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# Foliar application of sulfur on postharvest traits of onion hybrids

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**Abstract**

Onion is one of the most widely consumed seasoning vegetables in the world. Beyond productivity, onion quality is of great importance, influenced by factors such as appearance, aroma, flavor, and chemical composition. This study aimed to evaluate the effect of applying elemental sulfur at different growth stages on the postharvest quality attributes of onion bulbs. Two experiments were conducted at different times using a factorial design in randomized blocks. Four hybrids were tested: Diamantina®, Optima® F1, Serena® F1, and Gamay® F1 (purple). The second factor was the timing of foliar elemental sulfur application: at the development stages of 4–6 leaves, 6–8 leaves, 8–10 leaves, and 10–12 leaves, along with a control group that received solid elemental sulfur applied to the soil. The evaluated attributes included pungency (μmol.g$^{-1}$), soluble solids (°Brix), total titratable acidity (% pyruvic acid), pH, leaf sulfur content, and bulb sulfur content. Among the traits measured, the pyruvic acid content was influenced by the timing of sulfur application, with the Serena® F1 hybrid at the 10–12 leaf stage showing significant differences from the other hybrids. Regarding pungency, the Diamantina®, Serena® F1, and Gamay® F1 hybrids were classified as having medium pungency when sulfur was applied foliarly, while the Optima® F1 hybrid was classified as low/sweet pungency. Sulfur content in the bulbs and leaves of the onion cultivars was not significantly affected by foliar sulfur application.

**Keywords:** *Allium cepa L.*, pungency, pyruvic acid, total soluble solids

## Introduction

Onion (*Allium cepa* L.) is one of the most widely used condiments worldwide, consumed both fresh and processed in various forms (El-Hadidy et al., 2014; Backes et al., 2018; Rodrigues & Alencar, 2018).

Onions have a significant demand for sulfur, which plays a key role in growth, yield, and quality. The bulb's pungency, taste, and aromatic traits result from organosulfur compounds. These sulfur-containing secondary compounds not only contribute to a longer shelf life but also enhance resistance to pests and diseases (Magray et al., 2017; Aghajanzadeh et al., 2016, 2019). Sulfur is involved in the synthesis of three amino acids (cystine [27% sulfur], cysteine [26% sulfur], and methionine [21% sulfur]), which increases the production of allyl propyl disulfide (43% sulfur), a key alkaloid.

These antioxidant compounds protect cells, DNA, and other essential molecules from oxidative damage. Moreover, incorporating antioxidants directly into food can enhance stability, providing a natural alternative to synthetic antioxidants (Dosoky et al., 2021; Galavi et al., 2021).

In addition to antioxidant activity, the bioactive compounds in onions have hypolipidemic, hypotensive, diaphoretic, antibiotic, antidiabetic, anti-atherogenic, and anticancer properties. These biological activities are mainly attributed to the organosulfur and phenolic compounds present in onions (Kothari et al., 2019).

Important postharvest traits include total soluble solids content, pH, total titratable acidity, and pyruvic acid content. Total soluble solids are particularly important because the sugar content of onion bulbs plays a critical role in palatability and quality, contributing significantly to flavor (Lima et al., 2020).

Total titratable acidity is related to the concentration of organic acids in the juice or pulp, and


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when expressed as a percentage of pyruvic acid, it is used to measure pungency (Resende et al., 2010; Quartiero et al., 2014). Pungency is one of the most notable traits of onions, produced when the cells are mechanically ruptured by cutting or crushing, and defines the distinct flavor and aroma of the species (Rodrigues et al., 2020; Cramer et al., 2021).

This trait is affected by growth factors, genetics, and environmental conditions and can be influenced by sulfur levels in the plant (Cramer et al., 2021). Foliar sulfur fertilization can improve traits related to onion flavor and aroma.

The aim of the present study was to evaluate the postharvest traits of onion bulbs based on foliar sulfur application at different stages of crop development.

**Materials and Methods**

The onion bulbs used in this experiment were obtained from a study conducted in two different periods at the horticulture sector of Universidade Federal do Tocantins (UFT), Gurupi Campus, located in the southern region of Tocantins, Brazil. The geographical coordinates of the study site are 11° 44' 42'' S latitude, 49° 03' 05'' W longitude, and an altitude of 274 meters. **Figure 1** shows the main climatic traits during the onion production period.

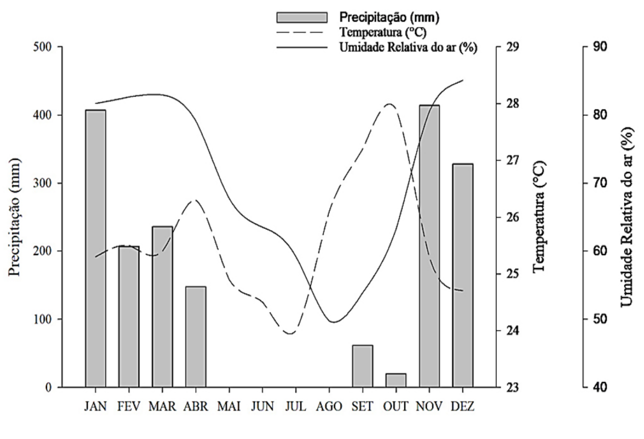


**Figure 1.** Temperature and precipitation data in the city of Gurupi, state of Tocantins, 2022
Source: Inmet, 2023.

The climate of the region is classified as tropical dry, with an average annual temperature of 26–27°C (Figure 1) (Köppen, 1948). The soil at the site is classified as dystrophic red-yellow latosol (Embrapa, 2013).

The experimental design used was a randomized block design (RBD) in a simple factorial scheme (4×4), with four replications. The treatments consisted of four onion hybrids, four stages of foliar sulfur application, and a control for each hybrid, which received elemental sulfur fertilization via soil at a rate of 300 kg ha$^{-1}$. Treatments involved different stages of foliar sulfur application: 4–6 leaves, 6–8 leaves, 8–10 leaves, and 10–12 leaves. Sulfur (96% purity) was applied at a rate of 300 kg ha$^{-1}$, diluted in water, and sprayed using a $CO_2$-pressurized backpack sprayer to ensure uniform and stable application.

The hybrids used in the study were Diamantina®, Optima®, Serena®, and Gamay®.

When the onion plants began to reach physiological maturity, marked by the "toppling" of the aerial part (necking), irrigation was stopped to accelerate and standardize plant senescence. Harvesting took place when most of the plants in each plot had reached this stage. After harvest, the onions were cured for 30 days in a covered, well-ventilated area. Upon completion of the curing process, the bulbs were cleaned by removing root debris and any remaining parts of the aerial stem.

Traits evaluated in the bulbs after the curing period were as follows:

Total soluble solids (°Brix): measured using a refractometer and expressed in °Brix, following AOAC (2000) standards;

Total titratable acidity (% pyruvic acid): determined using a 20 ml aliquot of bulb juice, to which three drops of 1% phenolphthalein were added. The solution was titrated with a standardized 0.1N NaOH solution until the endpoint was reached;

Pyruvic acid (pungency): measured based on the method by Schwimmer & Weston (1961), modified by Anthon & Barrett (2003), using pyruvic acid content as an indicator of pungency;

Bulb pungency classification: classified according to Dhumal et al. (2007) in the following manner: low/sweet pungency: 0–3 μmol pyruvic acid g$^{-1}$; medium pungency: 3–7 μmol pyruvic acid g$^{-1}$; high pungency: > 7 μmol pyruvic acid g$^{-1}$;

pH: measured following the method outlined by AOAC (2000);

Average sulfur content in leaves and bulbs: determined by collecting leaf and bulb samples from the treatments every 15 days.

The means for each trait were subjected to an analysis of variance (ANOVA), following a test for homogeneity of variance as described by Gomes (1990). In the case of significant interactions, the Scott-Knott test was used to compare means at a 5% probability level. Statistical analyses were performed by using Sisvar software (Ferreira, 2011). Graphs were generated by using Sigma Plot software, version 14.5 (2020).

**Results and Discussion**

Total soluble solids content (°Brix) is an important postharvest traits because the sugar content of onion bulbs is key to their palatability. In addition to sugar content, pH is another important factor that has an inverse relationship with acidity (Resende et al., 2010). However, the buffering capacity of acidity allows significant variations in titratable acidity without significant changes in pH (Chitarra & Chitarra, 2005).

Total titratable acidity is related to the amount of organic acids present in the bulb (Resende et al., 2010) and, when expressed as a percentage of pyruvic acid, is used to measure pungency (Quartiero et al., 2014). Pungency is a trait closely related to flavor and aroma, and in onion bulbs it is directly related to pyruvic acid content. The production of pungency is regulated by the genetic potential of the cultivar, which includes the synthesis of flavor precursors and the ability of the plant to absorb available sulfur (Randle, 1997).

Figure 1 shows that the average temperature during the experimental period was above 24°C, reaching about 28°C between September and October. Temperature and photoperiod are two critical factors that most influence the development of onion plants.

Regarding pH, Optima® had lower pH values compared to the other hybrids at the 4- to 8-leaf development stage. However, at later stages of development, no significant differences were observed among them (**Figure 2**).

From the average pH values observed, we can conclude that the foliar application of elemental sulfur did not cause any significant differences in pH between the treatments and the control group.

Among all the hybrids evaluated, pH values ranged from 5.00 to 6.07. Resende et al. (2010) also found no significant difference in pH, reporting values of 5.66 and 5.61 for the Baia Periforme cultivar under conventional and organic systems, respectively. These results suggest that pH is not affected by foliar sulfur fertilization and is therefore likely to be a cultivar-specific trait.

According to Calbo et al. (1979), lower pH values were associated with dormancy and resting of the bulb, which contributed to increased storage capacity. In this regard, the pH values observed for the hybrids in this study were very similar to those reported by Schunemann et al. (2006), who evaluated 18 onion genotypes in Vale do Itajaí, state of Santa Catarina, Brazil, with pH values ranging from 5.44 to 5.61, with no statistically significant differences.

When sulfur was applied at planting and during the 8- to 12-leaf development stage, there was no significant difference in pH (**Figure 3**). However, at the 6- to 8-leaf stage, the Gamay hybrid had the highest pH values (Figure 3).

According to Chitarra and Chitarra (2005), total soluble solids, represented by °Brix values, correspond to all substances dissolved in a solvent, which in the case of food is water. Soluble solids are primarily composed of

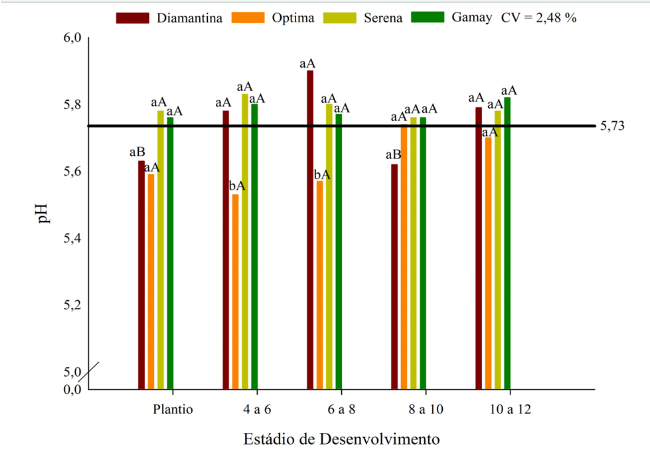


**Figure 2.** Mean pH values of onion hybrids as influenced by foliar sulfur application at different development stages under low-altitude tropical conditions, city of Gurupi, state of Tocantins, 2022

Means followed by the same lowercase letter within the bars across hybrids at each development stage do not differ statistically, according to the Scott-Knott test at a 5% probability level. Similarly, means followed by the same uppercase letter within the bars across development stages for each hybrid are not statistically different, based on the Scott-Knott test at a 5% probability level.

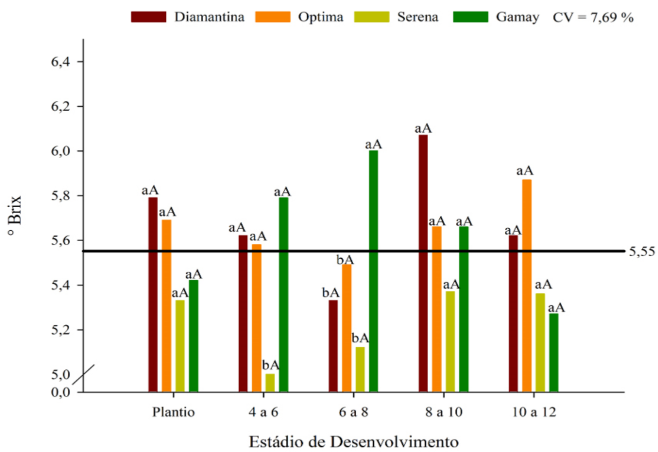


**Figure 3.** Mean total soluble solids (°Brix) of onion hybrids as influenced by foliar application of elemental sulfur at different development stages under low-altitude tropical conditions, city of Gurupi, state of Tocantins, 2022

Means followed by the same lowercase letter within the bars across hybrids at each development stage do not differ statistically, while means followed by the same uppercase letter within the bars across development stages for each hybrid are not statistically different, both according to the Scott-Knott test at a 5% probability level.

sugars, and their concentration can vary with genotype, maturity, management practices, and climate. Typically, °Brix values in onions range from 5% to 20%.

Differences in total soluble solids (°Brix) between cultivars and growing environments have been reported over the years. Schunemann et al. (2006) observed variations in total soluble solids ranging from 6.06 to 11.00 °Brix. Similarly, Grangeiro et al. (2008) evaluated 18 onion genotypes in the city of Mossoró, Brazilian state of Rio Grande do Norte, and found °Brix values ranging from 6.67 to 11.63. Bandeira et al. (2013) reported values between 9.83 and 10.81 °Brix.

In the current study, °Brix values ranged from 5.2 to 6.4 in all the stages evaluated, in agreement with the results of Muniz (2007), who evaluated Optima and CNPH 67400 onions 30 days after processing. According to Beerli et al. (2004), °Brix values are directly related to the storage time of the onions and tend to increase due to the consumption of substrates in respiratory metabolism, which is traits of the catabolic reactions of senescence.

Total titratable acidity is an important factor in evaluating onion quality because it is expressed as a percentage of pyruvic acid and is used to measure the degree of pungency, flavor, and aroma (Chitarra & Chitarra, 2005).

In this study, the total titratable acidity values ranged from 0.20% to 0.36% in all the evaluations. Significant differences were observed for the Optima® and Gamay® hybrids at the planting stage (control) and at the 10–12 leaf development stage (**Figure 4**).

Resende et al. (2010) found variations in titratable acidity between 0.21% and 0.30% in their study of Baia F1 and Baia Periforme under conventional growing systems. Acidity, in combination with total soluble solids content, can be used as an indicator of ripeness.

Albuquerque et al. (2013) also reported similar results for total titratable acidity, around 0.31%, when working with the Red Creole flat red variety. Lower values were observed by Miguel & Durigan (2007) in their study on the quality of Superex onion bulbs stored under refrigeration, where acidity levels did not exceed 0.17% over a 90-day storage period.

Pungency can be defined as a combination of flavor and odor, with the flavor dominated by volatile sulfonic and thiosulfonic acids released when tissue is ruptured. This activates the enzyme alliinase, which cleaves flavor precursors to produce pyruvate, ammonia, and sulfur (Crowther et al., 2005). Sulfur plays a key role in the flavor and aroma of certain spice vegetables such as onions, scallions, and garlic (Pôrto et al., 2006).

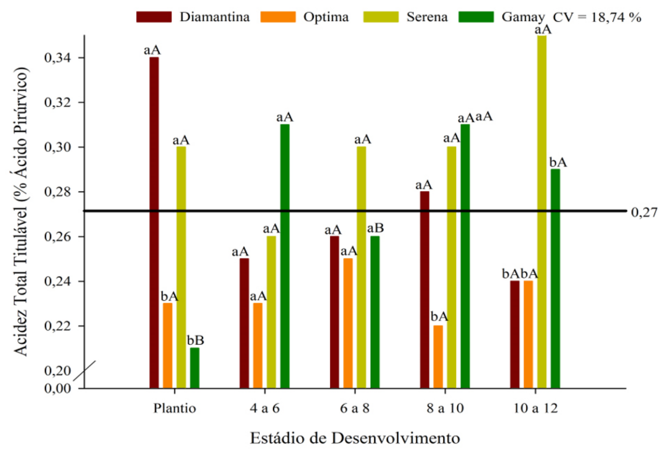


**Figure 4.** Mean total titratable acidity (% pyruvic acid) of onion hybrids as influenced by foliar application of elemental sulfur at different development stages under low-altitude tropical conditions, city of Gurupi, state of Tocantins, 2022
Means followed by the same lowercase letter within the bars across hybrids at each development stage do not differ statistically, according to the Scott-Knott test at a 5% probability level. Similarly, means followed by the same uppercase letter within the bars across development stages for each hybrid are not statistically different, based on the Scott-Knott test at a 5% probability level.

Pyruvic acid concentrations are positively correlated with the perception of onion pungency. The difference as small as 1 µmol of pyruvic acid per gram can be noticeable in the taste of onions (Anthon & Barrett, 2003). The cultivars in this study were classified as low/sweet to medium pungency based on the scale proposed by Dhumal et al. (2007), which classifies onions in the following manner: low/sweet pungency (0–3 µmol pyruvic acid $g^{-1}$), medium pungency (3–7 µmol pyruvic acid $g^{-1}$), and high pungency (>7 µmol pyruvic acid $g^{-1}$).

Pyruvic acid is a key component in the assessment of onion pungency. Changes in onion pungency during storage have been associated with the breaking of dormancy (Sharma et al., 2015). In uncured onions, pyruvic acid levels were reported to be 0.144 ± 0.19 µmol $kg^{-1}$, while in cured onions, the levels were 0.095 ± 0.05 µmol $kg^{-1}$.

Among the biochemical traits evaluated, pyruvic acid content showed significant differences among hybrids and sulfur application stages. Overall, the Diamantina®, Serena®, and Gamay® hybrids showed a significant increase in pyruvic acid content at the 10- to 12-leaf stage, with an overall increase in pyruvic acid composition towards the end of the growing cycle. For Optima®, no changes in pyruvic acid levels were observed at any of the stages evaluated (**Figure 5**).

In the orthogonal contrast analysis at the 10- to 12-leaf stage, significant differences were found for Diamantina®, Serena®, and Gamay®, with pyruvic acid

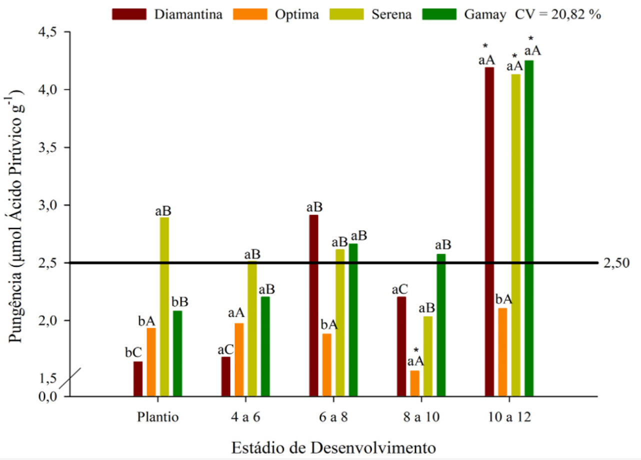


**Figure 5.** Mean pyruvic acid content (pungency) (μmol $g^{-1}$) of onion hybrids as influenced by foliar application of elemental sulfur at different development stages under low-altitude tropical conditions, city of Gurupi, state of Tocantins, 2022
**Means followed** by the same lowercase letter within the bars across hybrids at each development stage do not differ statistically, according to the Scott-Knott test at a 5% probability level. Similarly, means followed by the same uppercase letter within the bars across development stages for each hybrid are not statistically different, based on the Scott-Knott test at a 5% probability level.
*Orthogonal contrast indicates a significant difference between the treatment mean and the overall mean.

values of 4.19, 4.13 and 4.25 μmol $g^{-1}$, respectively. Conversely, Optima® showed a lower pyruvic acid content of 2.10 μmol $g^{-1}$, with significant differences observed at the 8 to 10 leaf stage (Figure 5).

According to Randle (1997), onion pungency is controlled by genetic factors and influenced by environmental conditions, particularly soil sulfur content, temperature, and water availability. However, Sun Yoo et al. (2006), who investigated the effects of genetic and environmental factors on onion pungency, found that 81.3% of the variation in pungency was determined by genetics, with the environment playing a lesser role. This finding is consistent with Grangeiro et al. (2008) who reported that approximately 80% of the variation in onion heat is explained by genetic factors.

Clayey and highly weathered soils may have a high capacity for sulfate adsorption. Phosphorus-amended soil also tends to reduce sulfur adsorption in the surface layers (Alvarez et al., 2000), which can increase the availability of sulfur in the soil solution, making it more accessible to plants. In addition, plant leaves can absorb small amounts of sulfur in the form of sulfur dioxide gas ($SO_2$ ), a process that occurs when stomata are open.

Onions are very demanding in terms of sulfur, which is typically the third or fourth most accumulated nutrient in the plant (May et al., 2008). Most of the sulfur, about 70%, is stored in the bulb, and the highest sulfur demand occurs between 70 and 130 days after sowing (DAS), as reported by Pôrto et al. (2006) for Optima®.

When foliar sulfur was applied from planting through the 8- to 10-leaf development stage, no statistically significant differences were observed in the mean results (**Figure 6**).

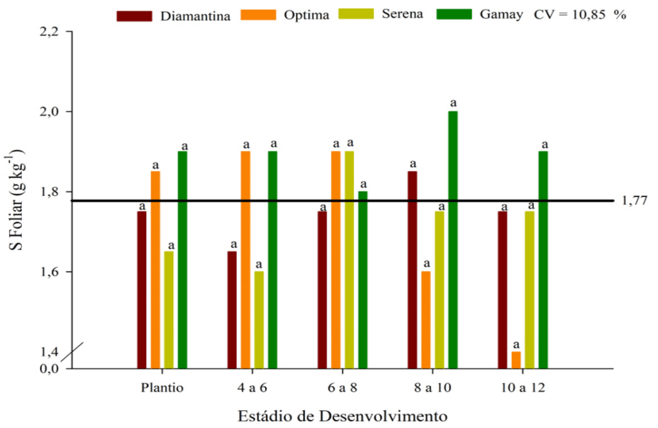


**Figure 6.** Mean foliar sulfur content (g $kg^{-1}$) of onion hybrids as influenced by foliar application of elemental sulfur at different development stages under low-altitude tropical conditions, city of Gurupi, state of Tocantins, 2022
Means followed by the same lowercase letter within the bars across hybrids at each development stage do not differ statistically, according to the Scott-Knott test at a 5% probability level.

For the onion hybrids, foliar sulfur content ranged from 1.4 to 2 g $kg^{-1}$ over the developmental stages evaluated (Figure 6). Lacerda et al. (2022) observed an increase in foliar S content to 2.8 g $kg^{-1}$ when applying a S dose of 60 kg $ha^{-1}$.

The low sulfur levels observed are related to plant absorption rates, nutrient availability in the soil, and genotype ability to redistribute soluble and insoluble sulfur fractions throughout the plant (Barker & Pilbeam, 2015). Additionally, the foliar sulfur levels found in this study were considered low because Trani et al. (2014) established an ideal range for foliar sulfur absorption of 5 to 8 g $kg^{-1}$, which differs from the values observed here.

The similarity between leaf and bulb sulfur levels across all evaluations and developmental stages throughout the crop cycle indicates that both soil and foliar applications of elemental sulfur provided satisfactory results for onion production (**Figure 7**).

The sulfur content in the bulbs, measured in g $kg^{-1}$ for the hybrids, ranged from 1.35 to 1.6 g $kg^{-1}$ at planting (control). The development stages showed the following values 1.4 to 1.75 g $kg^{-1}$ for the 4- to 6-leaf stage, 1.2 to 1.5 g $kg^{-1}$ for the 6- to 8-leaf stage, 1.45 to 2.22 g $kg^{-1}$ for the 8- to 10-leaf stage, and 1.55 to 1.70 g $kg^{-1}$ for the 10- to 12-leaf stage (Figure 7).

Nguyen et al. (2022), using sulfur doses of 20, 40, 60, 80, 100, 120, 140, and 160 kg $ha^{-1}$ on garlic cultivars,

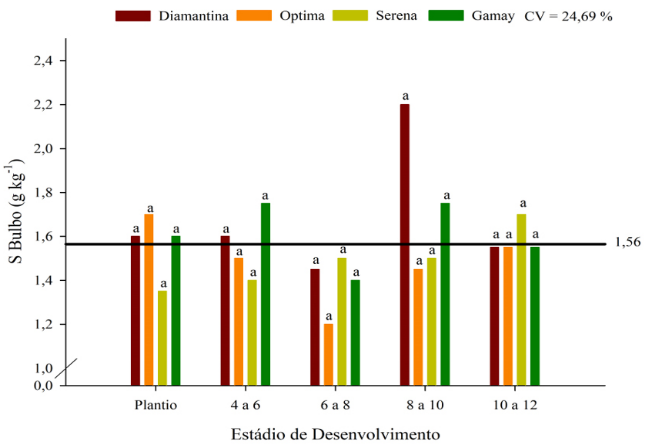


**Figure 7.** Mean sulfur content in onion bulbs (g kg$^{-1}$) as influenced by foliar application of elemental sulfur at different development stages under low-altitude tropical conditions, city of Gurupi, state of Tocantins, 2022
Means followed by the same lowercase letter within the bars across hybrids at each development stage do not differ statistically, according to the Scott-Knott test at a 5% probability level.

determined sulfur absorption rates of 0.0085 g kg$^{-1}$ for the Southern Glen cultivar and 0.0062 g kg$^{-1}$ for the Glenlarge cultivar. In this study, higher sulfur absorption rates were observed, ranging from 1.2 to 2.22 g kg$^{-1}$, depending on the developmental stage (Figure 7).

Similarly, in a study by Arunachalam et al. (2021), sulfur uptake rates in garlic bulb tissue were low, with sulfur application rates ranging from 0 to 60 kg ha$^{-1}$, resulting in sulfur contents between 0.007 and 0.008 g kg$^{-1}$. These values are lower than those observed for onion sulfur content in this study (Figure 7). Finally, sulfur uptake may be directly related to the genotypic traits of sulfur uptake efficiency or yield potential of the onion genotype (Nguyen et al., 2022).

## Conclusions

Pyruvic acid content in the onion hybrids was influenced by the stage of sulfur application;

Serena® $F_1$ showed the highest pyruvic acid content at the 10- to 12-leaf stage compared to other stages;

Foliar-applied sulfur resulted in a medium pungency classification for Diamantina® and Serena® $F_1$;

Gamay® $F_1$ exhibited a low to sweet pungency classification when sulfur was applied.


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