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## Growth and quality of chives in hydroponic system with concentrations of magnesium sulfate

Dalva Paulus <sup>1\*</sup>; Leonardo Barbieri <sup>1</sup>; Ana Márcia de O Febraio <sup>1</sup>; Dislaine Becker <sup>1</sup>

<sup>1</sup>Universidade Tecnológica Federal do Paraná (UTFPR), Dois Vizinhos-PR, Brasil; dalvapaulus@utfpr.edu.br (\*author for correspondence); leonardobarbieri06@gmail.com; anafebraio@alunos.utfpr.edu.br; engdislainebecker@gmail.com

### ABSTRACT

Chives are popular herbs, and highly appreciated by consumers. The experiment was conducted in the period from September to November 2020 in a greenhouse, located at the Federal University of Technology, Paraná, Brazil. This study aimed to evaluate the growth, physiological responses, and quality attributes of chives grown in hydroponic systems containing different concentrations of magnesium sulfate. The experimental design was randomized blocks, and the treatments consisted of a standard solution with the addition of magnesium sulfate at the following doses (g/L): standard solution 0.4; 0.42, 0.44; 0.46, and 0.48, with four repetitions per treatment. The analyzed variables were physiological indicators and growth; physical-chemical characteristics and nutrient content in tissues. The dose of 0.48 g/L resulted in the highest number of leaves (47.3) and contributed to 44% reduction in leaf drop, thereby positively influencing growth with higher fresh mass (231.40 g/plant). The relative chlorophyll index (58.64) obtained at 0.48 g/L dose revealed an increase in the chlorophyll content and, consequently, in the green color of the plants, with °hue angle of 140.54. Greener leaves is a visual aspect preferred by consumers. In addition, the higher concentration of magnesium sulfate provided 50.7% increase in the content of soluble solids and 50.6% rise in phenolic compounds. The dose of 0.48 g/L magnesium sulfate contributed to reduced leaf fall, improved visual appearance, greater bioactive compounds, and enhanced leaf sweetness to meet the quality standards that consumers expect for this condiment.

**Keywords:** *Allium schoenoprasum*, magnesium, nutrient film technique, chlorophyll, quality.

### RESUMO

#### Crescimento e qualidade de cebolinha em sistema hidropônico com concentrações de sulfato de magnésio

A cebolinha é uma erva popular, muito apreciada pelos consumidores. O experimento foi conduzido no período de setembro a dezembro de 2020 em casa de vegetação, localizada na Universidade Tecnológica Federal do Paraná, Brasil. Este estudo teve como objetivo avaliar o crescimento, as respostas fisiológicas e os atributos de qualidade da cebolinha cultivada em sistema hidropônico contendo diferentes concentrações de sulfato de magnésio. O delineamento experimental foi blocos casualizados e os tratamentos consistiram de uma solução padrão com adição de sulfato de magnésio nas seguintes doses (g/L): solução padrão 0,4; 0,42, 0,44; 0,46 e 0,48 com quatro repetições por tratamento. As variáveis analisadas foram indicadores fisiológicos e de crescimento; características físico-químicas e teor de nutrientes nos tecidos. A dose de 0,48 g/L resultou no maior número de folhas (47,3) e contribuiu para uma redução de 44% no tombamento das folhas, influenciando positivamente no crescimento com maior massa fresca (231,40 g/planta). O índice relativo de clorofila (58,64) obtido na dose de 0,48 g/L resultou em aumento no teor de clorofila e, conseqüentemente, na cor verde das plantas, com ângulo °hue de 140,54. Folhas mais verdes é um aspecto visual preferido pelos consumidores. Além disso, a maior concentração de sulfato de magnésio proporcionou um aumento de 50,7% no conteúdo de sólidos solúveis e um aumento de 50,6% nos compostos fenólicos. A dose de 0,48 g/L de sulfato de magnésio contribuiu para a redução de tombamento das folhas, melhoria do aspecto visual, maiores compostos bioativos e aumento da doçura das folhas para atender os padrões de qualidade que os consumidores esperam para este condimento.

**Palavras-chave:** *Allium schoenoprasum*, magnésio, técnica de fluxo de nutrientes, clorofila, qualidade.

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The European chives (*Allium schoenoprasum*) is a herb of the Alliaceae family that is prevalent and important for agribusiness, as the leaves are widely used in cooking. The chives crop can be grown in a traditional way (in beds) and in hydroponic cultivation, a technique that has generated greater

added value to the product and anticipation of harvest. (Thakulla *et al.*, 2021). There are few studies on chives production in hydroponic systems compared to the traditional system in soil beds (Santos *et al.*, 2021). In this sense, in hydroponic cultivation, data on the average production of 26.23 g/plant

of fresh and dry mass (3.67 g/plant) of the aerial part of chives are reported by Souza *et al.* (2021).

The cultivation of chives is typical of family farming, with significant economic and social importance, contributing to income generation, quality of life and involvement in family

work (Carvalho *et al.*, 2019). Seasoning plants have been used historically worldwide and play a fundamental role in economies and cuisines (Stefanaki & van Anel, 2021). Chives are capable of stimulating appetite, aiding in digestion, and acting in the fight against influenza and respiratory tract diseases, and sulfur compounds that have antibiotic properties (Shahrajabian *et al.*, 2021).

The flavor value of a plant is generally associated with the content of volatile compounds, such as pyruvic acid (Bianchi, 2015), that arise from secondary metabolic processes, which are susceptible to environmental (light, temperature, soil, and water), phytotechnical (fertilization, time and form of harvest, drying, and storage), and genetic factors, which can influence the quality and quantity of these compounds (Pavarini *et al.*, 2012).

This herb has low post-harvest durability due to its high water content and metabolic activity. The success in the commercialization of the chives is mainly related to its visual appearance, color, size, and health which can create challenges for producers, as the consumer market is increasingly demanding regarding the appearance of the product. The rapid growth of the plant and reduced resistance of the leaf tissue can cause the aerial part to fall, leading to deterioration, thereby affecting the appearance and quality of the product offered to the consumer. These symptoms occur in soil and hydroponics crops (Santos *et al.*, 2014).

Magnesium is directly related to the synthesis of chlorophyll and photosynthesis as it acts on plant tissues causing improvements to their visual appearance (greener leaves), and increases in mass deposition. Magnesium deficiency in species of the Alliaceae family results in a whitish-green color in older leaves and apex dryness (Malavolta, 2006). In onion (*Allium cepa*) the increase in magnesium nutrition (100 mg/dm<sup>3</sup>) resulted in increased production and quality with positive effect on dry matter contents in leaves, which are important for maintaining onion quality (Kleiber *et al.*, 2012).

The main challenge in the cultivation of chives is related to the visual appearance of the leaves, which can present yellowing at the tips and a high percentage of leaf drop, which are symptoms related to magnesium deficiency that result in the loss of quality, a problem that occurs in all production systems. Hydroponic cultivation represents a cultivation technique with the potential for quality production, using the supply of nutrients in accordance with the nutritional requirements of the culture, control of the growing climate and pests (Thakulla *et al.*, 2021).

Although the effects of magnesium have not been widely researched in hydroponically grown chives, studies evaluating different concentrations of magnesium have contributed to improving crop growth and quality aspects, such as the intensity of the green color. The hypothesis is that increasing magnesium concentrations in the nutrient solution reduces leaf fall and improves the visual appearance and commercial quality of chives. The objectives of our research were to evaluate the growth, physiological responses, and physicochemical characteristics of chives (*Allium schoenoprasum*) grown with different concentrations of magnesium sulfate in a hydroponic system.

## MATERIAL AND METHODS

The experiment was conducted from September to December 2020 in greenhouse, located at the Federal University of Technology, Paraná, Brazil (25°42'S, 53°06'W, altitude 520 m). The climate of the region according to Köppen's classification is Cfa (Alvares *et al.*, 2013). In the greenhouse, a red colored screen was installed with 50% shade net. The experiment was performed in a hydroponic system with nutrient film technique (NFT).

The experimental design was randomized blocks, with five concentrations of magnesium sulfate: T1 = 0.40 g/L (standard concentration proposed by Furlani *et al.* (1999); T2 = 0.42 g/L; T3 = 0.44 g/L, T4 = 0.46 g/L and T5 = 0.48 g/L, with four

repetitions per treatment. The treatments were randomly distributed to the 20 cultivation tables.

The nutrients used to prepare the solution standard concentrations were (mM/L): N-NO<sub>3</sub><sup>-</sup> (12.43), N-NH<sub>4</sub><sup>+</sup> (1.5), K (4.69), P-H<sub>2</sub>PO<sub>4</sub><sup>-</sup> (0.97), Ca<sup>+2</sup> (142), Mg<sup>+2</sup> (38), and S-SO<sub>4</sub><sup>-2</sup> (1.63) and for the micronutrients, a complete commercial fertilizer (Conmicros Standard®) was used with all the elements in the composition of 1.82% boron, 1.82% Cu EDTA, 7.26% Fe EDTA, 1.82% Mn EDTA, 0.36% Mo, 0.335% Na, and 0.73% Zn EDTA. In the other nutrient solutions of T2, T3, T4, and T5, only the magnesium concentration changed, as described above. The magnesium sulfate fertilizer (Magnesium ultra®) had a concentration of 12% Mg and 11.80% S-SO<sub>4</sub>.

The experimental area consisted of cultivation tables. Each plot (1.5 m<sup>2</sup>) was composed of six cultivation channels with 15 plants per channel, totaling 90 plants per plot. The cultivation table had eight polyethylene channels, 6 m long with a declivity of 8%, supported by wooden trestles. The system was closed with a reservoir of nutritive solution for each cultivation table, a pumping system (motor pump) for the cultivation channels, and a return system (gutters) for the reservoir.

The nutrient solution was prepared in a volume of 450 L water and stored in 500 L polyethylene reservoir. Water was replaced daily at an initial concentration of 450 L. The nutrient solution was replaced once during the experiment when the electrical conductivity (EC) readings were 50% of the initial solution, and 50% of the nutrient solution was replaced at 34 DAT.

The chives cultivar used in the experiment was 'Todo Ano', acquired as seedlings with 15 cm average height from a local nursery at 25 days after sowing and transplanted 15 seedlings in the cultivation channels. The spacing between plants was 0.20 × 0.30 m.

The pH readings were taken every two days by pH meter (GEHAKA® brand, model n PG 1400), with values maintained in the range of 5.5 and 6.0. Electrical conductivity of the solution

was determined using a portable conductivity meter (GEHAKA® brand model CG1400), and values were sustained in the range of 2.02 to 2.44 mS/cm (Table 1). Only one nutrient replacement was performed during the experiment, when the EC readings showed 50% of the initial value, where 50% of the nutrients of the nutritive solution were replaced.

#### Microclimatic conditions

During chive cultivation, the greenhouse microclimate was homogeneous and there was no effect of space. The average temperature during the experiment was 22.6°C, and minimum was 10.59°C, the mean relative humidity (RH%) was 62%, the mean global solar irradiance was 256.4 W/m<sup>2</sup>. The microclimatic conditions during the cultivation of chives were within the ideal for the crop (Kleiber *et al.*, 2012).

#### Physiological indicators and growth

For all analyses of the experiment, ten central plants, randomly obtained from the four cultivation channels of the center were evaluated from each treatment in each replication, the two cultivation channels on the sides of the cultivation tables were considered as borders.

#### Number of leaves and length of the largest leaf

The number of leaves was counted, and the length of the largest leaf was measured from the apex to the base by a millimeter ruler. Measurements were taken 40 days after transplantation (DAP).

#### Percentage of leaf drop and fallen leaves

The percentage of leaf drop was

determined by counting the number of leaves per plant (NL) and fallen leaves (FL), by the equation

$$\text{Leaf drop (\%)} = \frac{FL \times 100}{NL} \quad (1)$$

#### Relative chlorophyll index

To determine the relative chlorophyll index (RCI), two readings were performed, one near the apex and the other at the base of the leaves, at 11:00 AM on the 38<sup>th</sup> day after transplanting. For the readings, a portable chlorophyll meter (Clorofilog, Falker®) was used.

#### Fresh and dry biomass

The fresh mass of the aerial parts and roots was determined 40 days after transplanting (DAT), using a precision scale. Subsequently, the roots and aerial parts were dried in a forced air circulation oven at 65°C±3, until a constant mass was reached to obtain the dry biomass of the aerial part and root, weighing on a precision scale.

#### Physical-chemical characteristics

##### Epidermis color analysis

The epidermis color analysis was performed using a portable Konica colorimeter (Minolta® Chroma Meter CR400, Japan) with a D65 illuminant. The measurements were expressed in terms of luminosity (L\*), chromaticity parameters a\* and b\*, chromaticity C\* (chroma), and hue angle or color (°h) (Minolta, 2007), and were calculated using equations (2) and (3), respectively.

$$C = (a^{*2} + b^{*2})^{1/2} \quad (2)$$

$$h = \arctan\left(\frac{b^*}{a^*}\right) \quad (3)$$

For epidermal color analyses, ten plants were collected from each treatment. We randomly analyzed five leaves of each plant. The readings

were taken close to the apical and basal regions of the leaves, with double-sided repetition.

#### Soluble solids, total titratable acidity and pH

To determine soluble solids (SS) content, we randomly collected ten plants from each treatment and used a Hanna® model H196801 digital refractometer; values were expressed in °Brix (corrected for a temperature of 20°C). To obtain the liquid from the leaf, it was cut in half and shaved with a spatula until the liquid samples were obtained. In the sequence, the SS reading of the samples was performed.

The total titratable acidity was determined according to the technique described by AOAC (2010). For each sample, 10 g of leaves and 90 mL distilled water were used, which were homogenized in a blender, obtaining the juice from the leaves. It was not necessary to filter the juice. Acidity was expressed in milliequivalents of pyruvic acid per 100 g of fresh mass. The ratio was determined through the ratio of total soluble solids and titratable acidity (SS/TA) (AOAC, 2010).

The pH of the chives juice was evaluated using the potentiometric method according to the methodology proposed by AOAC (2010). Leaf juice was obtained by the methodology described for the analyses of soluble solids. The reading was performed using a digital pH meter (Gehaka®, model PG 1400). Three plants were analyzed per treatment, for a total of 15 repetitions.

#### Total phenolic compound and pyruvic acid content

The determination of the total phenolic compound content in the chives was based on the colorimetric method (Nuutila *et al.*, 2003). 1 g of leaf material from six plants in each treatment was sampled, totaling six replicates.

The samples were macerated using a porcelain mortar and pestle, and 1 mL distilled water and solvent were added. These samples were placed in tubes containing 9 mL distilled water, followed by centrifugation (Model NT 810). After centrifugation at 3,500 rpm for 30 min, 1 mL of the supernatant

**Table 1.** Means of electrical conductivities and pH of the nutrient solutions evaluated during the cultivation of chives in hydroponics. Dois Vizinhos, UTFPR, 2020.

Magnesium sulfate doses (g/L)	pH	EC (mS/cm)
0.40	6.03	2.00
0.42	5.96	2.02
0.44	5.88	2.09
0.46	5.94	2.11
0.48	6.00	2.44

was transferred to a test tube, where 2.5 mL 10% Folin-Ciocalteu solution was added. After a brief agitation of the tube, 2.0 mL 4% sodium carbonate was added following the methodology described by Nuutila *et al.* (2003).

The total phenolic content was expressed in milliequivalents of gallic acid per gram of fresh mass of chives, determined by the equation of the straight line of the calibration curve ( $R^2 = 0.9988$ ), after determining the absorbance in a spectrophotometer.

The pungency of chives was determined based on pyruvic acid content using the method developed by Anthon & Barrett (2003). The enzymatic production of pyruvic acid was expressed in  $\mu\text{mol/g}$  of chives.

#### Nutrient content in tissues

The macronutrient and micronutrient content in the leaf and root tissue was determined, and only completely expanded leaves of the middle third of the plant were collected, according to the methodology described by Malavolta *et al.* (1997). The samples of dry mass of leaves and roots were dehydrated, ground and determined the macronutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S); and micronutrient: boron (B), zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn), as described by Malavolta *et al.* (1997). Ten plants were evaluated from each treatment in each replication.

#### Statistical analysis

Treatment variances were tested for homogeneity using the Bartlett test and data normality using the Shapiro Wilk test. Data were subjected to analysis of variance with the F test ( $p < 0.01$ ), and when significant, the effect of treatments was applied to polynomial regression analysis using the statistical program "SAS Studio" (Sas Institute, 2014).

## RESULTS AND DISCUSSION

### Growth and physiological indicators

The number of leaves was significantly and linearly influenced by magnesium sulfate dose (Figure 1A). The 0.48 g/L treatment resulted

in a greater number of leaves (47.3) compared to the other doses. In chives, doses greater than 0.48 g/L of magnesium sulfate could result in a reduction in the number of leaves. Santos *et al.* (2021), testing different concentrations, 50, 75, 100 and 125% of nutrient solution in the hydroponic cultivation of chives found that the concentration of 125% showed 13% reduction in the number of leaves. According to the authors, a higher supply of nutrients reduced the number of leaves, negatively affecting the growth of chives in hydroponic systems.

Kleiber *et al.* (2012), in a research with onion (*Allium cepa*) grown in soil, found that magnesium nutrition with 100 mg/dm<sup>3</sup> resulted in 38% increase in productivity, but higher doses (150 - 200 mg/dm<sup>3</sup>) showed reduction of 12.5% in the commercial productivity of onions, negatively impacting productivity. The absorption of nutrients is different for each plant and the adequate dose of each nutrient is essential in hydroponics cultivation (Luz *et al.*, 2018).

On the other hand, a lack of Mg can directly affect the productivity and visual quality of leaves as well as interfere with their growth and tillering (Ye *et al.*, 2019).

In the present study, we found that the dose of 0.48 g/L was beneficial for chives growth, resulting in higher number and visual quality of leaves, compared to lower doses of magnesium. The quality and number of leaves are important parameters in purchasing decisions of consumers. In this sense, the number of leaves per plant provided larger bunches, which attracts buyers.

The length of the longest leaf increased quadratically with higher doses of magnesium sulfate (Figure 1B), and the superior result was observed with the dose of 0.48 g/L (48.5 cm) at 40 DAT. The shortest length of the longest leaf (41.7 cm) occurred with the standard dose of magnesium sulfate.

Considering the ideal point for commercialization in hydroponic cultivation (40 DAT) (Santos *et al.*, 2005), a dose of 0.48 g/L contributed significantly to increase the length of the leaves, thereby improving the

productivity and quality of the chives.

The percentage of leaf drop showed significant differences at the evaluated doses (Figure 1C). The higher dose (0.48 g/L) of magnesium sulfate in the nutrient solution resulted in a quadratic adjustment, with a lower percentage of leaves falling (0.71%). The standard dose of magnesium sulfate resulted in the highest percentage of leaf drop (1.62%), while the 0.48 g/L increase contributed positively to a 44% reduction in leaf fall.

Leaf drop affects the visual appearance and quality of the chives, which causes losses to the producer during marketing. According to Santos *et al.* (2014) the cause of foliar fall by chives can be nutritional deficit (magnesium deficiency) or lower tissue resistance. In previous studies with hydroponic chives (Bernal *et al.*, 2008), a low amount of Mg in the nutrient solution resulted in plant deficiency 58 days after transplanting, where 70% of the leaves presented nutritional insufficiency, and symptoms such as leaf drop, leaf apex yellowing, and turgor loss, compromising the commercialization of the product.

The RCI showed that the addition of magnesium sulfate to the nutrient solutions increased the green color of the plants, resulting in a linear equation adjustment (Figure 1D). The greatest amount of chlorophyll (58.64) was observed with the highest dose (0.48 g/L) of magnesium sulfate. The chlorophyll contents were higher than those reported by Silva *et al.* (2016), who evaluated the physicochemical quality of common chives (*Allium fistulosum*) and european chives (*Allium schoenoprasum*).

Similar results were demonstrated in onion culture by Kleiber *et al.* (2012) who found that increased levels of magnesium in the soil in the range of 100 to 150 mg/dm<sup>3</sup> resulted in an increase in total chlorophyll contents, enabling a significant improvement in dry matter contents in the leaves, which is important for maintaining onion quality.

We found that an increase in chlorophyll content can contribute to

the attractiveness and consumption of vegetables, as it is related to the intensity of the green color, the stage of maturation, and the nutritional value. In addition to genetic factors and luminosity, the availability of nutrients during cultivation is an intrinsic factor in the synthesis of chlorophyll. Magnesium is essential for the composition of the chloroplast pigment that occupies a central position in the molecule (Cakmak & Yazici, 2010). Approximately 10% of the total Mg of the leaves is allocated to chlorophyll, and increasing the supply of this mineral in the substrate can provide greater absorption and concentration of the pigment (Silva *et al.*, 2016).

For fresh and dry mass, the equations were quadratic (Figures 1D and 1E). The

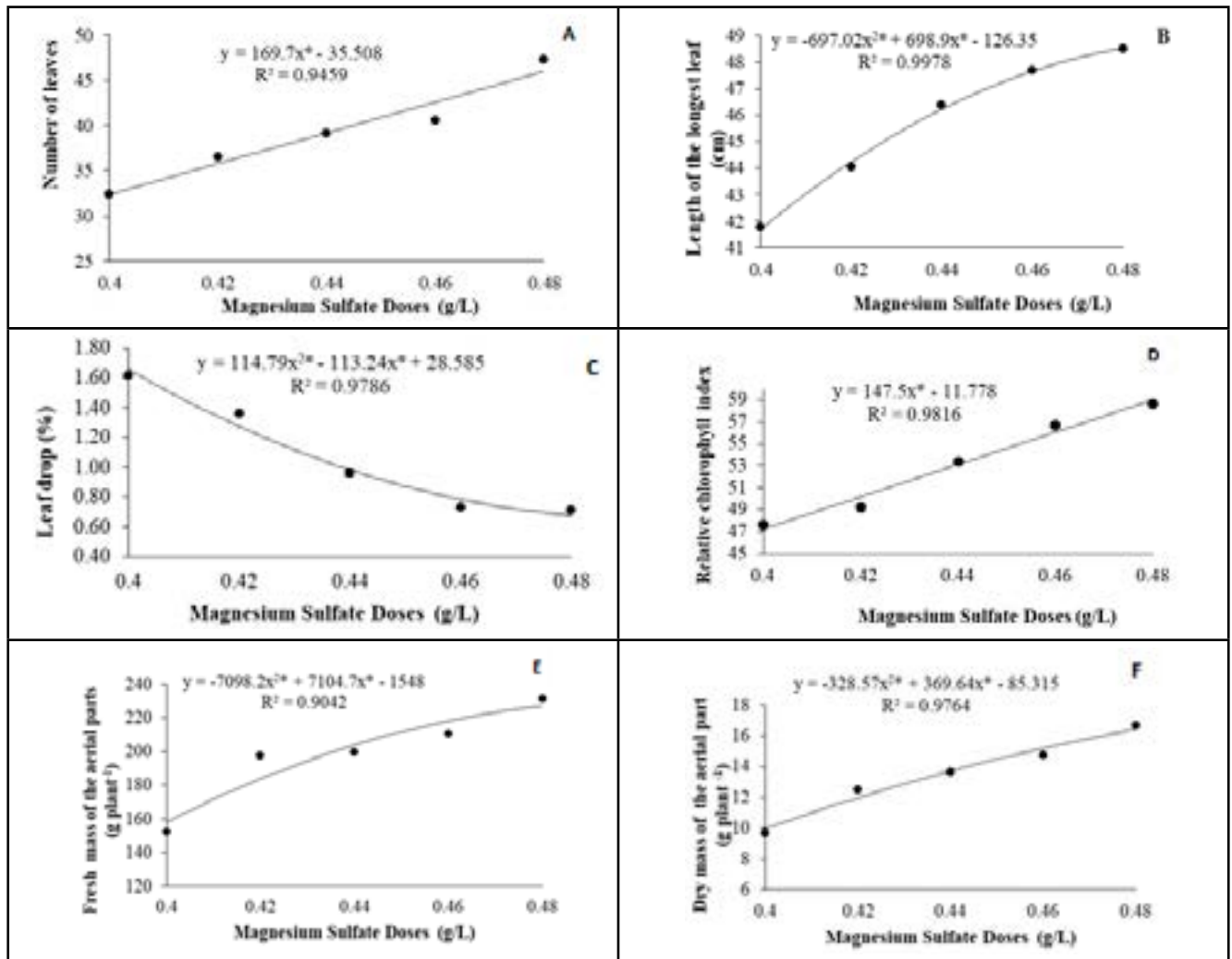
dose of 0.48 g/L of magnesium sulfate resulted in greater gains in fresh and dry biomass of leaves (231.40 g/plant and 16.65 g/plant, respectively) than the other evaluated doses. The maximum fresh biomass of 229.80 g/plant was estimated at a concentration of 0.50 g/L of magnesium sulfate. The fresh and dry mass of the roots did not differ between the evaluated-doses (data not presented).

We verified that the increase in the number of leaves, caused by the higher doses of magnesium sulfate, contributed to the increase in fresh and dry mass, and reduced leaf drop of chives. The commercial productivity in hydroponic system of 38.57 t/ha at a dose of 0.48 g/L magnesium sulfate is in agreement with the results obtained by Souza *et al.*

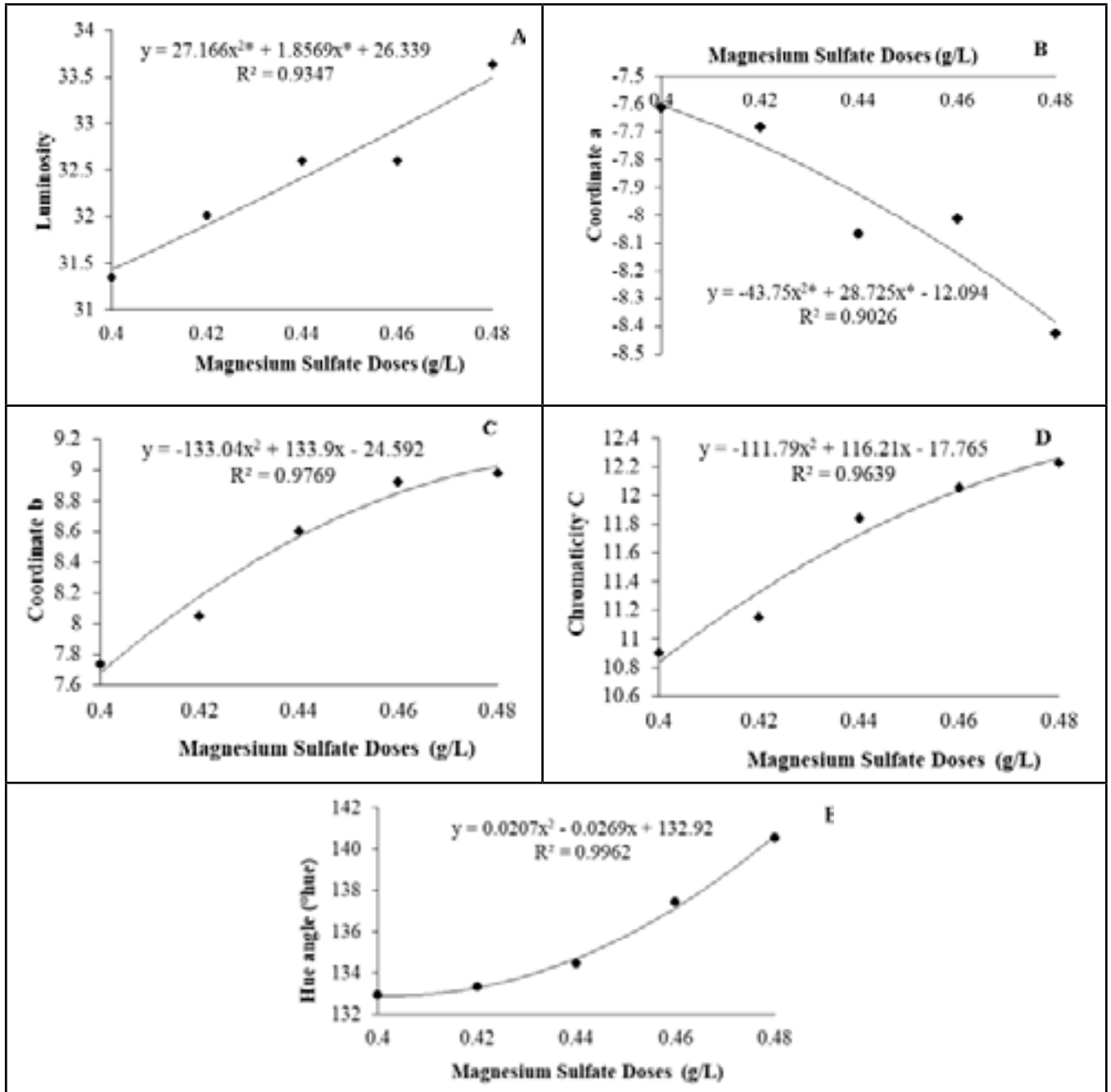
(2021). The accumulation of biomass is an important characteristic related to plant growth, and greater values indicate improved quality of the sold plants.

The positive effect of magnesium on onion production and quality were also verified by Kleiber *et al.* (2012) with a 45% increase in commercial production in relation to the control dose (50 mg/dm<sup>3</sup>) of magnesium.

In this context, it is interesting to highlight that our results demonstrate that the hydroponic cultivation of chives with a dose of 0.48 g/L of magnesium sulfate significantly reduced the harvest time (40 DAS), which allows the producer to sell chives before and according to quality and appearance (more intense green color



**Figure 1.** Number of leaves (A); length of the longest leaf (B); leaf drop (C); relative chlorophyll index (D); fresh (E) and dry mass of the aerial part (F) of chives cultivated in hydroponics with different doses of magnesium sulfate. \*significant at 1% probability by the F test. Dois Vizinhos, UTFPR, 2020.



**Figure 2.** Color parameters luminosity (A); coordinate a (B), coordinate b (C), chromaticity C (D) and °hue angle (E) of chives cultivated in hydroponics system with different magnesium sulfate doses. Dois Vizinhos, UTFPR, 2020.

and lower number of fallen leaves) that the consumer seeks, in a shorter period of time (45 DAS), in relation to cultivation in the soil, which is 85 DAS with seed propagation (Filgueira, 2008), and saving 8 DAS, compared to the results obtained by Santos *et al.* (2021).

#### **Luminosity, coordinates a, coordinates b, chromaticity C, and hue angle**

In the color evaluations, the

light aspect ( $L^*$ ) showed a quadratic adjustment at the different doses of magnesium sulfate (Figure 2A). The increase in  $L^*$  values signaled the lightening of the plants, as there was an increase in  $MgSO_4$  in the solutions. The highest value of  $L^*$  (32.63) was obtained at a concentration of 0.48 g/L which is a result similar to that of Santos *et al.* (2014) for chives cultivated in Portugal ( $L^* = 30.00$ ).

The chromaticity coordinates  $a^*$  and  $b^*$  revealed differences between the concentrations evaluated, with quadratic adjustment, respectively (Figures 2B and 2C). The negative values of the chromaticity coordinate  $a^*$  found at a concentration of 0.48 g/L represent the green color tone, which can be explained by the effect of magnesium on the increase in chlorophyll synthesis. The greater availability and absorption

of magnesium allowed for an increase in mass deposition and improvements in the visual appearance, deepening the green leaf color. The  $b^*$  coordinate presented positive values for the evaluated concentrations, indicating a higher content of yellow over blue.

Chroma (C) values represent color purity or saturation, ranging from 0 for neutral colors to 60 for vivid colors. The chromaticity had a quadratic behavior for the evaluated concentrations (Figure 3D), resulting in an increase in the color intensity of the chives.

Increasing concentrations of magnesium sulfate contributed to changes in hue, as assessed by the hue angle ( $^{\circ}$ hue), which presented a quadratic adjustment (Figure 2E). The yellowish-green color obtained is characteristic of the chives. These results agree with those presented by Vinã & Cerimele (2009), who obtained a hue angle of 135.2 for freshly harvested chives.

Magnesium sulfate and its direct relationship with the photosynthetic pigment contributed to the improvement in the color of the chives, as demonstrated

by the color parameters. The highest concentration resulted in plants with most intensive green color and slight lightening, signaled by the yellow content, characteristics that meet the standards of health and physical-chemical parameters sought by the consumer (Lima *et al.*, 2008). Color, one of the first attributes evaluated by the consumer, is decisive for the purchase of the product as it influences quality and indicates the stage of maturation. Furthermore, it is also correlated with the nutritional function of the plant during cultivation, which is associated with chlorophyll content (Kasim *et al.*, 2008).

#### Soluble solids

The addition of magnesium sulfate to the nutrient solutions resulted in chives with a higher degree of sweetness and maturation. The changes were evidenced by the quadratic adjustment of the soluble solids content (SS) (Figure 3A).

Even with the addition of magnesium sulfate, the values found in this work were lower than those reported by Silva *et al.* (2016) on conventionally grown

European chives (5.2°Brix), which can be explained by the different cropping systems and climatic conditions. Lower values of soluble solids relate to lower substrate content for the metabolic processes of deterioration (Silva *et al.*, 2016). Despite being a common criterion for determining the stability of vegetables, in some foods the soluble solids content is complementary to other maturation parameters, such as acidity and pungency levels.

#### Titrateable acidity and pyruvic acid

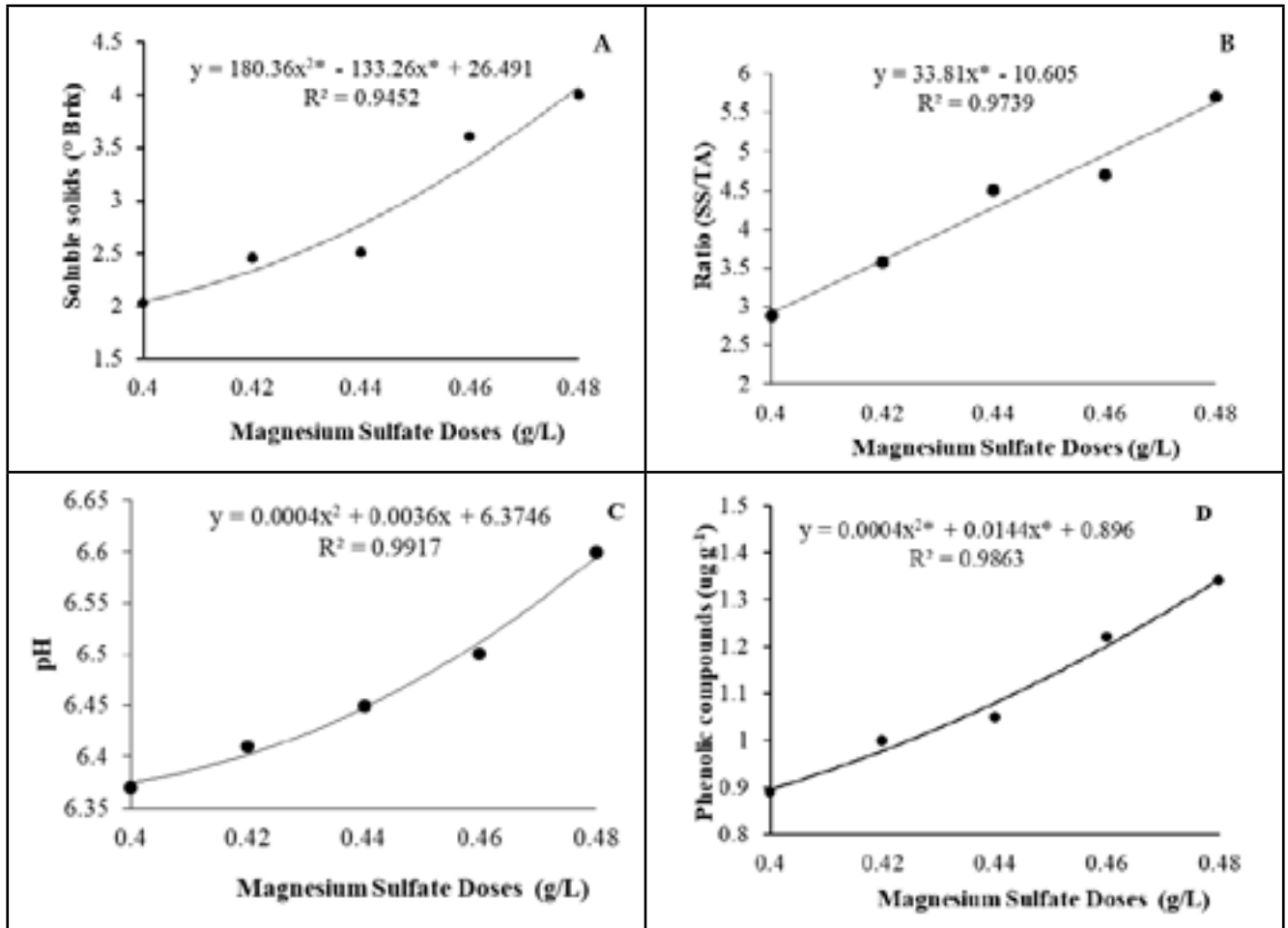
The evaluated concentrations of magnesium sulfate did not influence the titrateable acidity, with a mean value of 0.63 mEq/100 g of fresh mass (data not presented). Similar results were found by Silva *et al.* (2016).

The main organic acid present in chives is pyruvic acid, which for the concentrations evaluated had an average content of 0.081 g/100 g and no significant difference among the concentrations of magnesium sulfate evaluated (data not presented). Silva *et al.* (2016) analyzed the physicochemical characteristics of common and European

**Table 2.** Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) levels of chives leaves and roots cultivated in hydroponics with different doses of magnesium sulfate. Dois Vizinhos, UTFPR, 2020.

Doses (g/L)	Leaves											
	Macro (g/kg)						Micro (mg/kg)					
	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	
0.40	38.11b*	7.43b	21.60 <sup>ns</sup>	9.11b	2.22b	2.81 <sup>ns</sup>	27.79 <sup>ns</sup>	9.81b	302.10 <sup>ns</sup>	55.71a	10.48b	
0.42	38.22b	7.87b	21.70	9.85b	2.50b	2.63	27.58	9.30b	262.50	47.39b	9.56b	
0.44	42.88ab	8.25ab	22.00	9.90b	2.80b	2.83	27.60	10.26ab	307.10	55.57a	13.51ab	
0.46	43.12a	8.47a	22.80	10.74a	2.85a	1.59	28.63	11.00a	244.30	57.60a	14.46a	
0.48	43.70a	8.78a	22.90	10.12a	2.92a	2.15	28.70	11.20a	274.40	58.00a	14.78a	
Mean	41.21	8.16	22.20	9.94	2.66	2.40	28.06	10.31	278.08	54.85	12.56	
CV (%)	9	6	9	6	10	14	8	6	13	7	13	
Doses (g/L)	Roots											
	0.40	23.0 <sup>ns</sup>	4.8b	10.2 <sup>ns</sup>	7.5b	24.3ab	1.4 <sup>ns</sup>	25.9 <sup>ns</sup>	67.6 <sup>ns</sup>	529.9 <sup>ns</sup>	136.8 <sup>ns</sup>	36.2 <sup>ns</sup>
	0.42	21.6	5.7a	10.3	8.9ab	22.7b	1.7	26.6	60.9	557.6	175.5	38.4
	0.44	23.3	5.1a	11.1	9.3a	25.1a	1.6	22.0	71.6	578.9	175.1	41.7
	0.46	20.0	5.6a	11.3	10.0a	26.5a	1.5	22.7	74.5	693.0	156.6	41.5
	0.48	22.9	5.8a	11.8	10.9a	27.0a	1.6	23.0	74.7	693.7	156.8	41.9
	Mean	22.16	5.4	10.94	9.32	25.12	1.56	24.04	69.86	610.62	160.16	39.94
	CV (%)	12	7	9	13	9	11	7	8	16	9	13

CV (%): Coefficient of variance; <sup>ns</sup>Not significant; \*Means followed by distinct letters in the column differ by the Tukey test at 5% probability.



**Figure 3.** Soluble solids (A); ratio (B); pH (C) and phenolic compounds (D) of chives cultivated in hydroponics with different doses of magnesium sulfate. \*significant at 1% probability by the F test. Dois Vizinhos, UTFPR, 2020.

chives and found similar contents (0.09 g/100 g, respectively). The data obtained in this study reinforce the classification of chives as vegetables with low acidity (Silva *et al.* 2016).

#### Ratio, pH and phenolic compounds

Magnesium sulfate concentrations significantly influenced the ratio, resulting in a linear adjustment. The highest ratio (5.7) was observed at the concentration of 0.48 g/L, while the lowest ratio (2.88) was found in the standard solution (Figure 3B). There was no significant change in the proportion of organic acids, but there were gains in sugars. The difference in the evolution of the levels of soluble sugars and acidic compounds can result in changes in the product sensory properties, mainly in the sensations of sweetness and acidity (Santos *et al.*, 2014).

Higher ratio values observed at the dose of 0.48 g/L magnesium sulfate represent a greater amount of soluble sugar in the chives, contributing to the sweeter taste. According to Oliveira & Santos (2015), although there are no defined standards for this ratio in fresh consumption and industrial processing, a sweeter flavor is generally desired and, thus, a higher ratio.

Chives cultivated with increasing concentrations of magnesium sulfate showed a high pH and low acidity. With quadratic adjustment, the highest pH value (6.66) was observed at a dose of 0.48 g/L (Figure 3C).

The juice of chives cultivated with the greatest addition of magnesium sulfate (0.48 g/L) in the nutrient solution had the highest pH values, demonstrating that hydrogen ions

were replaced by metallic magnesium cations. According to Malavolta (2006), magnesium acts by regulating the pH of the plant cells. A large part of the magnesium, approximately 85%, is found in the free form, mainly in the vacuoles, operating in the osmotic regulation and cation-anion balance in the cytoplasm. The metallic cations Ca, Mg, K, and Na are base formers, as they directly influence the concentration of OH<sup>-</sup> ions in solutions. By replacing and decreasing the concentration of H<sup>+</sup> ions in the solution, the metallic cations increase the concentration of OH<sup>-</sup> ions and consequently the pH (Marschner *et al.*, 1996).

The magnesium sulfate concentrations significantly influenced the content of phenolic compounds present in the European chives (*Allium*



*schoenoprasum*) (Figure 3D). Plants subjected to treatment with a dose of 0.48 g/L showed an increase of 50.6% in phenolic compounds compared to the standard solution.

The present study found that the dose of 0.48 g/L of MgSO<sub>4</sub> contributed to an increase in the phenolic compound content in chives, which may be related to the improved performance of plant metabolism against the concentrations of magnesium and other salts dissolved in this treatment. The results for phenolic compounds agree with those obtained by Mendes *et al.* (2015).

Magnesium at higher concentrations likely favored an increase in the production of photoassimilates, enabling greater amounts of substrates and sugars for secondary carbon metabolism. Furthermore, magnesium acts in the formation of RNA, which in turn is responsible for the transcription of messenger RNA and the encoding of phenylalanine ammonia lyase (PAL). The stimulus for the synthesis of phenolic compounds may be associated with an increase in the amount of this enzyme in plants. The reaction catalyzed by PAL regulates the formation of the most abundant class of phenolic compounds (Taiz & Zeiger, 2017).

The higher concentration of magnesium sulfate (0.48 g/L) may have contributed to the increase in the concentration of the PAL enzyme and, consequently, its role in the formation of phenolic compounds (Taiz & Zeiger, 2017).

The expansion of vegetable consumption is closely linked to the supply of quality products. Attributes such as color, aroma, and nutritional composition are relevant to the consumer, mainly because they demonstrate the integrity of the plant. Several epidemiological studies have indicated that a high intake of plant products is associated with a reduced risk of a variety of chronic diseases, such as atherosclerosis and cancer. These effects have been mainly attributed to compounds with antioxidant activity. The main antioxidants in vegetables are vitamins C and E, carotenoids, and phenolic compounds. In contrast,

chlorophyll has shown beneficial effects on health due to its antimutagenic and anti-genotoxic properties (Saini *et al.*, 2015).

The higher dose of magnesium in the hydroponic cultivation of chives improved the visual appearance of the leaves, with more intense color and chlorophyll content. Furthermore, there were gains in sweetness, maturation, and bioactive compounds, with an increase in the content of phenolic compounds, which are important for human health. The increments in the physicochemical attributes evaluated in this study demonstrate that chives cultivated with additional magnesium sulfate can meet the quality standards that the consumer seeks for this herb.

#### **Nutrient content in leaf tissue and roots**

Analysis of macronutrient contents in leaves and roots, N in the leaves, P, Ca, and Mg, and micronutrients in the leaves, Cu, Mn, and Zn showed significant statistical differences, with a tendency to increase with higher doses of magnesium sulfate (Table 2). The absorption of other nutrients was not altered by the increased doses of magnesium sulfate.

Among the macronutrients, N was extracted in greater quantity by chives, followed by K, Ca, P, Mg, and S (Table 2). The micronutrients in descending order of extraction were Fe, Mn, B, Zn, and Cu. In chives, macronutrients are present at higher concentrations in the aerial parts. The results of leaf analysis and nutrient export by the leaves agree with the results obtained by Bernal *et al.* (2008) in the leaves of chives cultivated in a hydroponic system.

The highest dose of magnesium sulfate (0.48 g/L) resulted in 31.53% more Mg in leaves than that of the standard dose. Thus, the higher Mg content in the leaves may have contributed to a higher relative chlorophyll index, resulting in a more intense green color, reduction of leaf tipping, and gains in biomass.

The average (g/kg) levels of N (38.11 - 43.70) and P (7.43 - 8.78) found in leaf tissue were higher than the intervals recommended by Trani &

Raij (1997) of 25 - 35 g/kg of N; 2 - 4 g/kg P; the contents (g/kg) of K (21.60 - 22.90); Ca (9.11 - 10.74); Mg (3 - 5); S (1.59 - 2.83); B (27.58 - 28.70); and Zn (9.56 - 14.78) were lower than the recommended intervals (g/kg) by the authors mentioned above, for K (30 - 50), Ca (15 - 30), Mg (3 - 5), S (5 - 8), B (30 - 50), and Zn (30 - 100).

The micronutrients Cu, Fe, and Mn were within the ranges recommended by Trani & Raij (1997): 10 - 30 g/kg Cu; 60 - 300 g/kg Fe; and 50 - 200 g/kg Mn. However, the nutrient content is inherent to each genotype, sampling time, and growing condition.

The effect of Mg on the accumulation of other nutrients depends on the species, plant organ, and to a lesser extent, the form of application (Coolong *et al.*, 2004). Interactions can occur between Mg and N, P, K, and Ca (Deng *et al.*, 2019). There is a positive synergistic effect of plant nutrition and Mg on N accumulation in plants, which was confirmed by the increase in N in chives leaves (Coolong *et al.*, 2004).

For K, no antagonistic effects were observed, which caused a reduction in the absorption of this element with an increase in Mg doses. We observed higher absorption of P and Ca in leaves and roots due to Mg availability in the nutrient solution, which confirms the results obtained by Ye *et al.* (2019).

In this study, there were no symptoms of nutritional deficiency in the chives plants grown at the Mg doses evaluated. Therefore, the EC and pH values were adequate for the growth of chives plants, which can be explained by the production of fresh and dry masses obtained in the experiment. The EC and pH values (Table 1) were close to those reported by Santos *et al.* (2005) for hydroponic crops.

Nitrogen was the mineral element extracted in the highest quantities by chives, followed by K, Ca, P, Mg, and S. The highest dose of magnesium sulfate (0.48 g/L) resulted in 31.53% more Mg in leaves compared to the standard dose, which contributed to the higher relative chlorophyll index, resulting in more and intense green color, reduced leaf drop, and gains in biomass.

We conclude that the highest number of leaves, leaf drop reduction, fresh and dry biomass, higher relative chlorophyll index and phenolic compounds, with greener and consumer-attractive leaves were observed at a dose of 0.48 g/L of magnesium sulfate, which contributed to the growth and quality of chives.

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