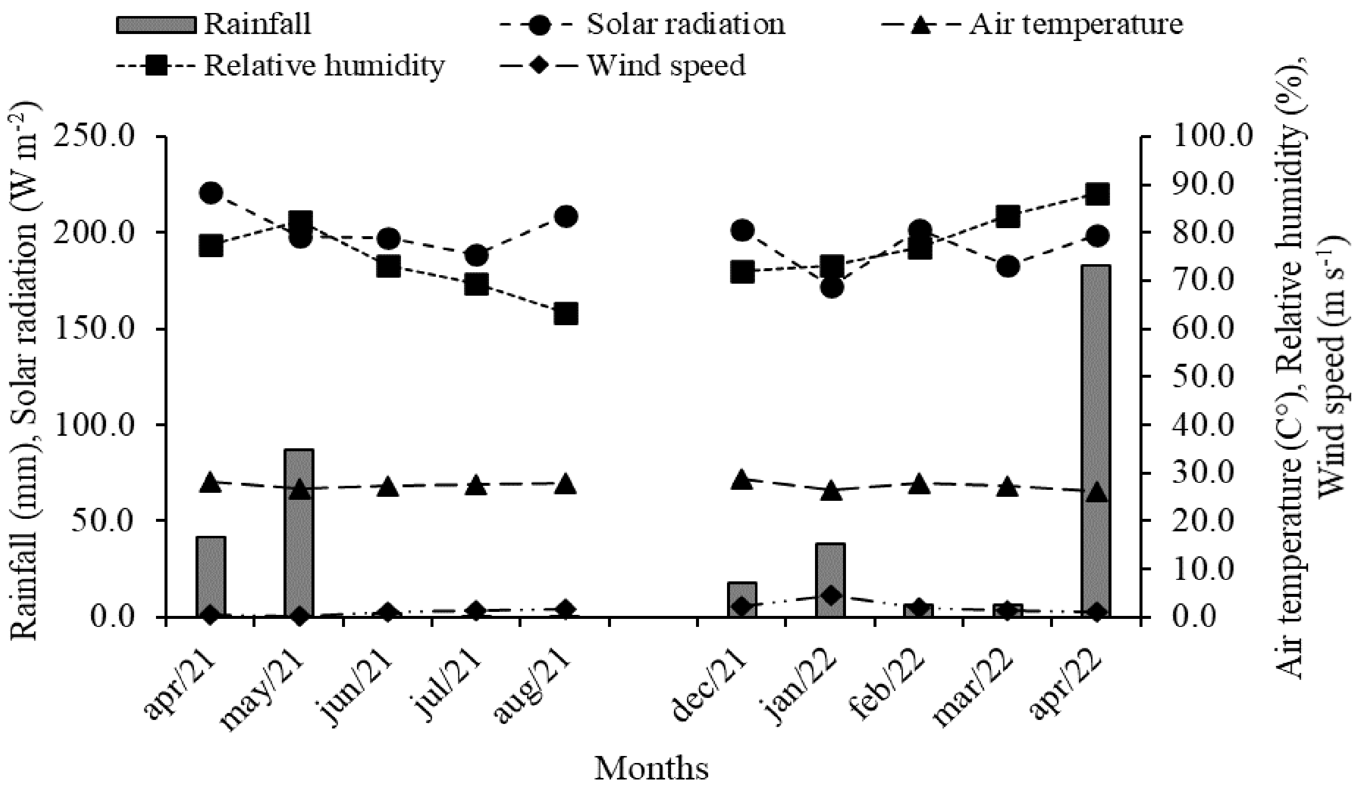


Figure 1. Average of the meteorological data at the Rafael Fernandes Experimental Farm, during the period of execution of the experimental tests, Mossoró, RN, Brazil.

The experimental design was randomized blocks with four replications. The treatments were composed of P doses, applied in the planting fertilization. Monoammonium phosphate (MAP) (61% P_2O_5 and 12% N) was used as a P source at the following doses: 0; 60, 120, 180, and 240 kg ha^{-1} of P_2O_5. Fertilization with nitrogen (N) and potassium (K) was performed according to Gomes, Silva and Coutinho (2008). The sources of N and K were urea (46% of N) and potassium chloride (KCl) (60% of K_2O), respectively applied in amounts of 40 and 60 kg ha^{-1}. N fertilization was adapted from Gomes, Silva and Coutinho (2008), and only 80% of the total N was applied 15 days after planting (DAP). Potassium was applied 50% at 20 DAP and 50% at 45 DAP. The amount of N applied was adjusted by discounting the N dose present in the MAP contained in basal fertilization.

In the experimental area, before offsetting up the experiments, soil samples were collected at depths of 0-0.20 m and 0.20-0.40 m to determine the chemical properties of the soil (Table 1). Plowing and harrowing operations were carried out to prepare the area, followed by lifting the 0.30 m high beds. The irrigation system was drip irrigation, with emitters spaced 0.30 m apart, applying an average daily depth of 11 mm. Tensiometers were installed to monitor soil moisture. Daily irrigation was performed until 30 days after planting (DAP). From 30 to 75 DAP, irrigation was performed when the tensiometers marked -20 kPa, using a methodology adapted from Embrapa (2021). From 75 to 90 DAP irrigation was suspended, resumed and performed once a week until harvest, always considering soil moisture between -15 and 25 kPa.

Table 1. Chemical analyses of the soil of the experimental area before offsetting up the experiments for seasons 1 (April to August 2021) and 2 (December 2021 to April 2022).

Depth	pH	EC	P*	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	SB	t	CEC
(m)	(water)	dS m^{-1}	mg dm^{-3}	---------- cmol$_c$ dm^{-3} ----------							
Season 1											
0 – 0.20	6.34	0.70	4.69	0.15	0.05	1.43	0.35	0.00	1.99	1.99	1.99
0.20 – 0.40	6.03	0.71	4.57	0.13	0.05	1.36	0.89	0.00	2.44	2.44	2.44
Season 2											
0 – 0.20	5.10	1.00	4.20	0.15	0.00	1.06	0.49	0.00	1.70	1.70	1.70
0.20 – 0.40	5.37	0.80	2.37	0.13	0.06	0.79	0.23	0.00	1.21	1.21	1.21

*Extractant: Mehlich-1; EC – Electrical conductivity of the soil saturation extract; SB – Sum of bases; t – Effective cation exchange capacity; CEC – Cation exchange capacity.

Each plot comprised four beds measuring 2.4 m in length and spaced 1 m apart, with a usable area of 3.6 m^2 and a total of 9.6 m^2. Apical branches with five to six buds were used, and two branches were planted per hole, spaced 0.30 m apart. The cultivar used was Paraná, which has a branching habit, leaves with a hastate base and acute apex, rounded roots with periderm and orange pulp (MOREIRA et al., 2011). Manual weeding was carried out in a total of four operations for each season. No pesticides were applied in the area because there was no occurrence of pests and diseases in the crop at the level of economic damage.

At 153 DAP, the roots were evaluated for the following characteristics: total number of roots (TNR); number of roots with commercial standard (NCR); number of roots with non-commercial standard (NNCR); total root yield (TRY); yield of roots with commercial (YCR) and non-commercial (YNCR) standards; average mass of commercial roots (AMCR) in g $root^{-1}$, equal to the ratio between YCR and NCR, and the percentage of commercial roots (%CR), equal to the ratio between YCR and TRY. The number of roots was counted manually, and root yield was obtained by weighing the roots of the usable area on an electronic scale and extrapolating the results to 1 hectare, expressed in t ha^{-1}.

Firmness, elasticity and cooking time (CT) were also evaluated. Firmness and elasticity were determined from two commercial roots of each plot using a benchtop texture analyzer – (Stable Micro Systems, model TA. XT Express/ TA. XT2icon). The cylindrical probe used was 2 mm in diameter, and three equidistant measurements were performed, considering the mean between them. Firmness was expressed in Newton (N), and elasticity in millimeters (mm). CT was determined in a Mattson cooker, with adaptations proposed by Feniman (2004). Initially, distilled water was placed in a water bath boiled at approximately 100 ºC. After boiling, the apparatus was placed in the water bath. Twelve standardized sweet potato cubes were used for each treatment. For each cube, twelve plungers were used, and their tips were positioned in the center of the cubes. The water level in the water bath was above the sweet potato cubes. CT was determined when the twelve plungers penetrated the cubes and touched the bottom of the water bath.

The data obtained in each growing season were checked for normal distribution by the Shapiro-Wilk test and then subjected to analysis of variance by the F test (5%). With the homogeneous data, a joint analysis was applied between the P doses and the growing seasons. Tukey's mean comparison test was applied to the doses with their respective seasons and between seasons. When significant, they were subjected to polynomial regression analysis for P doses. The analyses were performed in the statistical program Sisvar 5.6 (FERREIRA, 2014).

RESULTS AND DISCUSSION

Statistical difference ($p<0.05$) was observed between the seasons for the characteristics of number of commercial roots, yield of commercial roots and total root yield, average mass of commercial roots and percentage of commercial roots. There was an influence of P doses for the variables yield of commercial roots and total root yield. The dose of 60 kg ha^{-1} of P_2O_5 increased the number and yield of commercial and total roots for the two growing seasons. In addition, for the same dose, season 2 showed an increase of 126% in yield of commercial roots compared to season 1. It is worth mentioning that the dose of 60 kg ha^{-1} of P_2O_5, in season 2, increased the average mass of commercial roots for the treatment that did not receive phosphate fertilization (Table 2).

The scientific literature presents some reports on the gain in the production of commercial roots of sweet potato when fertilized with P (CORDEIRO et al., 2023). However, the data observed in the present study confirm the importance of the environment for characters related to root yield. Likewise, the need for evaluation and constant improvement in crop management is reinforced, mainly when it is intended to cultivate in different seasons and with different types of management. Cordeiro et al. (2023) tested doses of P (0; 22; 44; 88 and 176 kg ha^{-1} of P_2O_5) in sweet potatoes and observed an increase in yield for the dose of 68 kg ha^{-1} of P_2O_5, favoring an increase of 120% compared to the treatment that did not receive the dose of P. This finding corroborates the results found in the present study, where the dose of 60 kg ha^{-1} of P_2O_5 promoted an increase in the yield of commercial roots, equal to 126% for season 2 compared to season 1 and equal to 92% for season 2 compared to the treatment that did not receive the dose of P for the same season.

Table 2. Mean values of the total number of roots (TNR), number of commercial roots (NCR), number of non-commercial roots (NNCR), total root yield (TRY), yield of commercial roots (YCR), yield of non-commercial roots (YNCR), average mass of commercial roots (AMCR) and average percentage of commercial roots (%CR) of the cv. Paraná subjected to phosphorus doses for seasons 1 (April to August 2021) and 2 (December 2021 to April 2022).

Doses (kg ha^{-1})	NCR	NNCR	TNR	YCR	YNCR	TRY	AMCR	%CR
		(unt)			(t ha^{-1})		(g/root^{-1})	(%)
Season 1								
0	7.00aA	8.75aA	20.75aA	11.17aA	3.98aA	15.15aA	0.142aB	64.84aA
60	15.75aB	8.25aA	38.5aA	32.20aB	3.17aA	35.38aB	0.205aA	91.72aA
120	11.00aA	8.50aA	20.00aA	27.22aA	3.52aA	30.74aA	0.185aA	66.73aB
180	10.25aA	7.25aA	24.75aA	16.14aA	2.89aA	19.04aA	0.157aA	84.85aA
240	9.25aA	6.25aA	15.00aA	18.19aA	3.25aA	21.44aA	0.174aA	82.70aA
Season 2								
0	14.75aA	6.00aA	20.75aA	37.90abA	2.47aA	40.37abA	0.264aA	87.40aA
60	27.75aA	10.75aA	38.50aA	72.89aA	4.83aA	77.73aA	0.267aA	93.95aA
120	12.50aA	7.50aA	20.00aA	28.03bA	3.08aA	31.11bA	0.205aA	92.83aA
180	17.25aA	7.50aA	24.75aA	38.67abA	3.41aA	42.08abA	0.189aA	83.84aA
240	11.75aA	3.25aA	15.00aA	27.65bA	1.50aA	29.15bA	0.236aA	93.64aA
OM	13.72	7.40	21.12	31.00	3.21	34.22	0.203	84.20
CV (%)	28.83	30.31	27.96	31.80	26.88	30.59	2.37	10.46
D	ns	ns	ns	*	ns	*	ns	ns
S	*	ns	ns	**	ns	**	**	*
D x S	ns	ns	ns	ns	ns	ns	ns	ns

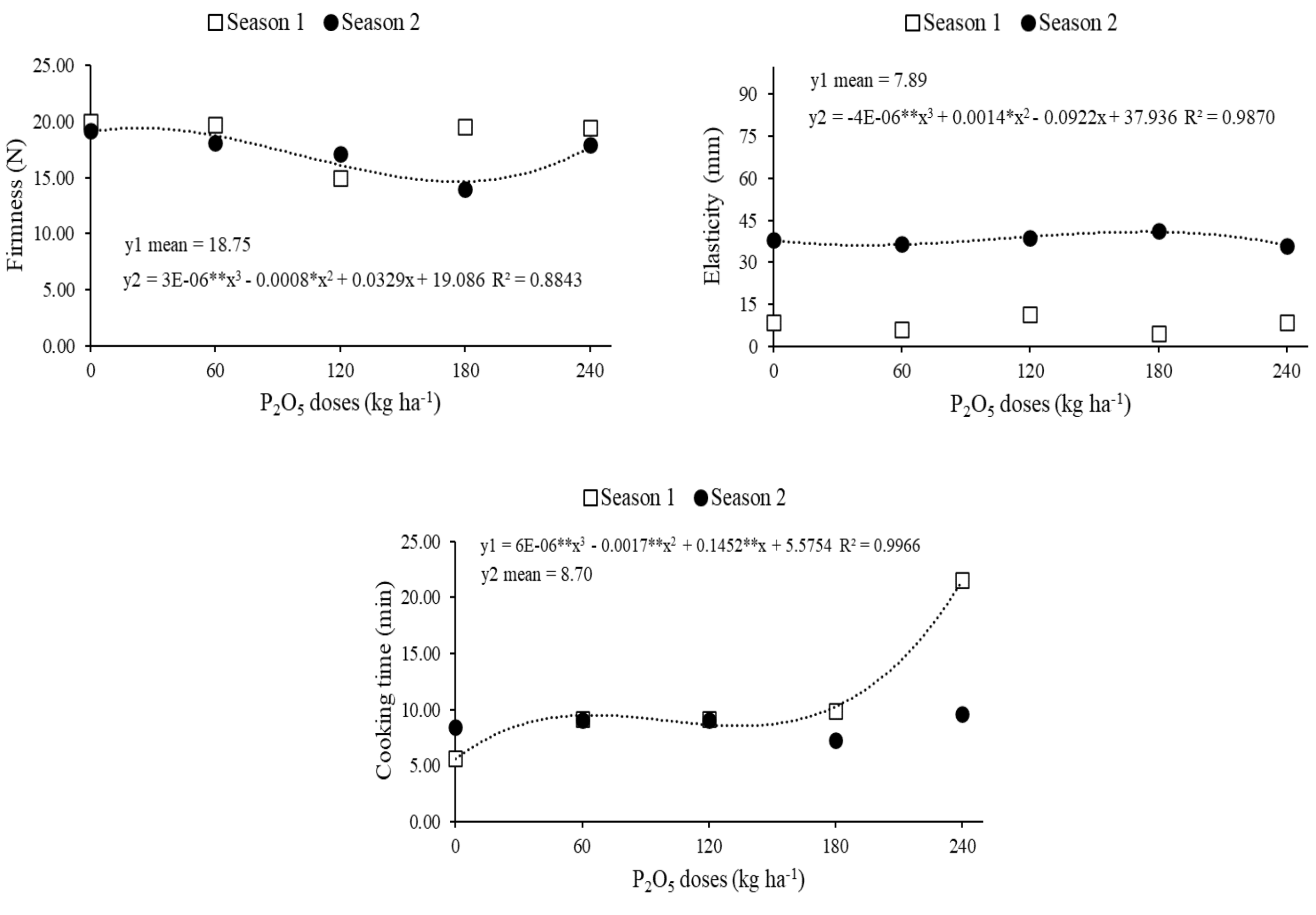
Means followed by different lowercase letters differ between doses, and means followed by different capital letters differ between growing seasons at 5% probability level by Tukey's test ($p<0.05$). OM – Overall mean. CV (%) – Coefficient of variation. (D) doses; (S) season; (D x S) interaction. * and **- significant at 5% and 1% probability levels by the F test; ns – not significant; unt– unit.

An essential parameter in the soil that should be considered is the pH, because it influences the availability of P to plants (VON TUCHER; HÖRNDL; SCHMIDHALTER, 2018). Regarding the pH values found in the present study, season 2 had values lower than those found in season 1 (Table 1). Under acidic pH (5.10 - 5.37), in season 2, sweet potato was responsive to the use of P. It is worth noting that the pH affects in different ways various mechanisms of P sorption; in addition, these mechanisms are partially affected by the properties of the soil, so there may be exceptions in which certain plants show better development under acidic conditions (PENN; CAMBERATO, 2019). Cerozi and Fitzsimmons (2016) assessed the effect of pH on the availability of P in nutrient solutions in aquaponics, recommending the pH range of 5.5 to 7.2 for optimal availability and absorption by plants. In large part, low availability of P is caused by precipitation and adsorption of inorganic forms (SANTOS et al., 2016).

Regarding the availability of P, the season 1 had contents < 5 mg dm^{-3}, while season 2 had contents of 4.20 and 2.37 mg dm^{-3}, respectively, for the depths 0–0.20 m and 0.20–0.40 m (Table 1). Cordeiro et al. (2023), when evaluating the yield and quality of sweet potatoes as a function of phosphate fertilization in different soils, found that in an area with low levels of P in the soil (< 3.7 mg dm^{-3} - resin), it was necessary to apply 68 kg ha^{-1} of P_2O_5 to obtain higher yield of tuberous roots of sweet potatoes. In addition, the same authors mentioned that the yield in the area with low P content was low due to low rainfall, which may explain the low yield of season 1 compared to season 2, since season 2 had high rainfall in the month preceding the harvest.

Another factor worth mentioning is the low activity of nutrient ions due to the Na^+/Ca^{2+} ratio in the soil solution. The Ca^{2+} contents were 1.43 and 1.36 $cmol_c$ dm^{-3}, equivalent to 286 and 272 mg dm^{-3} for season 1. On the other hand, Na^+ contents varied by 95% from season 1 to season 2 at the 0–0.20 m depth (Table 1). Dey et al. (2021) pointed out that these proportions of Na^+ and Ca^{2+} present in solution affect the absorption of nutrients by plants, in particular, the availability of P, which is reduced by the effect of ionic strength, high sorption capacity of soil particles and low solubility of minerals in saline soil. Ding et al. (2020) reported that low water intakes reduce salt leaching, causing the accumulation of calcium minerals and that much of the water-soluble P applied to the soil is converted into insoluble forms for plants.

The P doses influenced the firmness of the commercial roots in both seasons (Figure 2). In season 1, the firmness of the commercial roots at the 120 kg ha^{-1} dose of P_2O_5 differed from those obtained with the other doses, which led to higher firmness but were statistically equal. Although there was no significant difference between the doses 0, 60, 180 and 240 kg ha^{-1} of P_2O_5, there was a reduction in the average firmness. In season 2, the doses of P caused a reduction in firmness compared to the treatment that did not receive the doses of P. The mean values of firmness of the treatments with P were 18.11 N, 17.10 N, 14.01 N and 17.97 N, respectively, for doses of 60, 120, 180 and 240 kg ha^{-1} of P_2O_5. The reductions followed the same order: 6%, 11%, 27% and 7%.



* and **- significant at 5% and 1% probability levels by the F test.

Figure 2. Firmness (N), elasticity (mm) and cooking time (min) of the cv. Paraná subjected to phosphorus doses for seasons 1 (April to August 2021) and 2 (December 2021 to April 2022).

Firmness is linked to increased lignin content, conferring compressive strength and stiffness to the cell wall (ALBUQUERQUE et al., 2018). In addition, reduced lignin synthesis is an essential sign of sweet potato root formation (PONNIAH et al., 2017). Luo et al. (2022) found that adding phosphorus decreased plant lignin from the soil in a subalpine forest, as P caused a suppression in oxidase activity, favoring lignin decomposition. Thus, it can be deduced that the P doses influenced the reduction of firmness in the sweet potato cultivar.

P doses influenced elasticity (Figure 2). The elasticity of season 2 differed statistically from that found in season 1. In season 2, the doses of P influenced the elasticity, and the data was described by the cubic equation with $R^2 = 0.98$. It can be observed that firmness and elasticity showed inversely proportional points. At the same time, the P doses caused a reduction in firmness in both growing seasons and the elasticity was increased up to the dose of 180 kg ha^{-1} of P_2O_5 for season 2. In root pulp, the reduction of firmness and the increase in elasticity are critical physical parameters, as they provide softness and ease of handling and leave the product with a better quality (SILVEIRA et al., 2021).

In turn, elasticity is the degree to which the sample can recover after specific compression (PATERNINA; LUNA; BERMUDEZ, 2022). A possible hypothesis for the increase in elasticity is that, after harvest, the loss of water by transpiration compromises the firmness of fruits and vegetables, causing flaccidity, softness and wilting (CHITARRA; CHITARRA, 2005); in addition, high concentrations of P promote lower membrane permeability and root exudation, decreasing nutrition for microorganisms (KIRIACHEK et al., 2009). Dimkpa, Weinand and Asch (2009) mentioned that microbial communities of the rhizosphere improve the stability of the cell membrane by activating the antioxidant defense system, which can promote stability of the root cell membrane, favoring a greater tolerance to water stress.

Cooking time was influenced by the P doses in both seasons (Figure 2). In season 1, it was observed that the dose of 240 kg ha^{-1} of P_2O_5 had the highest mean statistically; in addition, it can be observed that, as the phosphate doses were increased, the cooking time increased. In season 2, the cooking time for the treatment that did not receive P was increased at doses 60, 120 and 240 kg ha^{-1} of P_2O_5, respectively, by 8%, 7% and 14%. On the other hand, the dose of 180 kg ha^{-1} of P_2O_5 reduced cooking time by approximately 14%. Silveira et al. (2021), who tested P doses in cassava cultivars, reported that the cooking time was reduced with increasing P doses, highlighting the influence of P on this characteristic.

CONCLUSIONS

The P doses influenced the production characteristics, especially the dose of 60 kg ha^{-1} of P_2O_5, which increased the yield of commercial roots.

The P doses promoted the reduction of firmness for both growing seasons.

The dose of 180 kg ha^{-1} of P_2O_5 promoted the shortest cooking time for the second growing season.

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