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DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v28n4e279061 ORIGINAL ARTICLE

Selenium as an inorganic biostimulant in onion grown in a semi-arid climate[1]

Selênio como um bioestimulante inorgânico em cebola cultivada em clima semiárido

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HIGHLIGHTS:

Se is concentrated in greater quantity in the onion leaf compared to the bulb.
Se availability promotes biofortification of onions with this element.
The hybrid Rio das Antas had more vigorous plants than Andrômeda.

ABSTRACT: The common climatic characteristics in semi-arid regions can cause abiotic stress and be a limiting factor for crops. Under these conditions, the use of beneficial elements such as selenium (Se) is an alternative to mitigate the harmful effects of abiotic stresses and increase yield. Therefore, this research aimed to evaluate the agronomic performance of onion grown in a semi-arid region under the application of Se. A field experiment was performed in a randomized block design, where five doses of Se (0, 15, 30, 45, and 60 g ha^{-1}), by foliar application, were tested on two onion hybrids (Andrômeda and Rio das Antas). Growth, nutritional and yield variables were analyzed. Se increased the height and accumulation of dry mass in onion plants, with a maximum at the 60 g ha^{-1} dose of Se, the same dose at which the highest commercial (78.15 t ha^{-1}) and total (86.03 t ha^{-1}) bulb yields were obtained in Rio das Antas; however, for Andrômeda, there was no effect of Se on yield. Applied Se doses also increased the content of this element in the bulbs. Despite increasing bulb yields only in the Rio das Antas hybrid, 60 g ha^{-1} of Se is recommended for onions due to its effects on plant growth and the biofortification of bulbs with Se.

Key words: *Allium cepa*, abiotic stress, beneficial element, biofortification

RESUMO: As características climáticas comuns em regiões semiáridas podem causar estresse abiótico e ser um fator limitante ao cultivo agrícola. Nessas condições, o uso de elementos benéficos como o selênio (Se) é uma alternativa para mitigar os efeitos deletérios dos estresses abióticos e aumentar a produtividade. Portanto, esta pesquisa teve como objetivo avaliar o desempenho agronômico da cebola cultivada em região semiárida sob aplicação de Se. Foi conduzido um experimento de campo, delineado em blocos casualizados completos, onde foram testadas cinco doses de Se (0, 15, 30, 45 e 60 g ha^{-1}), por aplicação foliar, em dois híbridos de cebola (Andrômeda e Rio das Antas). Foram analisadas variáveis de crescimento, nutricional e produtividade. O Se aumentou a altura e o acúmulo de massa seca em plantas de cebola, com máxima na dose 60 g ha^{-1} de Se, mesma dose em que foi obtida a maior produtividade comercial (78,15 t ha^{-1}) e total (86,03 t ha^{-1}) de bulbos em Rio das Antas, todavia, para Andrômeda, não ocorreu efeito do Se sobre a produtividade. As doses de Se também aumentaram o teor desse elemento nos bulbos. Apesar de aumentar a produtividade de bulbos apenas em Rio das Antas, recomenda-se a aplicação de 60 g ha^{-1} de Se em cebola devido aos efeitos no crescimento da planta e na biofortificação dos bulbos com Se.

Palavras-chave: *Allium cepa*, estresse abiótico, elemento benéfico, biofortificação

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Introduction

Semi-arid regions are characterized by environmental conditions that can cause abiotic stress on plants, such as high temperatures and water deficit. Using biostimulants is an effective and sustainable alternative to mitigate the harmful effects caused by the climate in these areas. This occurs due to improved nutrient and water use efficiency, tolerance to salinity, water stress, and extreme temperatures, resulting in increased crop growth and yield (Bulgari et al., 2019).

Selenium (Se) is considered an inorganic biostimulant, at low concentrations, capable of mitigating the effects of abiotic stresses (Gupta et al., 2022). It is also a beneficial element for the growth, resistance, and improvement of plant quality (Wang et al., 2022), playing an important role in photosynthesis, chlorophyll, antioxidant activity and stress modulation, as well as inhibition of the accumulation of reactive oxygen species (ROS) (Feng et al., 2013).

In crops such as kale (*Brassica oleracea* L.) and tomato (*Solanum lycopersicum* L.), grown under salt stress, the application of Se had positive effects on physiology, yield, water balance, and antioxidant activity (Kucukyumuk & Suarez, 2021; Mozafariyan et al., 2016). In garlic (*Allium sativum* L.) and onion (*Allium cepa* L.), there were also positive responses to the application of Se on the development, antioxidant activity, and nutrition of plants (Golubkina et al., 2020). In onions there are also benefits in growth, yield and water use efficiency, due to the role of Se in cell integrity and turgor and antioxidant activity, resulting in better photosynthetic efficiency (Semida et al., 2021).

Using Se in onion-producing areas in the semi-arid region can be an alternative to mitigate the damage caused by abiotic stress and promote increased crop yield. Therefore, this research aimed to evaluate the agronomic performance of onion grown in a semi-arid region under the application of Se.

Material and Methods

The experiment was performed between June and November 2021 at the Rafael Fernandes Experimental Farm at the Universidade Federal Rural do Semi-Árido. The area, located in the rural area of the municipality of Mossoró, RN, Brazil (5° 6' 37" S and 37° 23' 50" W, altitude 72 m), has a BSh-type climate, according to Köppen's classification. Climatic data on air temperature, precipitation, and air relative humidity during the experiment period are presented in Figure 1.

The area has soil classified as Ultisol (United States, 2014), which corresponds to Argissolo in the Brazilian Soil Classification System (EMBRAPA, 2018). The chemical attributes of the soil were described at a depth of 0–20 cm (Table 1). Se analysis was carried out; however, the Se content in the soil was below the detectable limit.

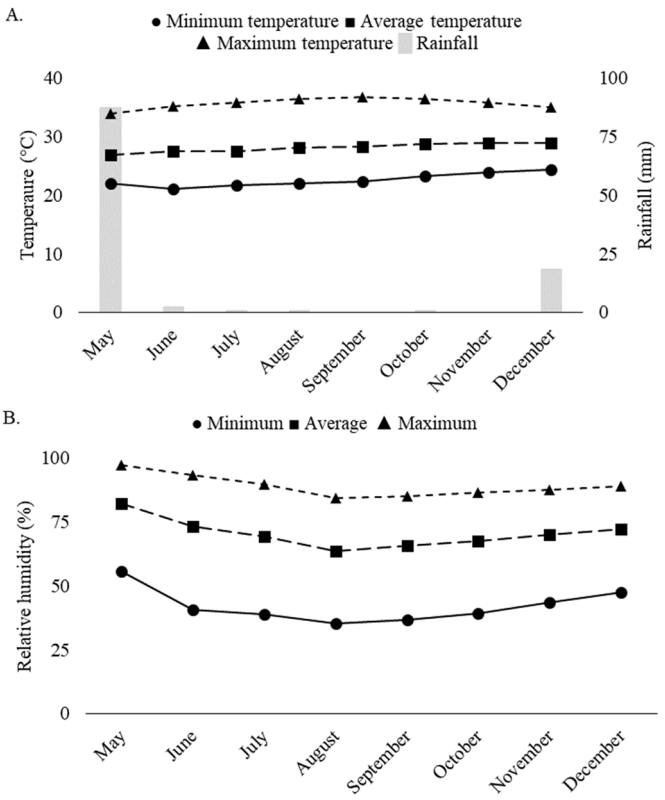


Figure 1. Climatological data obtained from Rafael Fernandes Experimental Farm in Mossoró, RN, in 2021

A randomized block design in a 2 x 5 factorial scheme was used, with four replicates. The treatments comprised the combination of two onion hybrids (Andrômeda and Rio das Antas) and five doses of Se (0, 15, 30, 45, and 60 g ha^{-1}), by foliar application. The source of Se used was sodium selenate (Sigma-Aldrich) with 99% purity and ≥ 41% selenium. The Andrômeda hybrid has tolerance to high plant density and the main foliar diseases. It is also characterized by being a short-day hybrid and having an early cycle in the Northeast region. The Rio das Antas hybrid is also a short-day hybrid, adapted to dense cultivation, and produces vigorous plants and uniform bulbs with a large shape and low pungency. Information about the hybrids was obtained from the companies TopSeed (Andrômeda) and HMClause (Rio das Antas).

The experiment was conducted in beds with plots sized 2.0 m long by 1.0 m wide. Eight rows of plants were distributed, spaced 0.10 x 0.06 m; however, , the six central rows were considered as usable area (1.06 m^2), disregarding two plants at each end of the rows.

Before raising the beds, the soil was plowed and harrowed. Planting fertilization was carried out with 190 kg ha^{-1} of P_2O_5 (Silva et al., 2021) as single superphosphate. Top-dressing fertilization was applied split and applied via fertigation, using 74.0 kg ha^{-1} of N, 204.0 kg ha^{-1} of K_2O (Gonçalves, 2019a;

Table 1. Chemical characterization of soil classified as Ultisols, at 0–20 cm depth

Chemical Attributes (0 – 20 cm)															
pH	O.M.	B	Cu	Fe	Mn	Zn	P	K	Na	Ca	Mg	H+Al	SB	CEC	V
H_2O	(g kg^{-1})	(mg dm^{-3})								(cmol$_c$ dm^{-3})					(%)
5.2	14.9	0.77	0.33	163.03	15.8	0.64	1.9	39.1	2.3	0.66	0.08	0.20	0.84	3.69	23.04

O.M.- Organic matter; H+Al- Potential acidity; SB- Sum of bases; CEC- Cation exchange capacity; V- Base saturation

Gonçalves, 2019b), 43.0 kg ha^{-1} of Ca, 14.0 kg ha^{-1} of Mg and 0.19 kg ha^{-1} of S. As nutritional sources, urea, potassium chloride, potassium nitrate, calcium nitrate, and magnesium sulfate were used.

Planting was carried out by direct sowing of three onion seeds per hole, and thinning was carried out 20 days after sowing (DAS), leaving one plant per hole. Micro-sprinkler irrigation was adopted in irrigation management between planting fertilization and up to 20 DAS. After this period, localized drip irrigation was adopted, with pressure-compensating drippers every 0.30 m and an average flow rate of 1.5 L h^{-1}. Four drip tapes were distributed per bed, and the daily water depths were defined based on the crop's evapotranspiration (Allen et al., 2006).

During the crop cycle, manual weeding and phytosanitary management were carried out using the chemical method to control thrips and mites (Cabrio TOP, Pirate, Manzate, Decis, Amistar TOP, and Trigard). At 122 DAS, with 70% of the plants fallen, irrigation was suspended, starting the curing process in the field. Fourteen days after suspending irrigation, the onion bulbs were harvested.

The growth variables plant height (cm), number of leaves, and equatorial and polar diameter of the bulbs (mm) were measured at 120 DAS, obtaining an average of eight plants per plot. The plant was then divided into aerial part and bulbs and dried in a forced air circulation oven at 65 °C until reaching constant mass to determine shoot dry mass, bulb dry mass, and total dry mass, with results expressed in g per plant.

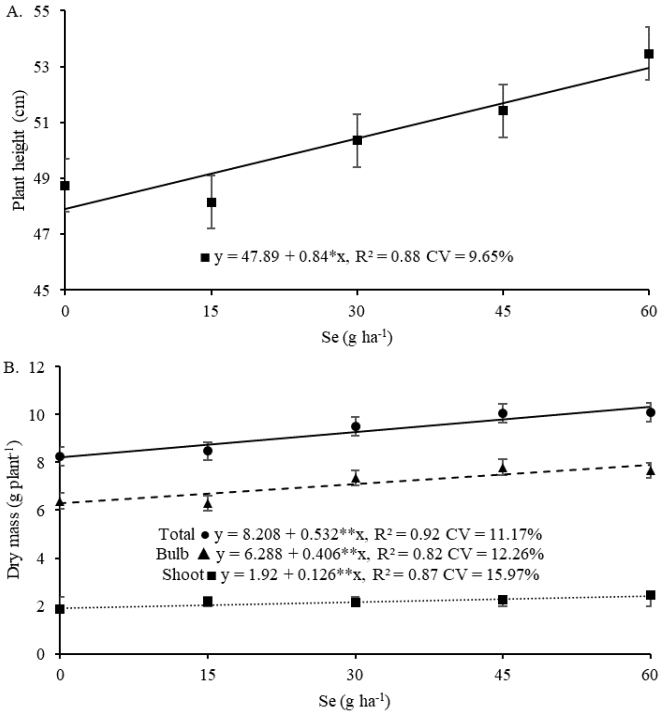
One day before harvest (135 DAS), eight plants were collected per plot to determine the concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S) and Se in the leaves and the bulb. For N, P, K, Ca, and Mg, sulfuric digestion was performed, while for S, dry digestion was performed. Both digestion and methods for determining nutrients followed those recommended by EMBRAPA (2009). Se extraction was performed in a microwave oven (Millestone) with digestion, following method 3051A (USEPA, 2007).

After harvesting, the bulbs were classified according to diameter following the recommendations of the Ministério da Agricultura, Pecuária e Abastecimento (Brasil, 1995). Those with a diameter of less than 35 mm and with the occurrence of anomalies were considered non-commercial, while bulbs with a diameter greater than 35 mm were classified as commercial. Commercial, non-commercial, and total yield of onion bulbs was determined in tons per hectare.

The data were subjected to analysis of variance at $p \leq 0.05$. Regression analysis was applied for Se doses. The SISVAR v.5.3 software (Ferreira, 2019) was used.

Results and Discussion

The application of Se did not influence the number of leaves per plant and the equatorial and polar diameters of onion bulbs. However, positive effects were observed on plant height, with a maximum of 53 cm at 60 g ha^{-1} of Se, corresponding to an increase of 10.58% (Figure 2A).



** - Significant at $p \leq 0.01$ by the F test; * - Significant at $p \leq 0.05$ by the F test. Vertical bars represent the standard error of the mean

Figure 2. Plant height (A) and shoot, bulb, and total (B) dry masses of onion plants in function of Se doses

High temperatures are one of the climatic characteristics of semi-arid regions and can be a limiting factor for the growth of onion plants (Ikeda et al., 2019). This abiotic stress condition can be mitigated with the availability of Se since this element increases antioxidant activity and, consequently, decreases the production of reactive oxygen species (ROS) and lipid peroxidation (Oliveira et al., 2018). Thus, there are no deleterious effects on the plant's metabolic activity and cellular integrity, with no harm to the onion's growth. Furthermore, Se also increases the accumulation of starch in the plant's chloroplasts (Wang et al., 2022), which may justify the increase in the height of plants treated with Se.

Se doses also resulted in dry mass accumulation in onions. At 60 g ha^{-1} of Se, there were increases of 26.0, 25.7, and 25.9% for shoot, bulb and total dry mass, respectively, compared to the control treatment (Figure 2B).

Se promotes greater assimilation and allocation of C to the roots, altering the morphology of the root system (Hamed-Far et al., 2022). Therefore, by making Se available to onion plants, there will be greater water absorption by the roots, resulting in greater dry mass accumulation (Mobini et al., 2019).

Differences were observed in plant height, number of leaves, and dry mass accumulation between onion hybrids. For all these variables, the highest averages occurred in Rio das Antas. Bulb diameters did not differ between hybrids (Table 2).

There is a relationship between the development of onion shoot and the bulbs. Although they do not differ concerning diameter, the greater height and number of leaves of the Rio das Antas hybrid may have influenced the dry mass characteristics (Table 2) due to the translocation of reserves from the shoot to the bulb.

Regarding the nutritional contents in the leaf, only S and Se were influenced by the applied Se doses. For the S content,

Table 2. Plant height (PH), number of leaves (NL), polar (PD) and equatorial (ED) diameter, and shoot (SDM), bulb (BDM) and total (TDM) dry mass of onion hybrids

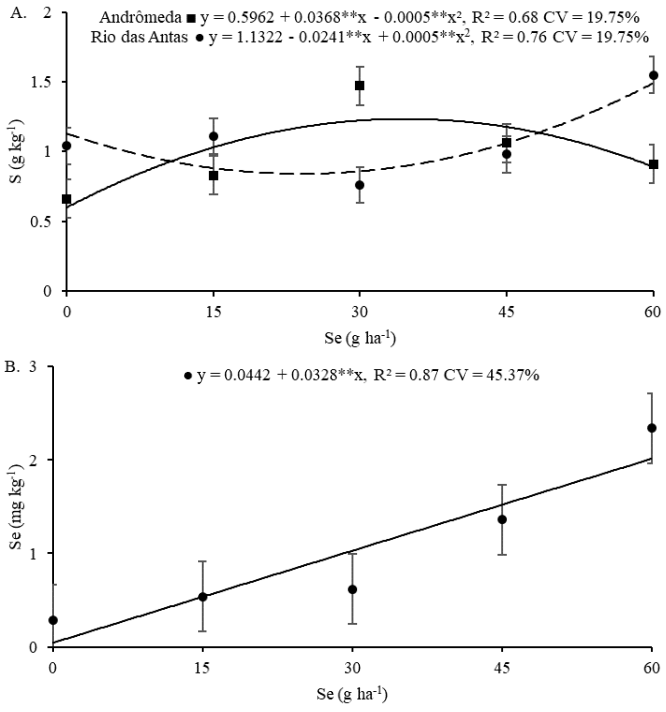
Hybrid	PH	NL	PD	ED	SDM	BDM	TDM
	(cm)	(per plant)	(mm)			(g plant^{-1})	
Andrômeda	47.41 b	7.93 b	57.18 a	55.19 a	1.77 b	6.57 b	8.34 b
Rio das Antas	53.44 a	9.10 a	57.81 a	54.93 a	2.57 a	7.63 a	10.21 a

* - Significant at $p \leq 0.05$ by the F test; Means followed by the same letter in the column do not differ significantly at $p \leq 0.05$ by the F test

there was a significant interaction between the doses and the hybrids, so that, in Andrômeda, the maximum S content (1.29 g kg^{-1}) was obtained with 36 g ha^{-1} of Se and, in Rio das Antas, when applying 60 g ha^{-1} of Se (1.49 g kg^{-1}) (Figure 3A). At the maximum dose, the highest leaf Se content was also obtained (2.01 mg kg^{-1}), corresponding to an increase of 4639% compared to the control treatment (Figure 3B).

There is a relationship of antagonism between Se and S (Izydorczyk et al., 2021) due to competition in terms of absorption and integration into metabolic pathways or construction of similar compounds, such as selenocysteine and cysteine (White, 2018; Mobini et al., 2019). However, the results obtained in this work suggest that the intrinsic characteristics of onion hybrids can influence the relationship between S and Se, depending on how much Se is available.

The genetic characteristics of the hybrids are attributed to an influence on the absorption of S depending on the doses of Se since, at low concentrations of Se, leaf S in Rio das Antas decreased compared to the control. However, it increased from 29 g ha^{-1} of Se, contrary to what was observed in Andrômeda, for which it decreased at doses above 39 g ha^{-1} of Se (Figure 3A). The behavior of S in the hybrids coincides with the more intense increase in Se content in the leaves (Figure 3A and B). Therefore, it is assumed that there is a relationship between the amount of available Se and the intrinsic characteristics of the hybrids in the absorption of S.



** - Significant at $p \leq 0.01$ by the F test; Vertical bars represent the standard error of the mean

Figure 3. Sulphur (S - A) and selenium (Se - B) content in onion leaves in function of Se doses

For Ca, there was an interaction between the factors. However, no fit of the equations was obtained for the linear and second-degree polynomial models. Applied Se doses did not influence the N, P, K, and Mg contents in the leaf. When comparing the nutritional content between onion hybrids, it was found that there was no significant difference for N, P, K, Mg, and Se ($p < 0.05$) (Table 3).

In bulbs, applied Se doses increased the concentrations of N (25.15 g kg^{-1}), Mg (0.67 g kg^{-1}), and Se (0.7 mg kg^{-1}), with maximum levels at a dose of 60 g ha^{-1} of Se (Figure 4A, 4B and 4E, respectively). The P content in Andrômeda (1.78 g kg^{-1}) did not respond to the Se doses. In contrast, in Rio das Antas, the maximum P content (2.52 g kg^{-1}) was obtained with the highest dose evaluated (Figure 4C). For Ca, there was also an interaction between the factors. While Se increased the Ca content in Rio das Antas bulbs, it decreased it in Andrômeda (Figure 4D).

Greater growth of the onion root system and increased rhizosphere activity, favoring greater spatial availability, mobilization, and acquisition of insoluble P, is attributed to Se (Hamed-Far et al., 2022). Presumably, the addition of Se associated with intrinsic characteristics of onion hybrids, expressed by greater height, number of leaves, and accumulation of dry mass (Table 2), may explain the effect of this beneficial element on the P content in bulbs in Rio das Antas. At the same time, for Andrômeda, the equations were not fitted. The effects on the root system may also have favored the absorption of other nutrients such as N and Mg.

Genetic differences between hybrids may also justify the Ca content in the bulbs. Under the application of low doses of Se, Ca in the bulb decreased in Andrômeda and increased in Rio das Antas, with the opposite behavior occurring at doses above 30 g ha^{-1} of Se (Figure 4D).

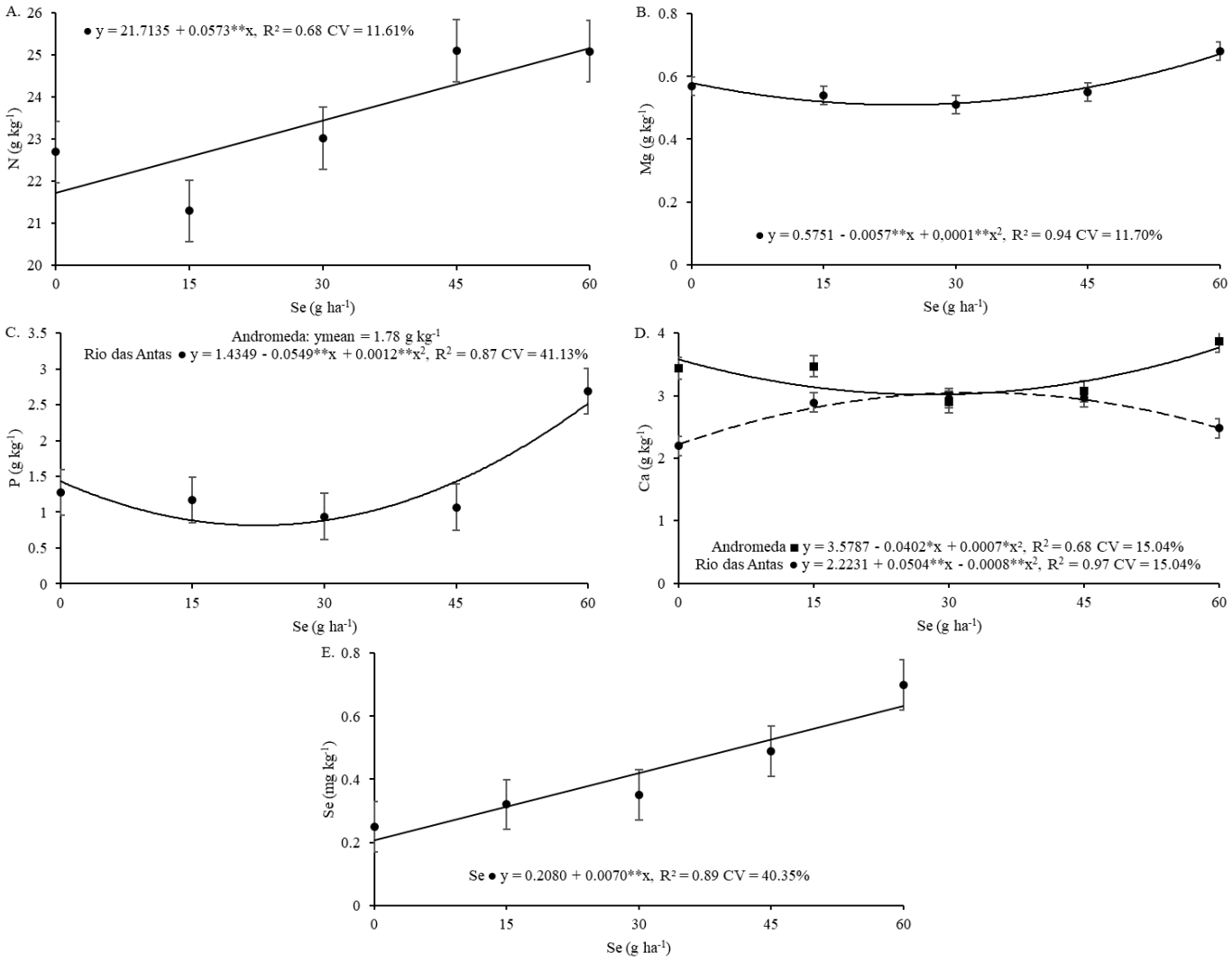
It is possible that the source of Se used, selenate, has contributed to the results of Se concentrations in the onion leaf and bulbs. This source is more efficient due to faster absorption of sodium selenate, translocation from the root to the shoot, and faster transformation into the organic form (Izydorczyk et al., 2021).

In addition to the source, how Se is made available to onion plants may also have influenced the crop's response. According to Izydorczyk et al. (2021), foliar application of Se is the most efficient form of fertilization since the increase of Se via soil

Table 3. Macronutrient and selenium content in the leaves of onion hybrids

Hybrid	N	P	K	Mg	Se
	(g ha^{-1})				(mg ha^{-1})
Andromeda	9.21 a	0.43 a	16.87 a	1.88 a	0.97 a
Rio das Antas	9.47 a	0.39 a	10.77 a	1.99 a	1.09 a

N- Nitrogen; P- Phosphor; K- Potassium; Mg- Magnesium; Se- Selenium; Means followed by the same letter in the column do not differ significantly at $p \leq 0.05$ by the F test



** - Significant at p ≤ 0.01 by the F test; * - Significant at p ≤ 0.05 by the F test. Vertical bars represent the standard error of the mean

Figure 4. Nitrogen (N) (A), magnesium (Mg) (B), phosphorus (P) (C), calcium (Ca) (D), and selenium (Se) (E) content in onion bulbs in function of Se doses

has its bioavailability affected by organic matter, pH, soil oxygenation, and concentration of other elements (Schiavon & Pilon-Smits, 2017). As an example, the authors mentioned earlier that using fertilizers containing N, P, and S can cause damage to the availability and accumulation of Se in plants due to competitive inhibition.

A higher Se content was observed in the leaves than in the bulbs. Compared to other forms of Se supply, the foliar application of Se also promoted a higher concentration of this element in the carrot aerial part compared to the tuberous root (Oliveira et al., 2018). This occurs because the leaves are the termination of the vascular tissue, implying a greater presence of Se (Pérez et al., 2019). It is important to highlight that although the method used to analyze Se in the soil was unable to quantify the concentration of this element, the results of the Se levels in the leaves and bulb in the control treatment suggest the availability of Se in the soil of the experimental area.

In addition to acting as an abiotic stress attenuator, the application of Se also promoted the biofortification of onion bulbs with this element. This finding, expressed by the increase in the Se content in the bulbs, is important because the organic form, in which Se is found in vegetables, is more efficient in the absorption and metabolism of Se in the human body (Oliveira et al., 2018). Furthermore, Se-biofortified onion bulbs can be a cheap and healthy substitute for commercial Se supplements (Mobini et al., 2019).

The K content in the bulb did not respond ($p < 0.05$) to Se. No significant difference was found when analyzing the average N, Mg, and Se content in the bulbs of the hybrids Andrômeda and Rio das Antas ($p < 0.05$). The average K content was higher in Andrômeda bulbs (Table 4).

Only bulb yield in the hybrid Rio das Antas was influenced by the application of Se. At 60 g ha^{-1}, maximum commercial yield, 78.15 t ha^{-1} ($y = 62.4155 + 0.02622*x$, $R^2 = 0.51$), and maximum total yield, 86.03 t ha^{-1} ($y = 68.3345 + 0.2949*x$, $R^2 = 0.48$), were obtained, corresponding to increases of 25

Table 4. Macronutrient and selenium content in the bulb of onion hybrids produced

Hybrid	N	K	Mg	Se
	(g ha^{-1})			(mg ha^{-1})
Andromeda	22.85 a	22.61 a	0.58 a	0.46 a
Rio das Antas	24.02 a	18.39 b	0.55 a	0.37 a

N- nitrogen; P- phosphorus; K- potassium; Mg- magnesium; Se- selenium; * - Significant at p ≤ 0.05 by the F test; Means followed by the same letter in the column do not differ significantly at p ≤ 0.05 by the F test

and 26%, respectively, compared to the treatment without Se application. The average yield of commercial and total bulbs of Andrômeda was 67.24 and 69.25 t ha^{-1}, respectively.

The yield of non-commercial bulbs was not influenced ($p < 0.05$) by Se. Among the hybrids, there was a statistically higher average ($p < 0.05$) in Rio das Antas bulbs (6.90 t ha^{-1}) than in Andrômeda bulbs (2.41 t ha^{-1}).

The increase in yield of onion bulbs can be attributed to the combined effects of photosynthetic pigment biosynthesis and the increase in antioxidant metabolism induced by Se (Khan et al., 2015). These effects are the main physiological mechanisms in the photochemical phase of photosynthesis that drive photosynthetic performance in several plant species (Lanza et al., 2021) and increase crop yields (Lanza & Reis, 2021).

The yield of onion crops is strongly influenced by the choice of hybrid, which in turn interacts strictly with climate and the environment (Caruso et al., 2014). The results of the present research may suggest Andrômeda's adaptation to the edaphoclimatic conditions of the study area regardless of the application of Se, whereas for Rio das Antas, the addition of Se in nutritional management proved to be important for increasing yield, which can be explained by the action of Se in the antioxidant defense system and improvement in the physiological state of the plant, exerting favorable effects on crop yield (Hasanuzzaman et al., 2020).

The results obtained in this research reaffirm the benefits of selenium for plants, especially in regions with a semi-arid climate. It is important to conduct new research that can corroborate the findings presented in this work.

Conclusion

1. Se acts as an inorganic biostimulant in onions grown in semi-arid regions, promoting increased height and dry mass, with foliar application of 60 g ha^{-1} of Se recommended.

2. The Rio das Antas hybrid has a better total and commercial bulb yield than Andrômeda.

Literature Cited

Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M. Evapotranspiración del cultivo: Guías para la determinación de los requerimientos de agua de los cultivos. Rome: FAO, 2006. 300p.

Brasil. Ministério da Agricultura, Abastecimento e Reforma Agrária. Brasília:DF, 1995. 13513p.

Bulgari, R.; Franzoni, G.; Ferrante A. Biostimulants application in horticultural crops under abiotic stress conditions. Agronomy, v.9, p.1-30, 2019. https://doi.org/10.3390/agronomy9060306

Caruso, G.; Conti, S.; Villari, G.; Borrelli, C.; Melchionna, G.; Minutolo, M.; Russo, G.; Amalfitano, C. Effects of transplanting time and plant density on yield, quality and antioxidant content of onion (*Allium cepa* L.) in southern Italy. Scientia Horticulturae, v.166, p.111-120, 2014. https://doi.org/10.1016/j.scienta.2013.12.019

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. Manual de análises químicas de solos, plantas e fertilizantes. 2.ed. Brasília: Embrapa, 2009. 627p.

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. Sistema brasileiro de classificação de solos. 5.ed. Rio de Janeiro: Embrapa, 2018. 356p.

Feng, R.; Wei, C.; Tu, S. The roles of selenium in protecting plants against abiotic stresses. Environmental and Experimental Botany, v.87, p.58-68, 2013. https://doi.org/10.1016/j.envexpbot.2012.09.002

Ferreira, P. V. SISVAR: a computer analysis system to fixed effects split plot type designs. Revista Brasileira de Biometria, v.37, p.529-535, 2019. https://doi.org/10.28951/rbb.v37i4.450

Golubkina, N.; Amagova, Z.; Matsadze, V.; Zamana, S.; Tallarita, A.; Caruso, G. Effects of arbuscular mycorrhizal fungi on yield, biochemical characteristics, and elemental composition of garlic and onion under selenium supply. Plants, v.9, p.1-15, 2020. https://doi.org/10.3390/plants9010084

Gonçalves, F. C.; Grangeiro, L. C.; Sousa, V. F. L. de.; Santos, J. P. de.; Souza, F. I. de.; Silva, L. R. R. Yield and quality of densely cultivated onion cultivars as function of nitrogen fertilization. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.847-851, 2019a. https://doi.org/10.1590/1807-1929/agriambi.v23n11p847-851

Gonçalves, F. C.; Grangeiro, L. C.; Sousa, V. F. L. de.; Jesus, P. M. M. de.; Silva, G. A. da. Agronomic and qualitative performance of densely cultivated onion cultivars as affected by potassium fertilisation. Revista Caatinga, v.32, p.889-896, 2019b. https://doi.org/10.1590/1983-21252019v32n404rc

Gupta, S.; Doležal, K.; Kulkarni, M. G.; Balázs, E.; Van Staden, J. Role of non-microbial biostimulants in regulation of seed germination and seedling establishment. Plant Growth Regulation, v.97, p.271-313, 2022. https://doi.org/10.1007/s10725-021-00794-6

Hamed-Far, M.; Hajiboland, R.; Aliasgharzad, N. Effect of selenium supplementation on mycorrhizal onion (*Allium cepa* L.) plants. New Zealand Journal of Crop and Horticultural Science, v.50, p.1-23, 2022. https://doi.org/10.1080/01140671.2022.2127797

Hasanuzzaman, M.; Borhannuddin Bhuyan, M. H. M.; Raza, A.; Hawrylak-Nowak, B.; Matraszek-Gawron, R.; Al Mahmud, J.; Nahar, K.; Fujitag, M. Selenium in plants: Boon or bane? Environmental and Experimental Botany, v.178, p.1-15, 2020. https://doi.org/10.1016/j.envexpbot.2020.104170

Ikeda, H.; Kinoshita, T.; Yamamoto, T.; Yamasaki, A. Sowing time and temperature influence bulb development in spring-sown onion (*Allium cepa* L.). Scientia Horticulturae, v.244, p.242-248, 2019. https://doi.org/10.1016/j.scienta.2018.09.050

Izydorczyk, G.; Ligas, B.; Mikula, K.; Witek-Krowiak, A.; Moustakas, K.; Chojnacka, K. Biofortification of edible plants with selenium and iodine – A systematic literature review. Science of the Total Environment, v.754, p.1-15, 2021. https://doi.org/10.1016/j.scitotenv.2020.141983

Khan, M. I. R.; Nazir, F.; Asgher, M.; Per, T. S.; Khan, N. A. Selenium and sulfur influence ethylene formation and alleviate cadmium-induced oxidative stress by improving proline and glutathione production in wheat. Journal of Plant Physiology, v.173, p.9-18, 2015. https://doi.org/10.1016/j.jplph.2014.09.011

Kucukyumuk, Z.; Suarez, D. L. The effect of selenium on salinity stress and selenate–sulfate comparision in kale. Journal of Plant Nutrition, v.44, p.2996-3004, 2021. https://doi.org/10.1080/01904167.2021.1936034

Lanza, M. G. D. B.; Silva, V. M.; Montanha, G. S.; Lavres, J.; Pereira de Carvalho, H. W.; Reis, A. R. Assessment of selenium spatial distribution using μ-XFR in cowpea (*Vigna unguiculata* (L.) Walp.) plants: integration of physiological and biochemical responses. Ecotoxicology Environmental Safety, v.207, p.1-9, 2021. https://doi.org/10.1016/j.ecoenv.2020.111216

Lanza, M. G. D. B.; Reis, A. R. dos. Roles of selenium in mineral plant nutrition: ROS scavenging responses against abiotic stresses. Plant Physiology and Biochemistry, v.164, p.27-43, 2021. https://doi.org/10.1016/j.plaphy.2021.04.026

Mobini, M.; Khoshgoftarmanesh, A. H.; Ghasemi, S. Biofortification of onion bulb with selenium at different levels of sulfate. Journal of Plant Nutrition, v.42, p.269-277, 2019. https://doi.org/10.1080/01904167.2018.1554678

Mozafariyan, M.; Kamelmanesh, M. M.; Hawrylak-Nowak, B. Ameliorative effect of selenium on tomato plants grown under salinity stress. Archives of Agronomy and Soil Science, v.62, p.1368-1380, 2016. https://doi.org/10.1080/03650340.2016.1149816

Oliveira, V. C.; Faquin, V.; Guimarães, K. C.; Andrade, F. R.; Pereira, J.; Guilherme, L. R. G. Agronomic biofortification of carrot with selenium. Ciência e Agrotecnologia, v.42, p.138-147, 2018. https://doi.org/10.1590/1413-70542018422031217

Pérez, M. B.; Lipinski, V. M.; Filippini, M. F.; Chacón-Madrid, K.; Arruda, M. A. Z.; Wuilloud, R. G. Selenium biofortification on garlic growth and other nutrients accumulation. Horticultura Brasileira, v.37, p.294-301, 2019. https://doi.org/10.1590/S0102-053620190307

Schiavon, M.; Pilon-Smits, E. A. H. The fascinating facets of plant selenium accumulation – biochemistry, physiology, evolution and ecology. New Phytologist Foundation, v.213, p.1582-1596, 2017. https://doi.org/10.1111/nph.14378

Semida, W. M.; Abd El-Mageed, T. A.; Abdelkhalik, A.; Hemida, K. A.; Abdurrahman, H. A.; Howladar, S. M.; Leilah, A. A. A.; Rady, M. O. A. Selenium modulates antioxidant activity, osmoprotectants, and photosynthetic efficiency of onion under saline soil conditions. Agronomy, v.11, p.1-18, 2021. https://doi.org/10.3390/agronomy11050855

Silva, L. R. R.; Grangeiro, L. C.; Sousa, V. F. L.; Souza, F. I.; Gonçalves, F. C.; Oliveira, G. S. R. Agronomic performance of onion cultivars as affected by phosphate fertilization. Revista Ceres, v.68, p.371-378, 2021. https://doi.org/10.1590/0034-737X202168050001

United States. Soil Survey Staff. Keys to soil taxonomy (12th ed.) Lincoln: USDA/NRCS. 2014. Available on: <http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/>. Accessed on: Sep. 2020.

USEPA - US Environmental Protection Agency. Method 3051A: microwave assisted acid digestion of sediments, sludges, soils, and oils. Washington D C, USA, 2007.

Wang, Z.; Huang, W.; Pang, F. Selenium in soil–plant-microbe: a review. Bulletin of Environmental and Contamination Toxicology, v.108, p.167-181. 2022. https://doi.org/10.1007/s00128-021-03386-2

White, P. J. Selenium metabolism in plants. Biochimica Biophysica Acta - General Subjects, v.1862, p.2333-2342, 2018. https://doi.org/10.1016/j.bbagen.2018.05.006