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Sources and doses of potassium affect the yield of *Cucumis anguria* L. in the Brazilian semiarid

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Abstract: The gherkin (*Cucumis anguria* L.) is a vegetable widely adapted to different edaphoclimatic conditions. It can be used for human consumption, being an alternative healthy nutrition source in the increasing world population. This study aimed to evaluate the yield, content of soluble solids, potassium and leaf sulfur accumulation, and the chlorophyll content of the gherkin cultivar 'Nordestino' under different sources and doses of potassium fertilizer. The experiment was carried out in a complete randomized block design, with treatments distributed in a 6 x 2 factorial scheme, with six doses (0, 50, 100, 150, 200, and 250 kg ha^{-1}) and two sources of K_2O (potassium chloride and sulfate), in four replicates. The highest soluble solids content (3.68%) was obtained under the dose of 78.75 kg ha^{-1} of K_2O with potassium sulfate. The maximum dose of K_2O resulted in a tissue K content of 20.7 g kg^{-1}, with a tissue S content of 4.49 and 3.24 g kg^{-1} under the doses of 250 and 164.16 kg ha^{-1} of K_2O, respectively, using sulfate and potassium chloride as K source. The total yield was 7.78 t ha^{-1} and 6.92 t ha^{-1} under the doses of 102.25 and 81.75 kg ha^{-1} of K_2O, respectively, using sulfate and potassium chloride as sources. Based on this study, the dose of 105.45 kg ha^{-1} of K_2O using potassium sulfate as K source is recommended to reach the maximum productivity of the gherkin cultivar 'Nordestino'.

Keywords: Cucurbitaceae, gherkin, K_2O, mineral nutrition, vegetable.
Abbreviations: CEC_Cation exchange capacity; DAS_days after sowing; OM_Organic matter; SB_Sum of bases.

Introduction

Gherkin (*Cucumis anguria* L.) is a highly adaptable vegetable to various edaphoclimatic conditions. This crop is a common ingredient in the Brazilian cuisine in the North and Northeast regions, with fruits rich in nutrients and minerals (Oliveira et al., 2017) being an optimum nutritional source to meet human needs in a scenario where the population is continuously growing and facing food insecurity. The average crop productivity in Brazil is 5.0 t ha^{-1}, but yields can vary according to cultivar and cultivation system (Filgueira, 2000).

The gherkin is cultivated in countries such as India, Hungary, Madagascar, and Mexico (Kamalnath et al., 2019). However, in Brazil, production is still limited due to the lack of specific technologies to implement the crop (Morais et al., 2018), possibly due to the low immersion of this vegetable in food and low commercial potential. Therefore, the search for technical and scientific information on crop nutritional management, such as potassium sources and rates, among other factors, can be an efficient strategy to improve the cultivation of gherkin.

Potassium is an essential macronutrient nutrient for vegetables that plays a fundamental role in the growth and development process (Filgueira, 2000). This nutrient regulates stomatal movements and acts on the transport of water and nutrients in plants (Taiz et al., 2017). Moreover, optimal potassium levels are involved in enzymatic activities in the carbon metabolism and optimization of photosynthetic efficiency helping to maintain an adequate supply of nitrogen by the enzyme Rubisco (ribulose-1,5-bisphosphate carboxylase oxygenase) (Xu et al., 2020).

Crops absorb potassium mainly by fertilization with potassium chloride (KCl) and potassium sulfate (K_2SO_4) sources (Hasanuzzaman et al., 2018). The KCl is the most used source in agriculture due to its low cost. Before applying the fertilizers, it is essential to assess the nutritional requirements of the crops and the edaphoclimatic characteristics of the region to have adequate nutrient management. Thus, research focusing on potassium nutrition is essential for profitable and environmentally sustainable gherkin cultivation.

The literature already demonstrates the effects of management with different potassium sources or doses on the cultivation of several crops from the Cucurbitaceae family, such as pumpkin (*Cucurbita moschata*), squash (*Cucurbita pepo*), melon (*Cucumis melo*) and watermelon (*Citrullus lanatus*) (Cecílio Filho and Grangeiro, 2004; Grangeiro and Cecílio Filho, 2006; Araújo et al., 2012; Fernandes et al., 2016). However, information on potassium fertilization on the production and quality of *Cucumis anguria* is still scarce.

Therefore, this study aimed to evaluate the yield, content of soluble solids, potassium and leaf sulfur accumulation, and the chlorophyll content of the gherkin cultivar 'Nordestino' in response to different sources and doses of potassium fertilization.

Results and discussion

Fruit length, fruit mass, number of commercial fruits per plant and fruit production per plant

The fruits reached 6.6 and 6.5 cm in length under the doses of 125 and 150 kg ha^{-1} of K_2O, respectively, when sulfate and potassium chloride were used as source (Figure 1A). The highest values of mass, 40.33 and 41.43, were obtained under the doses of of 141.5 and 125 kg ha^{-1} of K_2O, respectively, using the potassium chloride and potassium sulfate sources (Figure 1B). The gherkin number of commercial fruits per plant was 12.07 and 10.62 when the plants were fertilized with the doses 133.50 and 96.75 kg ha^{-1} of K_2O, respectively, using the potassium chloride and sulfate (Figure 1C). The highest fruit production per plant (352.58 g) was obtained when the dose of 97.77 kg ha^{-1} of K_2O was used (Figure 1D).

Although the difference between the variables is low when the maximum effect achieved with the two sources was evaluated, the difference between the doses is significant, as the potassium sulfate promoted the highest variable values with a lower dose. The fruit lengths obtained for the 'Nordestino' cultivar are within the commercial standards (5.0-6.0 cm) (CEAGESP, 2023). The greater fruit length obtained with potassium sulfate at a lower potassium dose can be attributed to the formation of organic compounds constituted of sulfur, such as cysteine, which is part of the carbon, nitrogen, and sulfur assimilation pathways, which favors plant metabolism (Jobe et al., 2019). Furthermore, cysteine associated with methionine and its derivatives are precursors for synthesizing various compounds, including acetyl-CoA, S-adenosylmethionine, and S-methylmethionine (Taiz et al., 2017). These enzymatic cofactors associated with potassium function on water use and enzymatic activity promoting a better use of photoassimilates (Taiz et al., 2017), favoring fruit growth.

The average mass values obtained are within the standards for commercialization, which ranges from 14.57 to 45.70 g fruit^{-1} for *Cucumis anguria*, depending on the sowing date (Resende, 1998). The different potassium sources promoted similar results, however, potassium sulfate provided fruits with higher mass at a lower doses. This can be attributed to the effects of potassium combined with sulfur, as potassium influences enzymatic activity, and sulfur composes enzymatic cofactors that form organic compounds, which are present in plant metabolism and storage organs (Taiz et al., 2017). Tuna et al. (2010) reported an increase in the fruit weight of melon under fertilization with different doses of K_2O using potassium sulfate as source. It is worth mentioning that potassium, together with sulfur, has important effects on the synthesis of amino acids and other components, and when supplied in adequate proportion a yield increase can be achieved.

Fertilization with the potassium chloride source promoted an increase of 13% in fruit number compared to the potassium sulfate source due to a possible combined effect between chloride and potassium on plant metabolism. This source positively impacts the movement and water content of the cells, ensuring the balance of charges, which favors the photosynthetic efficiency of plants (Wege et al., 2017), consequently, increasing photoassimilates necessary for the reproductive processes.

In addition, it could be observed that the combined effect of potassium and chloride probably affected, among several enzymes, the activity of ACC (1-carboxylic acid-1-aminocyclopropane) oxidase (ACC oxidase), which generated an increase in the concentrations of ethylene and then the formation of pistillate flowers, increasing the number of fruits (Manzano et al., 2014; García et al., 2020). Jalali and Jafari (2013), evaluated the effect of potassium fertilization on yield and production components of three *Citrullus lanatus* cultivars and observed that the potassium fertilization in all levels increased the number of fruits.

Several factors, nutrition levels in the soil, meteorological conditions, and number of harvests influence fruit production in gherkin. Here we reported that potassium promotes increased production per plant in this species, possibly due to its action on enzymatic activity, ensuring the synthesis of organic compounds used in plant metabolism translocated to reserve organs (Taiz et al., 2017). In a study with *Citrullus lanatus*, Granjeiro and Cecílio Filho (2006) obtained increments in fruit production when potassium fertilization was provided in doses ranging from 50 to 183 kg ha^{-1} K_2O.

Soluble solids, potassium and sulfur content of leaves

The soluble solids of the fruit under plant fertilization at the doses of 78.75 and 100 kg ha^{-1} of K_2O were 3.68 and 3.56%, respectively, using sulfate and potassium chloride sources (Figure 2A). The use of potassium sulfate promoted a higher value in tissue K content but did not show interaction with the evaluated doses (Figure 2B). Tissue K concentration increased linearly in response to potassium rates, reaching a maximum value of 20.7 g kg^{-1} at the highest dose (Figure 2C). Regarding the tissue S content, the concentrations were 4.49 and 3.24 g kg^{-1} at the dose of 250 and 164.16 kg ha^{-1} K_2O, respectively, using sulfate and potassium chloride as sources (Figure 2D).

The soluble solids contents are within the standards (2.0 to 6.8%) considered adequate for the species (Ribeiro et al., 2022). Therefore, we can infer that potassium sources provided nutrients that act on the main biochemical processes of the plant, such as the synthesis of amino acids, balance of loads in the cell, and activity of enzymes necessary for the constitution of organic compounds, ensuring fruit quality (Taiz et al., 2017).

The total soluble solids values for this crop are lower than the standard levels of other species in the same family such as *Citrullus lanatus* and *Cucumis melo* (8.0% and 9%, respectively). (Silva et al., 2021; Preçado-Rangel et al., 2018). However, in terms of consumption, *Cucumis anguria*, besides being used in salads, natural juices, and preserves (pickles), can be cooked and consumed in hot soups. It is worth mentioning that these fruits are generally rich in water. Therefore, the K^+ nutrient probably caused an increase in the soluble solids content of *Cucumis anguria* due to its action on the use of the water available in the soil solution in the developmental stages, such as flowering and fruiting (Hora et al., 2018).

The tissue K content increased linearly as the potassium dose increased. However, it showed values below the range (25-40 g kg^{-1}) described as standard for the Cucurbitaceae family, according to the manual by Prezotti and Guarçoni (2013). Hence, the low content of tissue K in *Cucumis anguria* found in this study can be attributed to the translocation of this nutrient from the vegetative parts to the fruit components. This behavior was similar to that reported by Moreira et al.

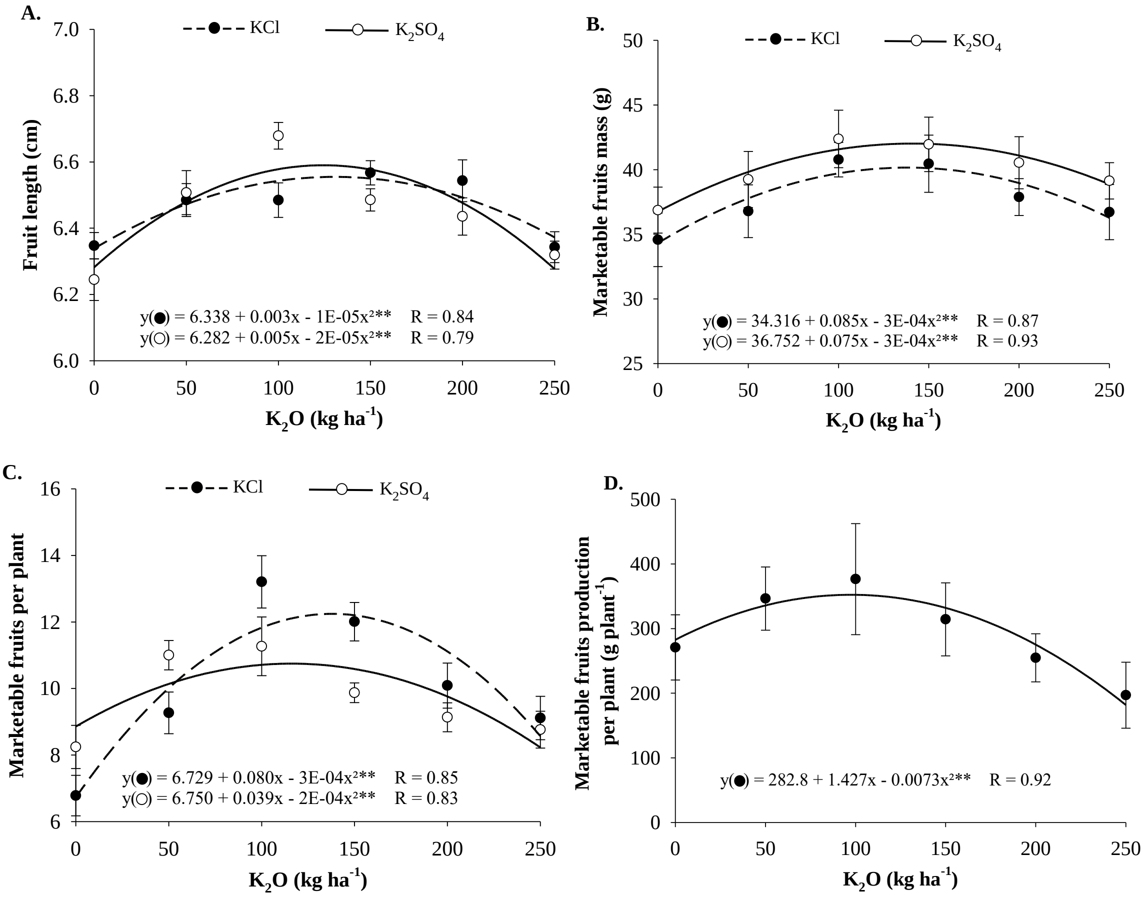

Figure 1. Length (A), mass (B), number (C) and production (D) of marketable gherkin fruits under different potassium sources and doses.

(2022) in the second cycle of *Cucumis melo*, where the K tissue content (22.25 g kg^{-1}) was considered low due to the greater redirection from the shoots to the fruits.

The linear behavior of K content in the leaves indicated that the gherkin cultivar 'Nordestino' accumulates potassium in detriment to the fertilization dose, which emphasizes the importance of a correct fertilization for this crop in different edaphoclimatic conditions. Furthermore, higher levels of potassium in the soil can inhibit the availability of magnesium by plants, causing a negative effect on chlorophyll synthesis, and consequently, on the photosynthetic processes (Taiz et al., 2017; Novais et al., 2007).

For tissue S content, it is observed that the values are adequate (3.0-7.0 g kg^{-1}) for *Curcubitacea*, according to Prezotti and Guarçoni (2013). However, an increment of 38% in the content was observed when potassium sulfate was used. Therefore, *Cucumis anguria* presents enhanced sulfur accumulation due to increased concentration in the soil. The decrease observed in the maximum potassium chloride dose can be attributed to a possible antagonistic effect, which reduced the sulfur accumulation by the plants. Barlóg, Grzebisz and Łukowiak (2019) described that a positive role of S is more apparent in soils with a low concentration of K available. In addition, the increasing linear effect for potassium sulfate was probably due to this source, which contains 18% of S in its composition, making it available in the soil during the entire crop cycle.

Total chlorophyll

The different sources and doses of potassium sulfate promoted isolated effects on total chlorophyll (Chlt). Chloride source promoted a higher effect than potassium sulfate (Figure 3A), and the maximum content (49.12) was observed under the fertilization dose of 152 kg ha^{-1} of K_2O (Figure 3B).

For total chlorophyll, a possible combined and balanced effect of the nutrients was observed with the chloride and potassium sources, which possibly acted on the enzymatic activity of oxygenases, boosting the chlorophyll synthesis (Taiz et al., 2017). However, potassium doses above 152 kg ha^{-1} of K_2O affected the concentration of total chlorophyll in *Cucumis anguria* in the edaphoclimatic conditions analyzed herein. The decreasing behavior of total chlorophyll with the increasing potassium doses can be attributed to its antagonistic effects on Mg^{2+} since it participates in the structure of the chlorophyll molecule, occupying the center of the molecule (Dias et al., 2019).

Total and commercial productivity

The total yield was 7.78 t ha^{-1} and 6.92 t ha^{-1} under the doses of 102.25 and 81.75 kg ha^{-1} of K_2O, respectively, using the sulfate and potassium chloride sources (Figure 4A) and the dose necessary to reach the marketable yield (6.90 t ha^{-1}) was 184 kg ha^{-1} of K_2O (Figure 4B).

Overall, the total yield was obtained with the sulfate source and was 12% higher compared to fertilization with the chloride. Sulfate reacts predominantly in the subsurface of the soil since part of the anion arising from the solubilization of the source used cannot be adsorbed by oxides present in the soil or by organic colloids, so they are diverted to other reactions, such as the increasing activity of calcium ions in the plant-soil-soil system (Novais et al., 2007). Also, one of the factors that may have contributed to the greater efficiency of potassium sulfate is that the SO_4^{2-} anion, which compared to Cl^-, is less prone to leaching into the soil (Grangeiro and Cecílio Filho, 2004). Thus, it is noteworthy that the Cl^- anion is more easily leached due to its ionic size,

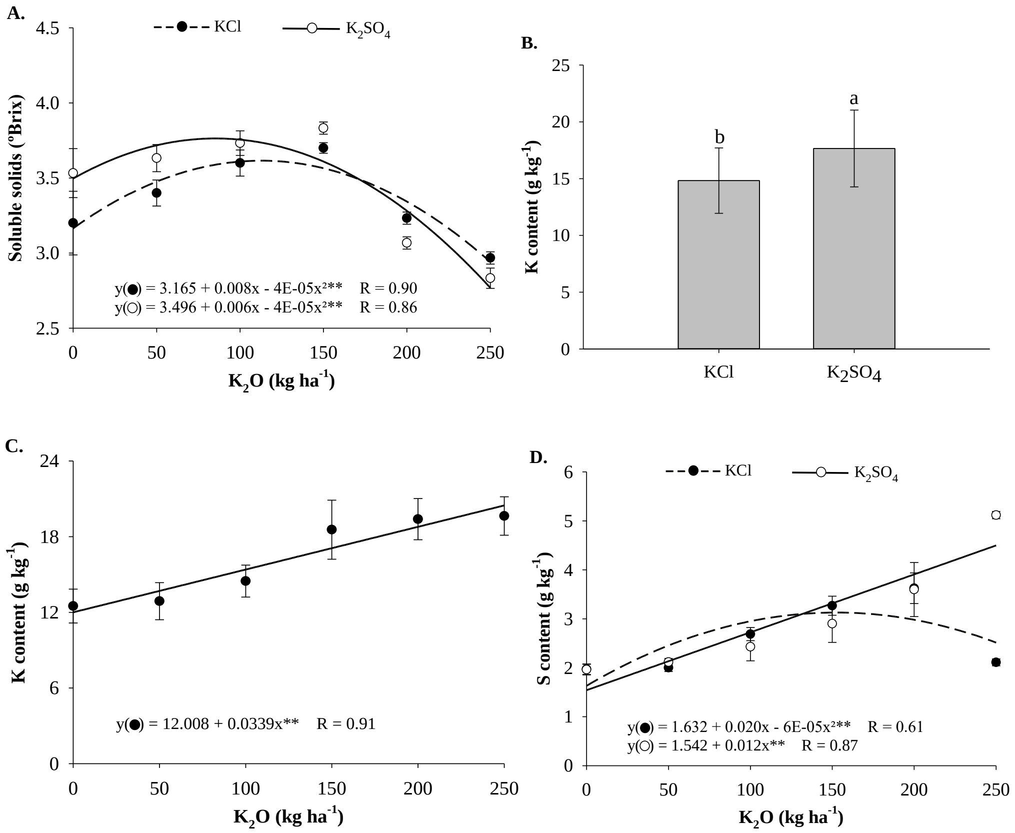

Figure 2. Fruit soluble solids (A), concentration of K (B and C) and S (D) in gherkin leaves under different potassium sources and doses.

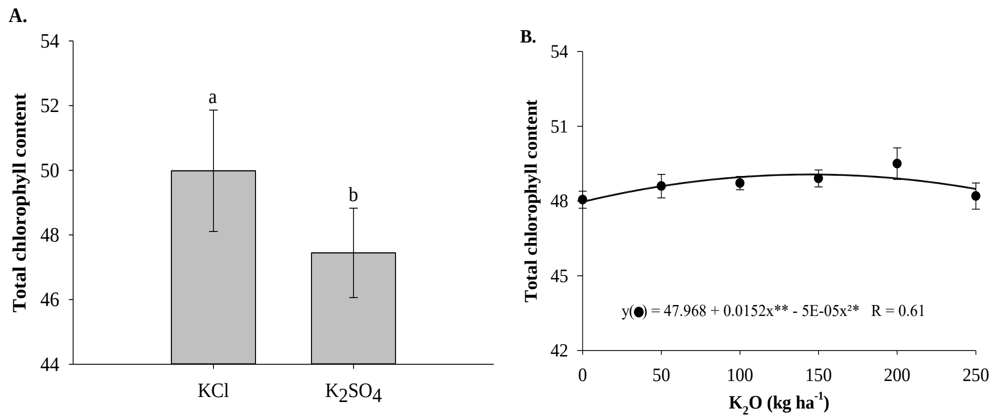

Figure 3. Total chlorophyll content of gherkin under different potassium sources (A) and doses (B).

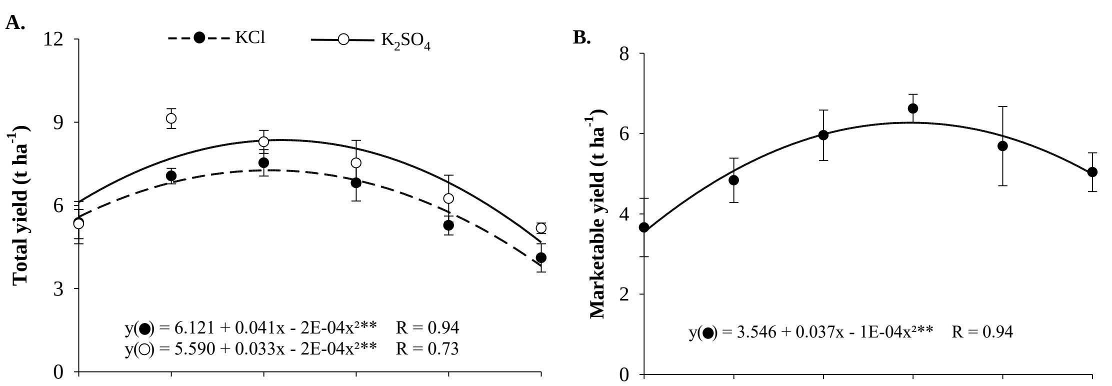

Figure 4. Total (A) and marketable fruit yield (B) of gherkin under different potassium sources and doses.

being weakly adsorbed, and due to it monovalent characteristic, it is more quickly hydratable in the soil solution than the SO_4^{2-} ion (Novais et al., 2007).

In the cultivation of vegetables, the supply of potassium is usually made with KCl due to its low price and availability in the market. However, the sulfate source can potentially increase crop yield and soil fertility in the superficial and deep layers. Slezák et al. (2010), evaluated the yield of sweet pepper fertilized with different potassium sources, and concluded that the use of potassium fertilizer is more favorable than the hydrochloric form.

The commercial productivity obtained in this study is within the standards for the species (5.0 t ha^{-1} of fruits) (Filgueira, 2000), and could be attributed to the potassium supply which favored the formation and translocation of carbohydrates from the vegetative parts to the fruits. In addition, this nutrient promotes Rubisco activity in leaves, increasing the photosynthetic activity of plants and consequently accumulating photoassimilates in reserve organs (Taiz et al., 2017; Hasanuzzaman et al., 2018). Araújo et al. (2012) concluded that the maximum commercial productivity of *Cucurbita moschata* was obtained with a potassium dose close to that used in our study (199.0 kg ha^{-1} of K_2O).

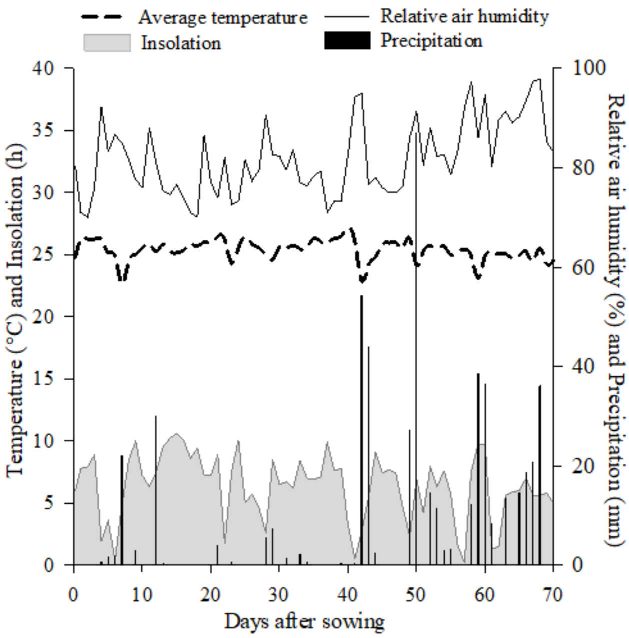

Figure 5. Meteorological conditions during the growing season of gherkin cultivated with different potassium sources and rates.

Table 1. Soil chemical characterization, in the 0 to 20 cm layer of the experimental area.

Chemical characteristics											
pH	P	K^+	S	Na^+	$H^+ + Al^{3+}$	Al^{3+}	Ca^{2+}	Mg^{2+}	SB	CEC	O.M.
H_2O (1:2.5)	-------mg dm^{-3}------			------------------------------cmol$_c$ dm^{-3}---------------------------							g kg^{-1}
6.2	68.46	11.43	4.61	0.12	1.88	0.0	4.12	1.56	5.82	7.70	17.44

P, K^+, Na^+ - Mehlich 1; $H^+ + Al^{3+}$ - Calcium acetate 0.5 M pH 7.0; Al^{3+}, Ca^{2+}, Mg^{2+} - Extrator KCl 1M; S - Gravimetric determination of the precipitate; SB - Sum of bases; CEC - Cation exchange capacity; OM - Organic matter (Walkley - Preto)

Fernandes et al. (2016) described that *Cucurbita pepo* responds with increased productivity with the addition of potassium, making it attractive for the farmer to invest in the acquisition and application of fertilizers, as the yield obtained is sufficient to cover the cost of the inputs.

It is possible that during gherkin development, the K_2O doses associated with other nutrients initially present in the soil, regardless of the source, were responsible for the maximum commercial fruit yield. However, doses above 184 kg ha^{-1} of K_2O reduced yield, indicating that the excess of this nutrient is harmful to the development of *Cucumis anguria*, possibly as a direct consequence of its competitive nature on other cations in the soil, such as calcium and magnesium, directly impairing the nutritional balance of plants (Novais et al. al., 2007).

Materials and methods

Location and experimental design

The experiment was conducted under field conditions from January to March 2022, at the Universidade Federal da Paraiba, in Areia-PB, located in the Microregion of Brejo Paraibano, with an altitude of 574.62 m (latitude 6° 57' 26" S and longitude 35° 45' 31' 'W). The region's climate is characterized as type As`, according to the Köppen classification, with an average annual rainfall of 1200 mm. Meteorological conditions during the experimental period are shown in Figure 5.

The soil in the experiment was classified as Regolithic Neosol, with a sandy loam texture. Before starting the experiment, soil samples were collected at a depth of 0-20 cm to determine their chemical characteristics (Table 1).

The experiment was conducted in a complete randomized block design with four replications. Treatments were assigned in a 6 x 2 factorial arrangement, with six K_2O doses (0, 50, 100, 150, 200, and 250 kg ha^{-1}) and two sources of K (potassium chloride and sulfate). The plot consisted of 24 plants (two plants per hole) spaced 2.0 x 1.0 m, respectively, between rows and holes. Therefore, there were four lines in total and the two centrals considered targets for sampling and collection.

Experimental conduction and evaluated characteristics

The soil was previously prepared by plowing followed by harrowing. Four seeds of the 'Nordestino' cultivar were sown per hole and after fifteen days, thinning was performed, leaving two plants per hole. For the fertilization, 15 t ha^{-1} bovine manure (moisture = 5%; N = 9.0 g kg^{-1}; P = 4.5 g kg^{-1};

$K = 11$ g kg^{-1}; $S = 2.0$ g kg^{-1}), 100 kg ha^{-1} P_2O_5 (triple superphosphate), and 50% of the potassium doses described in the experimental design were used. For the topdressing fertilization, 110 kg ha^{-1} of N (Urea) (Cavalcante et al., 2008) was provided, and the second part of the potassium doses was provided 20 days after sowing (DAS).

Manual weeding was carried out during the experiment to keep the area free of weeds. Water was supplied through drip irrigation, with a two-day irrigation shift, with a water depth of 4 mm per day and flow of 2 L $hour^{-1}$, with space between tapes and emitters following to the experimental spacing. Phytosanitary control was not carried out due to the absence of pests and diseases.

To estimate the S and K tissue content, 20 leaves per plant were removed from each treatment and replicate at 35 DAS, triple washed, packed in paper bags, and transported to the laboratory to dry in an oven with forced air circulation at 65°C for 72 hours. They were then ground to determine the K and S content (g kg^{-1}) according to the methodology described by Tedesco et al. (1995). The chlorophyll content was obtained by measuring three leaves in the middle third of four random plants in the two central rows of each plot using the chlorofiLOG®, model: CFL1030.

For yield assessment, plants were harvested from 43 to 70 DAS in the two middle rows. Fruits were harvested with an intense green color. Then, they were evaluated for production characteristics. The fruit length was obtained by measuring ten fruits from each treatment and replicate, with the aid of a digital caliper and the values expressed in centimeters (cm).

The average mass of marketable fruits was determined from the total weight of fruits divided by the number of commercial fruits, with results expressed in grams (g). The number of marketable fruits per plant was obtained by the ratio between the number of fruits and plants. The production of fruits per plant was quantified by the ratio between the weight of commercial fruits and the number of sampled plants, with the results expressed in grams for plant (g $plant^{-1}$). Fruits with an intense green color, measuring between 4 and 6 cm and without a white belly (white spot) were considered commercial fruits (Ceagesp, 2023).

The total yield was obtained by the weight of all the fruits harvested, and the marketable yield corresponded only to the commercial fruits, with the data expressed in tons ha^{-1}. On the second harvest, ten commercial fruits of each treatment were selected and transported to the laboratory to determine soluble solids through a digital refractometer °Brix with a scale of 0-90%.

Statistical analysis

Data were submitted to analysis of variance using the F test ($p<0.05$). The results obtained were submitted to regression analysis to evaluate the effect of sources (F) and doses (D) of potassium on the variables evaluated by testing the linear, quadratic, and interaction effects. The significance of the F test and coefficient of determination (R2) greater than 0.50 were considered to choose the best fitted model. The SISVAR software (Ferreira, 2019) was used for the analysis, and the responses were plotted with the SigmaPlot® software, version 12.5 (Systat Software, San Jose, CA, USA).

Conclusions

Fruit length, average weight of commercial fruits, tissue S content, soluble solids, and total productivity were higher under fertilization with the potassium sulfate source. The dose of 105.45 kg ha^{-1} of K_2O is recommended to reach the maximum yield of the gherkin cultivar 'Nordestino', using potassium sulfate as a K source.

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Authors contribution

Luiz Daniel Rodrigues da Silva: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. José Manoel Ferreira de Lima Cruz: Data curation, Investigation, Software, Methodology. Izaias Romario Soares do Nascimento: Data curation, Methodology, Software, Validation. Edileide Natália da Silva Rodrigues: Data curation, Formal analysis, Investigation, Writing – review & editing. Mylena Costa da Silva: Formal analysis, Investigation, Writing – review & editing. João Henrique Barbosa da Silva: Formal analysis, Investigation, Writing – review. João Paulo de Oliveira Santos: Data curation, Formal analysis, Investigation, Methodology, Software, Supervision. Amanda Santana Chales: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. Ademar Pereira de Oliveira: Funding acquisition, Methodology, Project administration, Supervision.

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