SODIUM AND POTASSIUM PROPORTION IN QUINOA CULTIVATED UNDER SALINE SOILS AND RICE HUSK BIOCHAR

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ABSTRACT: Quinoa is a plant that shows strong potential for adaptation to Brazilian's semiarid, which faces low rainfall, high soil salinity, and food insecurity. Quinoa has salt tolerance mechanisms such as regulating potassium (K) and sodium (Na) levels in its tissues to resist salt stress. Biochar (carbonaceous organic material) can help reduce the harmful effects of high salt levels. To assess how different doses of rice husk biochar (RHB) affect the K and Na content in quinoa grown in saline soils, a greenhouse experiment was conducted with the genotype CPAC 09, developed by EMBRAPA. The study used a 3x7 factorial design, involving three soil and seven biochar doses (0, 10, 20, 40, 80, and 100 t ha^{-1}). After harvest, plant samples were analyzed to measure Na and K concentration. The results showed that biochar increased K^+ uptake by quinoa, helping to reduce its salt stress and Na^+ effects. Since RHB is high in K, quinoa absorbed more K, leading to lower Na levels in its shoots, even under high salinity. Therefore, growing quinoa in saline-sodic soils should be combined with a K source to minimize Na uptake. For optimal cost-effectiveness, the recommended RHB application dose is 40 t ha^{-1} to lessen the negative impacts of sodicity on plants.

KEYWORDS: quinoa CPAC 09 genotype, salt tolerance, nutritional balance

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PROPORÇÃO ENTRE SÓDIO E POTÁSSIO EM QUINOA CULTIVADA SOB SOLOS SALINOS E BIOCHAR DE CASCA DE ARROZ

RESUMO: Quinoa é uma planta que apresenta potencial de adaptação à região semiárida brasileira, que enfrenta baixa pluviosidade, alta salinidade e insegurança alimentar. Por ser uma planta halófita, ela possui mecanismos de tolerância aos sais, como regulação dos níveis de potássio (K) e sódio (Na) em seus tecidos para resistir ao estresse salino. O biochar (material orgânico carbonáceo) pode ajudar a reduzir os efeitos nocivos dos sais no solo. Para avaliar como doses de biochar de casca de arroz afetam os teores de K^+ e Na^+ na quinoa cultivada em solos salinos, um experimento em casa de vegetação foi conduzido com o genótipo CPAC 09 (EMBRAPA). Foi utilizado um delineamento fatorial 3x7, com três solos e sete doses de biochar (0, 10, 20, 40, 80 e 100 t ha^{-1}). As amostras de plantas foram analisadas para determinação do K e Na. Os resultados mostraram que, devido à alta concentração de K^+ no biochar, a quinoa absorveu mais K^+ e reduziu o Na^+ na biomassa aérea, mesmo em solos salino-sódicos. Assim, o cultivo de quinoa em solos salinos deve ser combinado com fontes de K^+ para minimizar a absorção de Na^+. Para obtenção do melhor custo-benefício, a dose recomendada de biochar foi de 40 t ha^{-1} para diminuir os impactos negativos da sodicidade nas plantas.
PALAVRAS-CHAVE: genótipo de quinoa CPAC 09, tolerância a sais, balanço nutricional

INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) is a halophyte considered to be one of the promising crops for mitigating hunger. Because of its high nutritional value with all the essential amino acids for the human diet, quinoa has been gaining prominence in research, mainly because of its tolerance to adverse climate conditions such as drought, salinity/sodicity, and low temperatures (Bhargava et al., 2006; Bazile et al., 2016; Garcia-Parra et al., 2020).

Depending on the genotype, quinoa tolerates extreme environmental conditions and can be used as a tool in the phytoremediation of salt-affected soils, having a high potential for regions with water scarcity and advancing salinization/sodification (Jacobsen et al., 2003; Ruiz et al., 2016; Iqbal et al., 2019). In saline and sodic soils, quinoa has salt-tolerance mechanisms such as osmotic adjustment, osmoprotection, Na^+ storage and transportation, ROS tolerance, K^+ retention, and stomatal control (Adolf et al., 2013; Ruiz et al., 2016).

Biochar produced from different raw materials and pyrolysis temperatures has been studied as an alternative conditioner for saline-sodic soils. It has been used mainly by promoting improvements in soil physical, chemical, and biological properties, allowing increases in crop productivity by reducing associated stress as drought and toxicity of certain elements (Thomas et al., 2013).

As K^+ is a macronutrient and Na^+ generally has a negative impact on plant growth, this work aims to evaluate the proportion of K and Na in quinoa's shoot after application of increasing biochar doses in saline-sodic soils commonly found in the Brazilian semiarid region.

MATERIAL AND METHODS

The experiment was carried out in a greenhouse at the Agronomic Institute of Pernambuco (IPA), in Recife (PE), Brazil, in the months of Mar/Aug 2022. The genotype CPAC 09 of quinoa (*Chenopodium quinoa* Willd.) from EMBRAPA Cerrados was selected, which was cultivated under biochar doses of 0, 10, 20, 40, 80, and 100 t ha^{-1}, in three soils, one non-saline and two saline-sodic soils, in a randomized block design, with four replications, totaling 84 experimental units. The soils were collected at a depth of 0-20cm in the cities of Cabrobó-PE, Parnamirim-PE, and Caruaru-PE, and classified as Cambisol, Fluvisol, and Planosol, respectively.

Chemical analyses were carried out for soil characterization (Table 1): pH in water (1:2.5); soil electrical conductivity (ECe) and soluble cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) by saturated paste extraction; and exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) by the ammonium acetate method. K^+ and Na^+ were measured by flame emission photometry, and Ca+ and Mg^{2+} by atomic absorption spectrophotometry (USSL Staff, 1954; Embrapa, 2017). Exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) were calculated (Table 1).

The biochar feedstock was rice husk (RHB), which was ground and sieved through a 0.200 mm mesh for characterization. Ca, Mg, and K were determined by portable-XRF, and organic carbon, hydrogen, and nitrogen were determined by dry combustion, using a CHN628 elemental analyzer (LECO), enabling the calculation of C/N ratio. Biochar pH and EC were determined at a ratio of 1:10, according to Singh et al. (2017). The values obtained in biochar characterization were 7.25 for pH; 0.22 dS m^{-1} for EC; 47.67, 1.4, and 6.32% for C, N, and H; C/N of 34.05; and 1.52, 0.71, and 5.53 g kg^{-1} for Ca, Mg, and K, respectively.

Quinoa sowing was carried out in trays, where the plants were adapted to salinity conditions. Transplanting was carried out after the opening of the 6th definitive leaf. The experiment was conducted over three months. After the harvest, dry plant samples were ground and subject to digestion by HNO_3 1 mol L^{-1} to determine Na and K. Na and K were measured by flame photometry according to Embrapa (2009). The results obtained were initially subjected to normality tests (Shapiro-Wilk, $p < 0.05$) and homoscedasticity (Levene, $p > 0.05$). After these procedures, analysis of variance (ANOVA, $p<0.05$) was performed, and the average values of the results were compared among soils using the Tukey test ($p<0.05$).

RESULTS AND DISCUSSION

According to Table 1, Cambisol and Fluvisol were characterized as saline-sodic soils, with high concentrations of Na^+ and low concentrations of K^+. Planosol showed no salt accumulation compared to the other soils, with similar concentrations of the two monovalent cations (Na^+ and K^+).

Table 1. Chemical characterization of three soils from Brazil Semiarid

Soils	pH	EC_e	Ca^{2+}	Mg^{2+}	Na^+	K^+	SAR	Ca^{2+}	Mg^{2+}	Na^+	K^+	ESP
		dS m^{-1}		mmol$_c$ L^{-1}					cmol$_c$ kg^{-1}			%
Cambisol	8.1	31.0	40.1	46.3	152.2	1.7	23.3	25.2	6.6	2.1	0.3	6.1
Fluvisol	6.3	22.6	32.8	55.7	118.6	1.0	18.7	7.5	7.5	1.7	0.3	9.5
Planosol	5.7	0.9	1.8	6.2	3.03	2.3	1.5	0.4	0.9	0.4	0.4	8.0

ECe: Soil Electrical Conductivity; SAR: Sodium Adsorption Rate; ESP: Exchangeable Sodium Percentage.

There was a double interaction among biochar doses and soils for the monovalent ions (Na^+ and K^+) according to ANOVA ($p<0.05$). For Na^+, the increment in biochar doses reduced its concentration in quinoa shoots in all evaluated soils. In Cambisol, the Na concentration in quinoa shoots ranged from 6.43 to 1.57 g kg^{-1} between the control and 100 t ha^{-1} doses. For plants in Fluvisol, the averages went from 4.42 to 1.89 g kg^{-1} between the first and last treatments (Table 2).

For K, there was an increment in its concentration after biochar application, mainly in Fluvisol plants (69.2 to 89.75 g kg^{-1} between the first and last treatments). It is possible to observe, in Figure 1, that the proportion of Na^+ in relation to K^+ decreases with the RHB addition. For Cambisol plants, the relative proportion between Na^+ and K^+ went from 7.4 and 92.6% at a dose of 0 t ha^{-1} to 1.7 and 98.3% at a dose of 100 t ha^{-1}. For Fluvisol plants, this proportion changed from 5.2 and 94.8% to 2.3 and 97.7%. In Planosol plants, Na^+ and K^+

proportions changed from 1.5 and 98.5% to 1.2 and 98.8% under the same RHB doses. For nutritional parameters, the 40 t ha^{-1} biochar dose was considered the best one as it does not differ significantly from higher doses, especially between Na^+ and K^+ concentration (Table 2).

Table 2. Sodium (Na) and potassium (K) accumulation in quinoa under application of rice husk biochar (RHB) in three different soils of the Brazilian semiarid region

Biochar doses	Na				K			
	g kg^{-1}							
	Cambisol	Fluvisol	Planosol	Mean	Cambisol	Fluvisol	Planosol	Mean
0	6.43^{Aa}	4.42^{Ab}	1.22^{Ac}	4.02	80.00^{BCa}	69.20^{CBa}	80.13^{Aa}	76.44
10	4.00^{BCa}	3.44^{ABa}	1.47^{Ab}	2.97	84.5^{ABCa}	65.30^{Cb}	78.45^{Aab}	76.12
20	4.38^{Ba}	2.44^{BCb}	1.25^{Ac}	2.69	66.40^{Ca}	76.20^{ABCa}	77.25^{Aa}	73.28
40	2.79^{CDa}	2.34^{BCa}	1.14^{Ab}	2.09	78.4^{BCa}	86.20^{ABa}	76.88^{Aa}	80.51
60	2.20^{Dab}	2.87^{BCa}	1.04^{Ab}	2.04	88.6^{ABa}	86.50^{ABab}	71.20^{Ab}	82.11
80	2.31^{Da}	2.1^{BCab}	1.03^{Ab}	1.81	100.33^{Aa}	86.50^{ABab}	76.95^{Ab}	87.92
100	1.57^{Da}	1.89^{Ca}	0.95^{Aa}	1.47	91.25^{ABa}	89.75^{Aa}	80.75^{Aa}	87.25
Mean	3.38	2.79	1.16		84.22	69.96	77.37	
ANOVA	F				F			
Soil	78.44^{***}				4.12^{*}			
Dose	18.84^{***}				4.69^{***}			
Soil x Dose	5.85^{***}				3.06^{**}			
CV (%)	28.15				11.21			

Uppercase letters compare means in the column, and lowercase letters compare means in the line. Means compared using the Tukey test at 5% probability. ***, **, * are equal to 0.1, 1, 5% of probability, respectively.

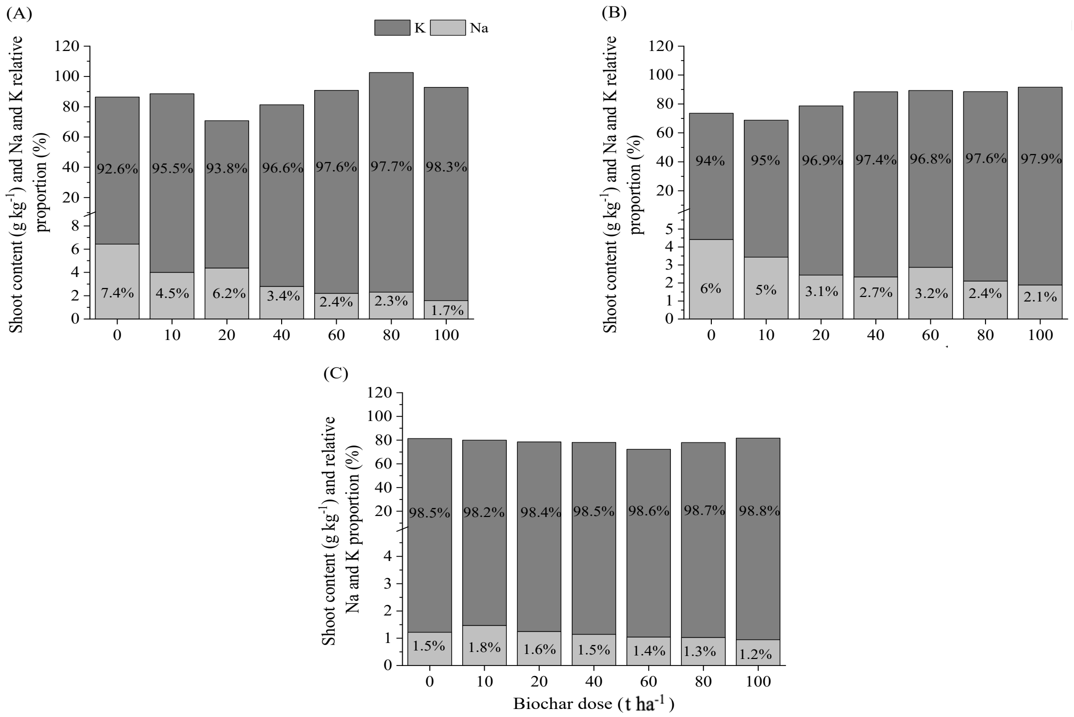

Figure 1 – Na and K relative proportion in quinoa shoot. (A) Cambisol; (B) Fluvisol;(C) Planosol.

It is evident, in Figure 1, that the relative proportion of Na^+ to K^+ is reduced with increasing biochar doses. This trend indicates a greater supply of K^+ from the RHB, as it is a material with a K^+ concentration of 5.53 g kg^{-1} according to biochar characterization. RHB also has the ability to alleviate the stress caused by Na^+. The effect of reducing Na^+ relative to K^+ is strongly evident in saline soils (Cambisol and Fluvisol), where Na^+ concentrations reached very high and potentially toxic values, which can be assessed from the SAR and ESP of these soils (Table 1).

Similar results were observed by Ferreira et al. (2020), where the authors evaluated K^+ absorption in spinach plants. As quinoa and spinach belong to the same botanical family, they have some similar mechanisms of mineral uptake and tolerance to salinity. According to the authors, the greater the availability of K^+ in the soil, the greater the absorption of this nutrient by spinach, even in saline soils.

In all soils evaluated, Na^+ absorption by plants has a negative correlation with K^+ concentrations in the soil, indicating a preference for K^+ absorption compared to Na^+, especially in saline soils. With these results, it is clear that quinoa uses K^+ as a way to minimize the impacts caused by Na^+. This mechanism of tolerance to saline environments was also described by Turcios et al. (2021) in a study on K^+ absorption in saline soils by quinoa. The authors concluded that a high K^+ concentration in soil increases quinoa biomass in saline and sodic soils regulating the K^+/Na^+ ratio inside the cells, alleviating the stress caused by salinity through osmotic regulation and also reduction in plant's stomatal conductance, allowing greater quinoa tolerance to saline environments.

CONCLUSION

In general, the addition of increasing doses of biochar favored the better development of quinoa, alleviating the harmful effect of Na^+ and increasing the absorption of K^+. One of the main tolerance mechanisms of quinoa in saline environments is the superabsorption of K. For tropical cultivation, the dose of 40 t ha^{-1} of RHB presented the best benefits for quinoa, promoting improvements in the crop compared to lower doses.

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