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Scientific Article

Growth stimulants for seed treatment and foliar aplication in watermelon crops

Estimulantes de crescimento no tratamento de sementes e adubação foliar em melancia

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ABSTRACT - Plant growth stimulants are a promising technology for agriculture to improve plant growth. These stimulants are often derived from a blend of plant regulators, minerals, amino acids, and other substances tested on various plants. The objective of this study was to evaluate the effects of a growth stimulant (micronutrients and amino acids) for seed treatment and foliar application on the initial growth of watermelon (*Citrullus lanatus*; cultivar Crimson Sweet). A randomized block experimental design with four replications was used, in a 6×2 factorial arrangement consisted of six growth stimulant rates (0, 1, 2, 3, 4, and 5 mL kg^{-1}) for seed treatment, combined or not with foliar application of the same growth stimulant at 300 mL ha^{-1} 26 days after sowing. The plant characteristics evaluated were: number of leaves per plant; shoot, root, and total plant lengths (cm); and shoot, root, and total dry weights. The use of the growth stimulant rate of 4 mL kg^{-1} for treating watermelon seeds, combined with foliar application of the growth stimulant (300 mL ha^{-1} 26 days after sowing), provided the best growth conditions to the plants, which was shown by their higher number of leaves, shoot length, and shoot and total dry weights.

Keywords: Amino acids. *Citrullus lanatus*. Micronutrients. Cucurbitaceae. Agressive Desperta®.

RESUMO - O uso de estimulante de crescimento é uma tecnologia promissora para a agricultura por proporcionar melhor condição de crescimento para as plantas, pois são oriundos da mistura de reguladores vegetais, minerais, aminoácidos e outras substâncias que têm sido testadas em diferentes plantas. Assim, objetivou-se com este estudo avaliar os efeitos do tratamento com micronutrientes e aminoácidos em sementes e adubação foliar em plantas de melancia (*Citrullus lanatus*), sobre o crescimento inicial das plantas. O delineamento experimental utilizado foi o de blocos casualizados, com quatro repetições e arranjo fatorial 6 x 2 composto por seis doses do tratamento de sementes (0; 1; 2; 3; 4 e 5 mL kg^{-1} sementes) e sem ou com adubação foliar utilizando o bioestimulante na dose de 300 mL ha^{-1}. Foram avaliados: número de folhas por planta; comprimento da parte aérea, raiz e total das plantas (cm); massa seca da parte aérea, raiz e total das plantas. A dose de 4 mL kg^{-1} sementes de melancia, cultivar Crimson Sweet, no tratamento de sementes e a adubação foliar no vigésimo sexto dia após a emergência das plântulas na dose de 300 ml ha^{-1} proporcionam melhores condições de crescimento as plantas devido aos incrementos nas variáveis número de folhas, comprimento e massa seca da parte aérea e total.

Palavras-chave: Aminoácidos. *Citrullus lanatus*. Micronutrientes. Cucurbitaceae. Agressive Desperta®.

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INTRODUCTION

Watermelon (*Citrullus lanatus* Thunb.) is a plant species of the Cucurbitaceae family that stands out for its sweet, juicy fruits. The flesh of these fruits is rich in lycopene, a carotenoid with antioxidant activity (MOHAMMED; AL-BAYATI, 2014), and a source of vitamins B, C, and E and minerals, such as phosphorus, magnesium, calcium, and iron (ROMDHANE et al., 2017). The agricultural potential and socioeconomic importance have made the Brazilian watermelon market significantly favorable for this crop, leading traditional growers of other crops to shift or diversify their system by including watermelon production (SOUSA; NUNES; ZONTA, 2019).

A balanced application of fertilizers has become increasingly important in agricultural production; it should include not only macronutrients but also micronutrients and amino acids, which were usually disregarded by most growers in fertilization practices. Additionally, determining the most effective application method is a key factor once the need for these micronutrients and amino acids is established (OHSE et al., 2012). Seed treatment with micronutrients and amino acids, which will be mobilized from seed reserve tissues to the embryonic axis, promote seedling growth and development during germination. The use of micronutrients and amino acids for seed treatment supply elements that support crucial metabolic pathways for plant development, mainly during initial plant growth (SILVA; OLIVEIRA, 2021).

Amino acids applied via seed treatment become part of the soil solution and stimulate plant growth. This application to crops is not focused on supply amino acids for protein synthesis but rather to activate plant physiological metabolism, which is important for reducing stress (DASS et al., 2022). Additionally, they can be precursors of plant hormones, as is the case of tryptophan, a precursor of indole acetic acid (TAIZ et al., 2017), and methionine, a precursor of ethylene (FATMA et al., 2022).

However, applying micronutrients and amino acids via seed treatment alone is insufficient due to the small quantity applied. Therefore, foliar fertilization through spraying assists in the distribution of micronutrients and amino acids, reducing losses compared to soil application (ISHFAQ et al., 2023). Growth stimulants are a promising agricultural technology derived from a blend of plant regulators, minerals, amino acids, and other substances tested across various plant species (LIMA et al., 2021; SILVA; OLIVEIRA 2021).

In this context, the objective of the present study was to evaluate the effects a growth stimulant (micronutrients and amino acids) for seed treatment and foliar application on the initial growth of watermelon (*Citrullus lanatus;* cultivar Crimson Sweet).

MATERIAL AND METHODS

The study was conducted at the experimental area of the School Farm of the Federal Institute Goiano, in Iporá, Goiás, Brazil (16°25'29"S, 51°09'04"W, and altitude of 584 meters), from September to November 2021. The climate of the region was classified as Aw, tropical, with two well-defined seasons (dry and rainy seasons), according to the Köppen classification (ALVARES et al., 2013). Air temperature and rainfall depths during the experimental period are shown in Figure 1.

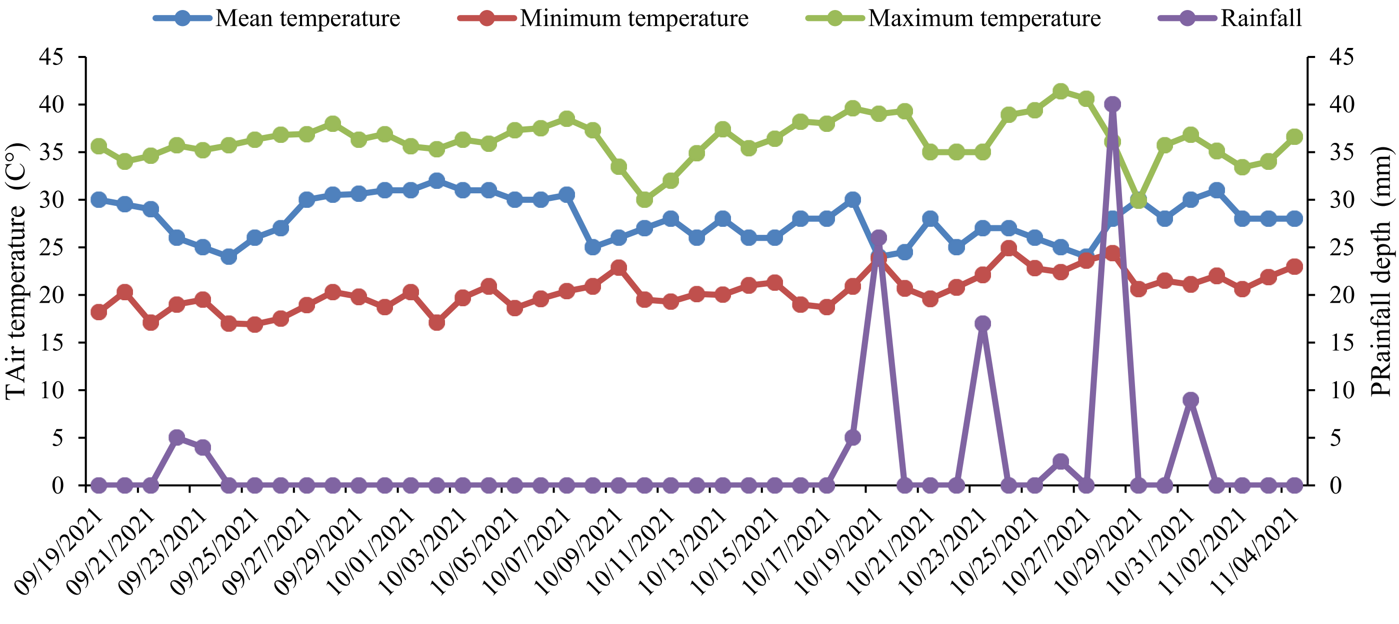

Figure 1. Rainfall depth (mm) and air temperature (°C) in Iporá, GO, Brazil, from September to November 2021.

The experimental area is within the Cerrado biome; the soil was classified as Lithic Quartzipsamment (Neossolo Litólico Distrófico; EMBRAPA, 2018). The soil was prepared using agricultural machinery, starting with soil loosening using a leveling harrow, followed by a rotary hoe. Soil fertilizers were applied at planting based on the soil chemical analysis (Table 1) and recommendations for the crop (EMBRAPA, 2007), using 100 kg ha^{-1} of N, 120 kg ha^{-1} of P_2O_5, and 120 kg ha^{-1} of K_2O. Watermelon seeds of the cultivar Crimson Sweet were sown directly to the planting holes on September 19, 2021.

Table 1. Chemical attributes of the soil used in the experiment.

Soil layer	pH	OM	P_{Mel}	Al^{3+}	H+Al	K	Ca	Mg	S	B	Zn
(cm)	$CaCl_2$	g dm^{-3}	mg dm^{-3}	------------------ cmolc dm^{-3} ------------------					----- mg dm^{-3} ------		
0-20	5.6	16.00	1.5	0.0	2.4	0.4	3.5	1.7	2	0.05	0.7
20-40	4.7	10.00	0.7	0.1	3.4	0.2	1.8	0.9	1	0.03	0.1

OM = organic matter; Mel = P extracted by Mehlich-1.

The seeds were treated using six rates (0, 1, 2, 3, 4, and 5 mL kg^{-1}) of a commercial growth stimulant (Agressive Desperta®; Fertilizer Agrosciences, Altinópolis, Brazil). This growth stimulant was composed of 1.5% sulfur, 0.1% boron, 0.5% cobalt, 0.1% copper, 0.6% manganese, 5% molybdenum, 2% zinc, 5% amino acids (0.69% aspartic acid, 1.68% glutamic acid, 0.89% alanine, 0.67% arginine, 0.01% cysteine, 0.26% phenylalanine, 1.58% glycine, 0.13% histidine, 0.39% isoleucine, 0.41% leucine, 1.56% methionine, 0.18% proline, 0.01% tyrosine, 0.01% ornithine, 0.02% methylhistidine, 0.37% tryptophan, 0.31% serine, 0.31% valine, and 0.22% threonine), 5% algae extract, and 3.7% carboxylic acid, according to the manufacturer.

The preparation of the solution and adjustment of the rates was carried out for 10 g of seeds, using 10 mL of distilled water. Then, 5 mL of the solution was withdrawn, placed in plastic bags together with 200 seeds, and shaken for three minutes to ensure a uniform distribution and coating of the seeds with the product. Treated seeds were then placed on paper towels at room temperature (25 °C) for absorption of the product, following the methodology described by Nunes (2005). Control seeds were moistened with the same volume of distilled water without the product. Seed treatment was carried out on the day of sowing.

A micro-sprinkler irrigation system was used, with daily watering schedule and irrigation time of 1 hour and 15 minutes. Weed control was carried out through manual weeding. Each experimental plot consisted of 200 plants, with spacing of 15 cm between plants and 80 cm between rows, totaling an area of 12 m².

The same growth stimulant product was applied to plant leaves at a rate of 300 mL ha^{-1} 26 days after sowing (DAS). The growth stimulant was applied uniformly via foliar application using a manual sprayer to ensure complete leaf coverage without runoff to the soil. The application was stopped when the leaves were completely covered with the solution. No spreader-sticker was used in the solution.

Four evaluations were carried out with 5-day intervals, starting at 5 days after application. The characteristics assessed in each evaluation were: number of leaves per plant, by counting all fully developed leaves on ten plants per treatment; shoot, root, and total plant lengths (cm) measured on ten plants per treatment, using a tape measure; and shoot, root, and total dry weights. Shoot length was measured from the base to the apex and root length was measured from the base to the root cap; these measurements were summed to obtain the total plant length. Dry weights were determined by washing the plant parts after harvest, drying them in a forced air circulation oven at 60 °C for 48 hours, and weighing them on a digital scale with precision of 0.001 g.

The experiment was conducted in a randomized block design with four replications, using 6×2 factorial arrangement consisted of six growth stimulant rates (0, 1, 2, 3, 4, and 5 mL kg^{-1}) for seed treatment, combined or not with foliar application of the same growth stimulant at a rate of 300 mL ha^{-1} at 26 DAS.

The obtained data were subjected to analysis of variance. When the seed treatment factor was significant, the means of the evaluated characteristics were subjected to polynomial regression, determining the best fit based on a combination of significance and the highest coefficient of determination. Statistical analyses were performed using the SISVAR statistical program (FERREIRA, 2019).

RESULTS AND DISCUSSION

According to the analysis of variance, the interaction effect between the factors (seed treatment and foliar application of growth stimulant) was significant for number of leaves per plant, shoot length, and total plant length in all evaluations (Table 2). The interaction effect was significant on root length in the evaluations at 15 and 20 days after foliar application of the growth stimulant (DAA); however, the seed treatment factor had significant effect in the all evaluations and the foliar application factor had significantly effect on root length in the evaluation at 10 DAS. Shoot dry weight (SDW) and total dry weight (TDW) were significantly affected by the interaction effect in all evaluations, except at 5 DAA. Root dry weight (RDW) was significantly affected by the seed treatment in all evaluations and by the interaction at 20 DAA.

Comparing the number of leaves of plants with or without foliar application in the evaluation at 15 DAA, the means were different for the seed treatment rate of 4 mL kg^{-1}, which resulted in the highest mean (Table 3). Considering plants that were not subjected to foliar application, seed treatment was efficient only in the last evaluation (20 DAA), with the rate of 4 mL kg^{-1} resulting in the highest mean. However, those treated with foliar application were affected by seed treatments in the evaluation at 10 DAA, with the rate of 4 mL kg^{-1} resulting in the highest mean; this dynamic was also found for subsequent evaluations.

Seed treatment is a technique used to improve plant stand uniformity, mainly under no-tillage systems. Products based on amino acids and micronutrients are applied to seeds to enhance the initial performance of plants under field conditions (MONDAL et al., 2015), reduce the incidence of pathogens, and promote a better condition for plant growth and development. Application of amino acids serves not only to supply amino acids for synthesis of proteins but also for activate the plant physiological metabolism, focused on antistress responses (SILVA et al., 2017). Micronutrients such as Mn and Mo are important for increasing plant dry weight (OLIVEIRA et al., 2010), as they are essential for enzyme constitution, electron transport, and photosynthesis, all crucial for plant growth (TAIZ et al., 2017).

Combining foliar application of growth stimulant to plants grown from seeds treated with high growth stimulant rates provided better conditions to watermelon plants few days after application (10 DAA). However, without foliar application, the benefits were observed only at 20 DAA; thus, foliar application is essential for faster growth responses in watermelon plants and improves their resistance to adverse field conditions.

Table 2. Analysis of variance for growth characteristics of watermelon plants of the cultivar Crimson Sweet as a function of seed treatment with different growth stimulant rates, with or without foliar application of 300 mL ha^{-} of growth stimulant 26 days after sowing, evaluated at 5, 10, 15, and 20 days after foliar application (DAA).

Source of variation	DF	Mean square			
		5	10	15	20
		-------- DAA --------			
		Number of leaves plant^{-1}			
Seed treatment (ST)	5	138.9**	151.5**	322.3**	1991.6**
Foliar application (FA)	1	280.1**	92.3**	38.6^{ns}	777.0**
ST × FA	5	65.1**	32.4**	243.2**	425.2**
Block	9	3.6^{ns}	6.7^{ns}	17.9^{ns}	82.9^{ns}
Residue	99	2.9	4.5	22.2	61.7
Total	119				
CV (%)		22.5	26.0	34.7	45.1
		Shoot length			
Seed treatment (ST)	5	801.2**	1520.1**	3475.9**	15629.2**
Foliar application (FA)	1	1639.7**	992.7**	12.9^{ns}	1418.1*
ST × FA	5	438.4**	229.2**	1494.3**	2931.9**
Block	9	16.0^{ns}	73.9^{ns}	53.0^{ns}	136.1^{ns}
Residue	99	23.7	57.3	152.7	316.4
Total	119				
CV (%)		40.0	47.0	46.1	49.0
		Root length			
Seed treatment (ST)	5	162.5**	411.5**	378.5**	783.7**
Foliar application (FA)	1	19.2^{ns}	87.4**	44.1^{ns}	177.2*
ST × FA	5	3.9^{ns}	23.8^{ns}	191.3**	148.9**
Block	9	7.2^{ns}	24.2^{ns}	45.3^{ns}	21.5^{ns}
Residue	99	9.7	16.6	35.3	38.6
Total	119				
CV (%)		27.3	29.7	29.4	30.0
		Total plant length			
Seed treatment (ST)	5	1569.6**	3429.0**	5201.1**	23241.4**
Foliar application (FA)	1	1369.6**	1669.5*	8.9^{ns}	592.5^{ns}
ST × FA	5	469.4**	346.5**	2178.4**	4082.9**
Block	9	15.7^{ns}	144.2^{ns}	55.7^{ns}	135.7^{ns}
Residue	99	34.1	100.6	247.9	421.8
Total	119				
CV (%)		25.0	33.9	33.1	36.0
		Shoot dry weight			
Seed treatment (ST)	5	407249.9**	1065530.1**	4941805.3**	43569493.4**
Foliar application (FA)	1	250185.8**	1224739.4**	2373468.6**	17833056.0**
ST × FA	5	86598.1^{ns}	199430.8**	1493716.4**	4873145.6**
Block	9	5654.9^{ns}	8512.7^{ns}	633425.0^{ns}	3552.6^{ns}
Residue	11	294743.1	41645.1	169928.7	930896.3
Total	23				
CV (%)		28.7	23.3	24.9	26.5
		Root dry weight			
Seed treatment (ST)	5	28.7**	3534.4**	9297.8**	61340.3**
Foliar application (FA)	1	0.66^{ns}	596.0^{ns}	180.4^{ns}	4374.0*
ST × FA	5	2.1^{ns}	1185.3*	1694.5^{ns}	7816.0**
Block	9	0.2^{ns}	35.5^{ns}	466.4^{ns}	150.0^{ns}
Residue	11	1.4	390.4	1033.4	940.9
Total	23				
CV (%)		9.3	29.0	34.0	18.6
		Total dry weight			
Seed treatment (ST)	5	412331.4**	1188806.2**	5377274.8**	48980528.0**
Foliar application (FA)	1	249369.7**	1171300.1**	2415033.9**	21705624.0**
ST × FA	5	86619.2^{ns}	195258.1**	1567142.1**	4433729.2**
Block	9	5593.7^{ns}	9648.1^{ns}	668267.6^{ns}	195120.6^{ns}
Residue	11	29533.2	46154.5	169062.5	772531.9
Total	23				
CV (%)		28.0	22.0	23.5	22.7

DF = degrees of freedom; ** and ^{ns} = significant at 0.01 and not significant; CV = coefficient of variation.

Table 3. Number of leaves per plant (NL) and shoot (SL) and total (TL) lengths of watermelon plants of the cultivar Crimson Sweet, grown from seeds treated (ST) with growth stimulant rates (0, 1, 2, 3, 4, and 5 mL kg^{-1}), with or without foliar application (FA) of 300 mL ha^{-1} of growth stimulant 26 days after sowing, evaluated at 5, 10, 15, and 20 days after foliar application (DAA).

		5 DAA		10 DAA		15 DAA		20 DAA	
	ST	Without FA	With FA	Without FA	With FA	Without FA	With FA	Without FA	With FA
NL	0	5.7 Aab	6.6 Ab	7.0 Ab	6.2 Ac	15.8 Aab	9.2 Bb	12.5 Ab	8.3 Ac
	1	5.9 Aab	5.6 Ab	6.8 Bbc	4.9 Ac	12.2 Abc	12.2 Ac	13.3 Ab	11.8 Ac
	2	2.8 Ab	5.3 Ab	4.1 Bc	6.2 Ac	6.8 Ac	10.0 Ac	9.5 Ab	4.0 Ac
	3	7.4 Aa	9.1 Aab	9.3 Aab	11.0 Ab	11.1 Abc	9.6 Ac	16.2 Bb	28.2 Ab
	4	8.3 Ba	12.8 Aa	9.9 Ba	14.5 Aa	12.5 Bbc	24.7 Aa	28.2 Ba	40.9 Aa
	5	6.2 Bab	9.6 Aab	6.7 Bbc	11.0 Ab	20.2 Aa	14.7 Bb	8.7 Bb	23.7 Ab
SL (cm)	0	6.6 Aa	11.5 Ac	9.4 Aab	8.3 Ac	15.7 Ad	13.2 Ab	18.5 Ab	15.1 Ac
	1	9.6 Aa	8.7 Ac	9.9 Aab	8.1 Ac	28.5 Abc	24.9 Ab	32.2 Ab	10.8 Bc
	2	5.7 Aa	6.5 Ac	5.8 Ac	7.7 Ac	10.0 Acd	17.7 Ab	15.8 Ab	4.3 Ac
	3	10.1 Aa	16.1 Abc	16.2 Aab	22.6 Ab	26.6 Abc	15.4 Bb	26.7 Bb	63.7 Aab
	4	12.7 Ba	26.9 Aa	18.6 Ba	33.4 Aa	31.8 Bb	58.4 Aa	87.0 Aa	87.0 Aa
	5	12.2 Ba	21.4 Aab	18.7 Ba	31.3 Aab	51.7 Aa	27.5 Bb	18.4 Bb	53.7 Ab
TL (cm)	0	19.2 Aab	22.9 Acd	20.3 Abc	19.6 Ac	40.3 Abc	29.3 Ab	39.0 Ab	27.2 Ac
	1	18.9 Aab	17.1 Acd	22.3 Abc	20.0 Ac	46.4 Ab	44.9 Ab	50.4 Ab	24.0 Bc
	2	13.7 Ab	13.9 Ad	12.2 Ac	16.4 Ac	24.2 Ac	37.4 Ab	32.3 Ab	13.7 Bc
	3	22.5 Aab	27.5 Abc	30.7 Aab	35.6 Ab	46.9 Ab	32.4 Bb	48.0 Bb	90.8 Aab
	4	29.3 Ba	41.9 Aa	35.6 Ba	54.2 Aa	56.3 Bab	91.2 Aa	117 Aa	116 Aa
	5	25.8 Ba	36.8 Aab	35.5 Ba	52.4 Aa	67.8 Aa	46.4 Bb	40.0 Bb	74.2 Ab

Means followed by the same lowercase letter in the columns or uppercase letter in the rows, within each variable and evaluation, are not significantly different from each other by the Tukey's test ($p>0.05$).

Silva et al. (2020) evaluated the effects of foliar application of different fertilizer rates, with and without micronutrients, to pineapple cultivars in different seasons and found significant effect of the interaction between foliar application with micronutrients and season. Additionally, they reported a higher number of leaves over the evaluations for plants subjected to foliar application of fertilizer with micronutrients, regardless of the season.

Comparing the mean shoot lengths of plants with and without foliar application, the rate of 4 mL kg^{-1} for seed treatment resulted in higher means for all evaluations, except for the last evaluation. Plants without foliar application were significantly affected by seed treatments only in the last evaluation, denoting the efficiency of the 4 mL kg^{-1} rate. Plants treated with foliar application were affected by seed treatments in the evaluation at 10 DAA; the seed treatment rate of 4 mL kg^{-1} stood out for resulting in the highest mean, with significant difference from the others in the evaluations at 10, 15, and 20 DAA. This denotes the importance of using foliar application, as plants respond faster to this management, presenting higher shoot lengths.

Watermelon production is affected by several factors, including the plant vegetative development, which is vital as it supports the plant by directing and transporting essential substances for its growth (OLIVEIRA et al., 2020). Growth stimulants assist in the expression of the genetic potential upon changes in vital and structural processes, promoting hormonal balance (KOLLING et al., 2016), and act in cell division and stretching processes, increasing the absorption and use of nutrients and affecting several plant metabolism phases.

Growth stimulants contain amino acids that are precursors of plant growth regulators, as tryptophan, a precursor of auxins, which are essential for the synthesis of reserve substances (TAIZ et al., 2017). Plant hormones act as mediators of plant physiological processes, contributing to plant growth and total length; this growth is attributed to stimulus of cell division, differentiation, and stretching by increase plant hormone production. Thus, plants with greater shoot lengths are stronger and more resistant to biotic and abiotic challenges in field conditions.

Oliveira et al. (2023) testing the same growth stimulant (Agressive Desperta®) at different rates for watermelon seed treatments and found a better development of seedlings under laboratory conditions when using a rate of 3 mL kg^{-1}. This denotes the contribution of these growth stimulants during the early stages of plant establishment, resulting in higher growth rates and, consequently, faster plant establishment with a better structure for high yields.

Figure 2 shows the total plant length in the last evaluation, in which the highest mean was found for plants from seeds treated with 4 mL kg^{-1}, however not statistically differing from plants with foliar application (Table 3). Thus, comparing the means of plants with and without foliar application, 4 mL kg^{-1} stans out among the seed treatment rates. Considering the means of plants subjected to foliar application, the increase in plant length from the seed treatment rate of 0 mL kg^{-1} (27.2 cm) to 4 mL kg^{-1} (116.2 cm) was 427%.

Figure 2. Watermelon plants at 46 days after sowing. Plants grown from seeds treated with different growth stimulant rates (0, 1, 2, 3, 4, and 5 mL kg^{-1}), with or without foliar application (FA) of 300 mL ha^{-1} growth stimulant.

Root length at 5 DAA was significantly affected only by the seed treatment factor ($y = 0.1916x^2 + 0.6628x + 7.9582$; $R^2= 0.84$**) (Table 4); treating seeds with growth stimulant rates equal to or higher than 2 mL kg^{-1} resulted in longer roots, with a slight trend to decrease at the highest rate (5 mL kg^{-1}).

An experiment with watermelon seeds treated with different rates of the same growth stimulant (Agressive Desperta®) showed that rates higher than 3 mL kg^{-1} can cause phytotoxicity in seedlings (OLIVEIRA et al., 2023). In the present study, toxic effects were found at 5 DAA for the highest rate (5 mL kg^{-1}). In this sense, studies using growth stimulants are important to provide information on their effects on different crops and ideal concentrations and application timing for achieving better results (LACERDA et al., 2020). Some growth stimulant groups promote root system development, ensuring a good shoot growth and satisfactory plant yields, mainly when they contain precursors of plant hormones that boost fertility, such as auxins, cytokinins, and gibberellins.

Plants from seeds treated with 4 or 5 mL kg^{-1} of growth stimulant presented longer roots at 10 DAA. Moreover, plants in seed treatments with 0 or 2 mL kg^{-1} presented the lowest increases in root length. The mean root length of plants with foliar application was higher than that of plants without foliar application.

The micronutrients in the composition of the growth stimulant used, as Zn, Co, Mo, B, and Mn, have important functions in plant metabolism. Boron is involved in sugar transport, synthesis of RNA, DNA, and phytohormones such as auxin, cell division, and development of tissues. The auxin synthesis occurs in the root apical region; however, the highest concentration is in meristematic regions of growth organs; it also participates in tissue differentiation, cell stretching, and development of organelles. Manganese participates in energetic connections between ATP and the photosynthetic enzyme complex, whereas molybdenum participates as a cofactor of enzymes (TAIZ et al., 2017). This indicates the importance of supplementing fertilizers with amino acids and micronutrients for the growth of watermelon plants, as it provides better conditions to root system development, thus benefiting the entire plant.

Table 4. Root length (cm) of watermelon plants of the cultivar Crimson Sweet grown from seeds treated with growth stimulant rates (0, 1, 2, 3, 4, and 5 mL kg^{-1}), with or without foliar application (FA) of 300 mL ha^{-1} of growth stimulant 26 days after sowing, evaluated at 10 days after foliar application (DAA).

Seed treatment (mL kg^{-1})	Root length (cm)
0	11.1 bc
1	12.2 b
2	7.5 c
3	13.8 b
4	18.9 a
5	18.9 a
Foliar application (300 mL ha^{-1})	
Without	12.9 b
With	14.9 a

Means followed by the same letter in the column are not significantly different from each other by the Tukey's test (p>0.05).

Plants from seeds treated 4 mL kg^{-1} of growth stimulant showed longer roots at 15 DAA, regardless of foliar application (Table 5). However, seed treatment at the highest rate (5 mL kg^{-1}) resulted in a decreased root length, regardless of foliar application. Thus, growth stimulant rates higher than 4 mL kg^{-1} may cause toxicity to plants, directly affecting root growth.

Table 5. Root length (CR) of watermelon plants of the cultivar Crimson Sweet grown from seeds treated with growth stimulant rates (0, 1, 2, 3, 4, and 5 mL kg^{-1}), with or without foliar application (FA) of 300 mL ha^{-1} of growth stimulant 26 days after sowing, evaluated at 15 and 20 days after foliar application (DAA).

	Seed treatment (mL kg^{-1})	15 DAA		20 DAA	
		Without FA	With FA	Without FA	With FA
CR (cm)	0	25.2 Aa	16.2 Bb	20.5 Ab	21.1 Bd
	1	17.9 Aab	19.9 Ab	18.2 Ab	13.2 Acd
	2	14.2 Bb	19.7 Ab	16.5 Ab	9.3 Bd
	3	20.4 Aab	17.4 Ab	21.1 Bb	27.1 Aab
	4	24.5 Ba	32.8 Aa	30.2 Aa	29.9 Aa
	5	16.1 Ab	18.8 Ab	21.6 Ab	20.5 Abc

Means followed by the same lowercase letter in the columns or uppercase letter in the rows, within each variable and evaluation, are not significantly different from each other by the Tukey's test (p>0.05).

It is essential to carefully manage foliar application rates of micronutrient fertilizers, as excessive rates can cause nutritional imbalances and reduce crop quality and yield (DAS, 2014). Plant toxicity occurs when an excess of one or more nutrients is absorbed, leading to delays in physiological functions that can be lethal. Zinc has a narrow range between its beneficial and toxic effects compared to other micronutrients (MALAVOLTA, 2006). Zinc phytotoxicity can reduce shoot and root biomass production and inhibit plant growth (MORAES, 2020).

The seed treatment rate of 4 mL kg^{-1} resulted in the highest shoot and total dry weights at 5 DAA (Table 6). Foliar application promoted watermelon plant development more effectively than the absence of foliar application of growth stimulant.

Shoot and total dry weights presented similar results at 10 DA (Table 7). Plants from seeds treated with 4 mL kg^{-1} of growth stimulant presented the highest means. Comparing the treatments with and without foliar application, those with foliar application showed positive effects only when combined with seed treatments at 4 and 5 mL kg^{-1}; the rate of 4 mL kg^{-1} resulted in the highest mean.

The mean shoot and total dry weights of plants subjected to foliar application presented significant differences at 15 DAA. Plants without foliar application presented similar results at 5 DAA. Considering plants with foliar application, the seed treatment with 4 mL kg^{-1} resulted in the highest mean shoot and total dry weights.

The effect of seed treatment with rates equal to or higher than 3 mL kg^{-1} was significant at 20 DAA for shoot dry weight of plants without foliar application. Plants with foliar application presented significant difference in mean shoot dry weight, regardless of the seed treatment rate; the highest mean was found for the rate of 4 mL kg^{-1}. Plants from seeds treated with 4 mL kg^{-1} and subjected to foliar application had a mean shoot dry weight 19 times higher than plants without seed treatment. Zn, applied through the growth stimulant, may have promoted endogenous synthesis of indole-3-acetic acid (mainly in the stem apex), which was partly used for shoot growth (MELLO; SANTOS; OSHE, 2021), contributing to the increase in dry weight accumulation in watermelon plants.

Table 6. Shoot total dry weights (mg plant^{-1}) of watermelon plants of the cultivar Crimson Sweet grown from seeds treated with growth stimulant rates (0, 1, 2, 3, 4, and 5 mL kg^{-1}), with or without foliar application of 300 mL ha^{-1} of growth stimulant 26 days after sowing, evaluated at 5 days after foliar application (DAA).

Seed treatment (mL kg^{-1})	Shoot dry weight	Total dry weight
0	347.6 c	360.4 c
1	498.3 bc	508.6 bc
2	171.8 c	181.4 c
3	764.6 ab	776.1 ab
4	1034.5 a	1049.8 a
5	789.3 ab	805.4 ab
Foliar application (300 mL ha^{-1})		
Without foliar application	498.9 b	511.7 b
With foliar application	703.1 a	715.5 a

Means followed by the same letter in the columns are not significantly different from each other by Tukey's test (p>0.05).

Table 7. Shoot (SDW) and total (TDW) dry weights (mg plant^{-1}) of watermelon plants of the cultivar Crimson Sweet grown from seeds treated (ST) with growth stimulant rates (0, 1, 2, 3, 4, and 5 mL kg^{-1}), with or without foliar application of 300 mL ha^{-1} of growth stimulant 26 days after sowing, evaluated at 10, 15, and 20 days after foliar application (DAA).

	ST	10 DAA		15 DAA		20 DAA	
		Without FA	With FA	Without FA	With FA	Without FA	With FA
SDW	0	383.2 Ab	547.7 Acd	774.8 Abc	892.6 Ac	188.0 Ab	542.0 Ac
	1	740.9 Aab	682.4 Acd	1383.2 Aabc	1317.4 Abc	144.0 Bb	4454.0 Ab
	2	109.4 Ab	327.7 Ad	221.8 Ac	994.4 Ac	156.0 Ab	88.0 Ac
	3	761.1 Aab	1154.3 Abc	1702.9 Aabc	955.8 Ac	3383.0 Bab	5965.0 Ab
	4	1096.1 Ba	2128.3 Aa	2242.2 Ba	5048.9 Aa	6094.0 Ba	10166.0 Aa
	5	789.8 Bab	1750.9 Aab	1705.8 Aabc	2595.3 Ab	6650.0 Aa	6044.0 Ab
TDW	0	426.4 Ab	572.1 Acd	823.5 Abc	949.2 Ac	214.0 Ac	262.0 Ac
	1	805.2 Aab	731.8 Acd	1485.6 Aabc	1377.0 Abc	178.0 Ab	4686.0 Ab
	2	142.7 Ab	364.3 Ad	254.5 Ac	1063.9 Ac	186.0 Ac	102.0 Ac
	3	835.2 Aab	1232.3 Abc	1804.6 Abc	1010.1 Ac	3605.0 Bb	6218.0 Ab
	4	1235.3 Ba	2197.5 Aa	2401.9 Ba	5241.3 Aa	6368.0 Bab	10449.0 Aa
	5	867.1 Bab	1858.8 Aab	1807.2 Bab	2742.4 Ab	6972.0 Aa	7218.0 Ab

Means followed by the same lowercase letter in the columns or uppercase letter in the rows, within each variable and evaluation, are not significantly different from each other by the Tukey's test (p>0.05).

According to Mattos and Caires (2022) increases in total plant dry weight promote the crop initial development and increase plant resistance to abiotic stress at the beginning of the vegetative stage. Mello, Santos, and Oshe (2021) found positive effects of different growth stimulants on shoot dry weight of maize seedlings.

In the final evaluation (20 DAA), the means of total dry weight in treatments without foliar application were similar to those found for shoot dry weight. Plants with foliar application presented significant different means, and the seed treatment with 4 mL kg^{-1} resulted in the highest means and in a positive increase that was 40 times higher compared to plants without seed treatment. Thus, foliar application is essential to increase watermelon nutritional quality and improve metabolic processes that demand energetic resources through respiration, as it provides substances that are readily metabolized and incorporated and, therefore, converted in dry weight.

Root dry weight evaluated at 5 DAA was significantly affected only by seed treatments ($y = 0.3643x^2 - 0.4586x + 9.9571$, $R^2= 0.91^{**}$). The growth stimulant rates equal to or higher than 3 mL kg^{-1} resulted in longer roots, with a trend of stabilization at higher rates (4 and 5 mL kg^{-1}). Considering the evaluation at 15 DAA, the plants were significant affected only by seed treatments ($y = 3.9018x^2 + 4.4111x + 44.839$, $R^2= 0.73^{**}$); the rate of 4 mL kg^{-1} resulted in a higher increase in root dry weight than lower rates. Contrastingly, the rate of 5 mL kg^{-1} resulted in decreases in root dry weight.

Root dry weight evaluated at 10 DAA was not significantly affected by seed treatments; only the rate of

4 mL kg^{-1} presented difference between treatments with and without foliar application (Table 8). In the evaluation at 20 DAA, root dry weight was significantly different between plants with and without foliar application and between the seed treatments with 3, 4, and 5 mL kg^{-1} of growth stimulant (Table 8). According to Mello, Santos, and Oshe (2021), part of the zinc absorbed by plants is translocated via phloem parenchyma cells undergoing differentiation to the root system, where it affects cell division and stretching and root geotropism. The application of bioestimulantes during the early plant developmental stages results in a fast and uniform root growth and plant establishment, improving absorption of nutrients and crop yield (GUERRA et al., 2023).

Table 8. Root dry weight (mg plant^{-1}) of watermelon plants of the cultivar Crimson Sweet grown from seeds treated with growth stimulant rates (0, 1, 2, 3, 4, and 5 mL kg^{-1}), with or without foliar application of 300 mL ha^{-1} of growth stimulant 26 days after sowing, evaluated at 10 and 20 days after foliar application (DAA).

	Seed treatment (mL kg^{-1})	10 DAA		20 DAA	
		Without FA	With FA	Without FA	With FA
Root dry weight	0	43.2 Ab	24.4 Ab	26.0 Ab	20.0 Ab
	1	64.3 Ab	49.4 Aab	34.0 Bb	232.0 Aa
	2	33.3 Ab	36.6 Ab	30.0 Ab	14.0 Ab
	3	74.1 Aab	84.1 Aab	222.0 Aa	253.0 Aa
	4	139.2 Aa	69.2 Bab	274.0 Aa	283.0 Aa
	5	77.3 Aab	107.9 Aa	322.0 Aa	268.0 Aa

Means followed by the same lowercase letter in the columns or uppercase letter in the rows, within each variable and evaluation, are not significantly different from each other by the Tukey's test (p>0.05).

Sousa et al. (2020) found increases in root volume and dry weight of watermelon plants (Crinson Sweet cultivar) subjected to application of growth stimulant (Viusid-Agro). Guerra et al. (2023) evaluated the effect of a growth stimulant (Stimulate®) on bell pepper seeds and found increases of 62.50% and 20.58% for shoot and root dry weights, respectively, compared to the control, when using a concentrated solution of 8.0 mL L^{-1}. Lima et al. (2021) found greater expansion of the root system in melon crops when using the highest evaluated rate of Stimulate® (4.8 L ha^{-1}).

Thus, the results of the present study show the importance of applying growth stimulants focused on improving the performance of watermelon plants. Growth stimulants make possible a lower response time of plants when under abiotic stress conditions, as climate conditions during the early stages of plant establishment in the field can negatively affect the stand and compromise the success of the crop. Moreover, studies on combining application of amino acids via seed treatment and foliar application are essential to improve the understanding of plant initial growth and crop yield, which should be further investigated.

CONCLUSION

The growth stimulant (Agressive Desperta®) rate applied at 4 mL kg^{-1} as seed treatment for growing watermelon plants (Crimson Sweet cultivar), combined with its foliar application at 300 mL ha^{-1} 26 days after sowing, resulted in better conditions for plant growth by increasing the number of leaves, shoot length, and shoot dry and total weights.

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