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Productivity and postharvest quality of 'Crimson Sweet' watermelon using *Lithothamnium*

Abstract – The objective of this work was to evaluate the production and postharvest quality of watermelon fruit using *Lithothamnium* with different formulations, rates, and application intervals and methods. The experiment was conducted in a Brazilian commercial watermelon farm, in a randomized complete block design, with ten treatments, one control, and four replicates. Marketable fruits were harvested 90 days after sowing and counted. The fruits were measured for fresh mass, productivity, length, diameter, pulp thickness and firmness, and peel thickness. Moreover, pulp characteristics, such as firmness, pH, total sugar content, soluble solids content, and titratable acidity, were evaluated. Most variables did not differ significantly, but variations were observed in peel thickness, pulp firmness, pH, total sugars, soluble solids, and titratable acidity. Notably, the use of *Lithothamnium* nanoparticles via fertigation positively affected watermelon yield (36.20 Mg ha^{-1}). Additionally, all *Lithothamnium* treatments resulted in thicker peels (1.74 to 2.10 cm), firmer pulps (10.78 N), and higher SS/TA ratios (46.00 to 73.25%) compared with the control treatment. Therefore, *Lithothamnium* emerges as a viable alternative to synthetic calcium and magnesium inputs, enhancing fruit postharvest quality.

Index terms: *Citrullus lanatus*, algae, fertigation.

Produtividade e qualidade pós-colheita de melancia 'Crimson Sweet' com uso de *Lithothamnium*

Resumo – O objetivo deste trabalho foi avaliar a produção e a qualidade pós-colheita de frutos de melancieira com uso de *Lithothamnium*, com diferentes formulações, doses, e intervalos e métodos de aplicação. O experimento foi conduzido em uma fazenda comercial brasileira de melancia, em delineamento em blocos ao acaso, com dez tratamentos, um controle e quatro repetições. Os frutos comercializáveis foram colhidos 90 dias após a semeadura e contados. Os frutos foram avaliados quanto à massa fresca, à produtividade, a comprimento, a diâmetro, à espessura e à firmeza da polpa, e à espessura da casca. Além disso, foram avaliadas as características da polpa, como firmeza, pH, teor de açúcares totais, teor de sólidos solúveis e acidez titulável. A maioria das variáveis não apresentou diferenças significativas, mas foram observadas variações na espessura da casca, na firmeza da polpa, no pH, nos açúcares totais, nos sólidos solúveis e na acidez titulável. Notavelmente, o uso de *Lithothamnium* em nanopartículas via fertirrigação teve efeito positivo no rendimento da melancia (36,20 Mg ha^{-1}). Além disso, todos os tratamentos com *Lithothamnium* resultaram em maior espessura da casca (1,74 a 2,10 cm), firmeza da polpa (10,78 N) e relação SS/AT (46,00 a 73,25%), em comparação com o tratamento controle. Dessa forma, o *Lithothamnium* surge como uma alternativa viável aos insumos sintéticos à base de cálcio e magnésio, ao melhorar a qualidade pós-colheita dos frutos.

Termos para indexação: *Citrullus lanatus*, algas, fertirrigação.

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Introduction

Watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] is a cucurbit cultivated extensively worldwide, with a significant production in countries such as China, Turkey, and India (FAO, 2022). Brazil holds the fourth position in global production, with the Northeast region being a notable contributor, yielding approximately 669,302 tons in 2022 (IBGE, 2022). In this region, key-producing states include Rio Grande do Norte, Bahia, and Pernambuco, which produced 204,158, 195,456, and 110,654 tons, respectively (IBGE, 2022).

Watermelon cultivation requires a simplified management, which results in a reduction in production costs and in a consequent high socio-economic significance, benefiting small and medium-sized producers (Guerra & Frigoni, 2021). Allied to this, the escalating global consumption of this fruit has encouraged farmers to adopt technological advancements to enhance productivity and postharvest fruit quality, which involves meticulous crop management, consideration of environmental factors, and cost-reduction strategies (Spagnol et al., 2018). In this sense, ensuring a superior postharvest fruit quality, a pivotal determinant of product excellence, has transitioned from a mere advantage to a fundamental market requirement (Spagnol et al., 2018; Valenzuela, 2023).

Among the economically viable and environmentally friendly options for agricultural practices, organic sources have emerged recently, fully replacing or supplementing synthetic chemical fertilizers. Of these alternatives, organic matter from natural sources serves as a promising fertilizer, mitigating the need for synthetic inputs into soils and plants (Syed et al., 2021). In the coastal regions of France, England, and Ireland, calcareous algae have a historical precedence as corrective materials, particularly in ameliorating acidic or calcium-deficient soils (Dias, 2023). In Brazil, the abundant presence of calcareous algae along the North-Northeast continental shelf of the country has been documented since the 1960s by researchers from the oceanographic institute of Universidade Federal de Pernambuco (Dias, 2000).

Lithothamnium, a seaweed-derived product, stands out for its high calcium and magnesium content, in addition to offering more than 20 trace elements in varying proportions, contributing to a robust plant development (Ramos et al., 2023). This contribution enhances hectare-based yield, reducing input requirements, restoring plant organic equilibrium, facilitating nutrient absorption, bolstering pest and disease resistance, fostering microbial flora, neutralizing soil acidity, improving photosynthetic activity, and, consequently, increasing fruit production and quality (Dias, 2000).

The objective of this work to evaluate the production and postharvest quality of watermelon fruit using *Lithothamnium* with different formulations, rates, and application intervals and methods.

Materials and Methods

The experiment was carried out at a commercial watermelon farm, located in the municipality of Mossoró, in the state of Rio Grande do Norte, Brazil (4°54'28"S, 37°24'06"W). According to Köppen's classification, the climate of the region is of the BSWh type, which stands for hot and dry conditions, with an irregular rainfall, with an annual average of 675.8 mm (Alvares et al., 2013).

Soil samples were collected and sent for analysis, which showed the following chemical characteristics: pH in water (1: 2.5) 7.7, pH in $CaCl_2$ 6.8, 10 g kg^{-1} organic matter, sum of bases of 36.7 $cmol_c$ dm^{-3}, cation exchange capacity of 44.7 $cmol_c$ dm^{-3}, 2.4 $cmol_c$ dm^{-3} Ca, 0.7 $cmol_c$ dm^{-3} Mg, 0.36 $cmol_c$ dm^{-3} K, 49 mg dm^{-3} Na, and 100 mg dm^{-3} P.

For the experiment, seeds of the Crimson Sweet cultivar were germinated in polystyrene trays and supplemented with the Pole commercial organic compost (Nibrafértil, Mossoró, RN, Brazil). Eight days after sowing, seedlings were transplanted to the field under a double-sided plastic mulch, with a white top layer and a black bottom layer. The seedlings were then covered with a nonwoven fabric until 28 days after transplanting. Plants were spaced at 2.0x0.5 m, with each plot/replicate consisting of 12 plants.

The soil was tilled using the plowing, harrowing, and furrowing techniques. The rows were spaced 2.0 m apart, and the furrows were approximately 20 cm deep. Fertilization consisted of 98.5 kg urea, 57.5 kg potassium sulfate, 370 kg potassium nitrate, 64 kg magnesium sulfate, 10 kg boric acid, 80 kg ammonium monophosphate, 160 kg PeKacid (ICL Group Ltd., Tel Aviv, Israel), and 35 kg ExtraHumus (Ecofertil,

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Mossoró, RN, Brazil) per hectare. The fertilizers applied in the planting furrows were incorporated using a rotary hoe, and topdressing fertilizers were applied through weekly fertigation.

High-frequency drip irrigation was used. The emitters were spaced 0.40 m apart and operated at a pressure of 1.5 kgf cm^{-2} and flow rate of 3.5 L h^{-1}, following the manufacturer's specifications. Furthermore, when necessary, phytosanitary control was carried out using fungicides and insecticides duly registered for the crop.

The experimental design was a randomized complete block, with ten treatments (T2 to T11), one control (T1), and four replicates. The treatments consisted of the application of *Lithothamnium* in micronized powder, concentrated suspension, and nanoparticle formulations at different rates and times (Table 1). The concentrated suspension and micronized powder of *Lithothamnium* were obtained from the Valeagro company (Petrolina, PE, Brazil), whereas the nanoparticles consisted of the micronized powder milled according to the method described by Negreiros et al. (2023). This product was chemically analyzed, containing 25% calcium in the form of calcium oxide (CaO), 3.4% magnesium in the form of magnesium oxide (MgO), and 16.25% silica and insoluble components. The control treatment corresponded to the standardized watermelon cultivation and management practices for the state of Rio Grande do Norte. The treatments were applied, as follows: T1, according to the producer's standard (control); T2, T3, T4, T5, T6, and T7, via fertigation; and T8, T9, T10, and T11, by spraying. The experimental unit was represented by one fruit.

Fruits were harvested 90 days after sowing. The marketable ones were counted per plot, and two fruits from each plot were collected for postharvest analyses, totaling eight fruits per treatment.

The fruits were evaluated for the following characteristics: fruit number, by counting the fruits within the useful plot area, expressed as fruits per hectare; fruit fresh mass (g), determined by weighing each fruit per treatment individually on a semi-analytical balance; and productivity (Mg ha^{-1}), obtained by counting and weighing the commercially accepted fruits from each treatment, i.e., those that met quality standards.

Fruit length and diameter, peel thickness, and pulp thickness (cm) were determined using a digital caliper. To obtain peel thickness, the distance between the epicarp (peel) and the mesocarp layers were measured. For pulp thickness, the fruit was divided lengthwise into two parts, and the thickness of the endocarp was measured on each side.

Pulp firmness was determined using the FT 327 fruit firmness tester (T.R. Turoni Srl, Frolí, Italy), equipped with a conical tip probe with an 8.0 mm diameter. Each watermelon fruit was cut lengthwise, and readings were taken equidistantly on each of the equatorial halves, resulting in two readings per fruit. The results, originally recorded in pounds, were converted into Newton using a conversion factor of 4.45 (Negreiros et al., 2023).

Table 1. Treatments with *Lithothamnium* (*Lit.*) applied to 'Crimson Sweet' watermelon (*Citrullus lanatus*) plants using different formulations and application times and rates (whole or fractioned), as well as the control.

Treatment[1]	Formulation	Application form	Time of application (DAS)[2]	Rate (kg or L ha^{-1})
T1	Control (producer's standard)	-	-	-
T2	*Lit.* micronized powder	Via fertigation	10	50
T3	*Lit.* micronized powder	Via fertigation	10 and 20	25 + 25
T4	*Lit.* concentrated suspension	Via fertigation	10	10
T5	*Lit.* concentrated suspension	Via fertigation	10 and 20	5 + 5
T6	*Lit.* nanoparticles	Via fertigation	10	1
T7	*Lit.* nanoparticles	Via fertigation	10 and 20	0.5 + 0.5
T8	*Lit.* nanoparticles	By spraying	10	1
T9	*Lit.* nanoparticles	By spraying	10 and 20	0.5 + 0.5
T10	*Lit.* concentrated suspension	By spraying	10, 20, and 30	1 + 1 + 1
T11	*Lit.* concentrated suspension	By spraying	30 and 50	1.5 + 1.5

[1]Days after sowing (DAS).

For the analyses of the chemical characteristics, the samples extracted from the edible fraction (pulp) of the fruit were used. After being processed in a blender, the samples were evaluated for pH, total sugars, soluble solids, and titratable acidity.

pH was measured using the mPA-210 pH meter (MS Tecnopon Equipamentos Especiais Ltda, Piracicaba, SP, Brazil), which was properly calibrated with pH 7.0 and pH 4.0 buffer solutions. Aliquots of 5.0 g of the extract were diluted in 50 mL distilled water. The measured data were expressed as real pH values.

Total sugars (%) were determined using the Anthrone method ($C_4H_{10}O$). An extract was obtained from aliquots of 0.5 g of each sample, which were diluted in a 100 mL volumetric flask, and then filtered through grade 1 qualitative Whatman filter paper. Subsequently, 50 µL of the extract and 950 µL distilled water were mixed in a test tube and placed in an ice bath, after which the Anthrone reagent was added. The tubes were stirred and then heated in a boiling water bath for 8 min before being cooled to room temperature in an ice water bath. Readings were taken using a spectrophotometer at 620 nm.

Soluble solid content (%) was measured with the RTDS-28 digital refractometer (Instrutherm Instrumentos de Medição, São Paulo, SP, Brazil), equipped with automatic temperature compensation, ranging from 0 to 45%. Two samples of the extract were evaluated per replicate.

Titratable acidity was determined in duplicate by titrating the watermelon extract with a 0.1 N NaOH solution; the results were expressed as percentage of citric acid. The soluble solids/titratable acidity (SS/TA) ratio (%) was calculated as the quotient of the soluble solids and titratable acidity values.

The experiment was repeated, and the data obtained for all studied variables were subjected to Shapiro-Wilk's and Hartley's tests ($\alpha = 0.05$) to check for normality and homoscedasticity, respectively. Independence of errors was verified using a standardized residual plot. The data met the assumptions and, therefore, were subjected to the one-way analysis of variance using the Assistat statistical software, version 7.7 (Silva & Azevedo, 2016). When the treatment data showed significant differences according to the F-test, at 5% probability, means were compared by Scott-Knott's test.

Results and Discussion

No statistical difference was observed for fruit number, mass, and productivity when *Lithothamnium* was applied at different intervals and rates (Table 2).

The fruits harvested from plants fertilized with *Lithothamnium* did not differ significantly from those of the control. However, the average number of fruits produced per hectare was 14.63% higher in the treatments with the addition of *Lithothamnium*. Among these treatments, the concentrated suspension and nanoparticle formulations applied via spraying showed the highest averages, ranging from 11,750 in T11 to 12,750 fruits per hectare in T8 and T10. Furthermore, average fruit weight (3.53 kg) and productivity (36.20 Mg ha^{-1}) were higher in treatment T6, in which the full rate of *Lithothamnium* nanoparticles was applied via fertigation.

Previous research indicates favorable responses of watermelon to calcium and magnesium applications, which significantly influence fruit production and quality (Andrade Júnior et al., 2007). In other fruit species, such as red pitahaya [*Hylocereus undatus* (Haw.) Britton & Rose], the incorporation of *Lithothamnium*-type bioclastic granules enhanced substantially fruit number and productivity (Costa et al., 2015). Similarly, onion (*Allium cepa* L.) and melon (*Cucumis melo* L.) crops treated with *Lithothamnium* showed an increased fruit production and yield in the studies of Mógor et al. (2021) and Negreiros et al. (2023), respectively. In this line, Negreiros et al. (2023) and Simões et al. (2022) reported an increase of 17 and 20% in the productivity of yellow melon and 'Palmer' mango (*Mangifera indica* L.), respectively, with the use of *Lithothamnium*. However, when *Lithothamnium* sp. was used as a source of calcium and magnesium in combination with potassium, negative effects were observed on carrot (*Daucus carota* L.) yield, which was reduced in approximately 31% (Rodrigues Neto et al., 2021). Therefore, fruit productivity may be influenced by the applied rates and interactions between the components of the agricultural system (Ramos et al., 2023).

A significant effect was observed for peel thickness when *Lithothamnium* was applied at different intervals and rates to the watermelon plants. However, no statistical difference was observed for fruit length and diameter (Table 2).

Peel thickness was 2.10 cm in treatments T7 and T8 and 2.06 cm in T11, representing increases of 25 and 22.6% in comparison with the value of 1.68 cm obtained in T1 (control). Differences in the thickness of the fruit peel can be attributed to its anatomical and physiological characteristics. The cells of the peel serve primarily a protective function, characterized by smaller cells and a larger cell wall (Zhang et al., 2019). The formation and maintenance of the cell-wall structure is affected by calcium, which directly influences the thickness and strength of the fruit skin, increasing its resistance against physical damage. Therefore, the primary purpose of using *Lithothamnium* is to supply the necessary calcium for an efficient fruit development. Negreiros et al. (2023) also reported comparable results in melon fruit treated with *Lithothamnium*, which showed thicker peels than the control group.

Statistical differences were found for pulp firmness, pH, total sugars, soluble solids, and total acidity; the exceptions were pulp thickness and the SS/TA ratio (Table 3).

Watermelon pulp firmness was 10.78 N in treatment T4, in which the full rate of *Lithothamnium* was applied in concentrated suspension via fertigation; this value was 33.6% greater than that of 8.07 N in T1, the control. Furthermore, the averages obtained for all *Lithothamnium* treatments were higher than those of the control. This could be attributed to a possible increase in the contact surface area of the plant root system due to the application of *Lithothamnium*, which probably enhanced the use of fertilizers by the roots, leading to a greater solubilization and absorption of nutrients and a consequent increase in firmness (Negreiros et al., 2023). Previous research on melon and watermelon also indicated a positive relationship between an increased pulp firmness, higher calcium levels, and the use of *Lithothamnium* (Silva, 2016; Negreiros et al., 2023). Santos et al. (2014) associated a good firmness with the appropriate stage of ripeness for marketing watermelon, meaning that this is a crucial characteristic for fruit export, among others. Additionally, firmness can have a synergistic effect on other sensory attributes such as aroma, color, and flavor, while also influencing shelf life, transportability, resistance to shearing, and susceptibility to attack by phytopathogens, as well as consumer acceptability (Paiva et al., 2009).

An efficient mean to evaluate fruit quality is by monitoring fruit pH, soluble solids, and titratable acidity (Chitarra & Chitarra, 2005).

The pH values of the plants in the treatments with *Lithothamnium* ranged from 5.46 to 5.61, not differing

Table 2. Means and mean test results for fruit number, fruit fresh mass (FFM), productivity, fruit length, fruit diameter, and peel thickness as a function of the application interval and whole or fractioned rates of *Lithothamnium* in 'Crimson Sweet' watermelon (*Citrullus lanatus*) plants[(1)].

Treatment[(2)]	Fruit number (ha)	FFM (kg)	Productivity (Mg ha^{-1})	Fruit length (cm)	Fruit diameter (cm)	Peel thickness (cm)
T1	10,250a	3.48a	35.64	19.65a	18.23a	1.68b
T2	10,750a	2.77a	28.37	17.56a	16.56a	1.74ab
T3	11,000a	3.09a	31.71	18.45a	17.43a	1.90ab
T4	11,000a	3.18a	32.64	19.01a	17.25a	1.96ab
T5	12,250a	3.36a	34.42	18.86a	17.49a	1.86ab
T6	11,250a	3.53a	36.20	19.95a	18.14a	1.95ab
T7	11,750a	3.40a	34.84	19.22a	17.79a	2.10a
T8	12,750a	3.31a	33.95	19.56a	18.29a	2.10a
T9	12,250a	3.48a	35.71	19.61a	18.33a	2.00ab
T10	12,750a	3.43a	35.17	19.79a	17.90a	2.04ab
T11	11,750a	3.35a	34.30	19.34a	18.01a	2.06a
LSD[(3)]	3,910	1.30	-	3.13	2.53	0.38
CV[(4)] (%)	13.80	23.56	-	9.85	8.60	11.79

[(1)]Means followed by equal lowercase letters, within the column, do not differ significantly from each other by Tukey's test, at 5% probability. [(2)]T1, producer's standard (control); T2, T3, T4, T5, T6, T7, product applied by fertigation; and T8, T9, T10, T11, product applied by spraying. [(3)]Least significant difference. [(4)]Coefficient of variation.

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significantly from each other, but were lower than that of 5.78 obtained for the control. pH is widely used to evaluate the postharvest quality of fruit due to its easy and rapid analysis. According to Negreiros et al. (2023), the observed stability in pH is attributed to the predominance of certain acids in the vacuolar sap of fruit cells; these acids are categorized as di- and tri-basic, have multiple pK values, and show a significant buffering capacity over a broad pH range, in addition to a higher pH than the vacuole. Similar pH values were also reported by other authors for cultivars Audrey and Shapah in Syria (Massri & Labban, 2014), as well as for the Extasy seedless triploid in Brazil (Silva, 2016).

Chitarra & Chitarra (2005) concluded that pH acts as a general indicator of the acidity of food and fruit, in inversely proportional values, i.e., the lower the pH, the higher the acidity. This finding was consistently observed in the present study. Similarly, when evaluating the Crimson Sweet cultivar, Lima Neto et al. (2010) highlighted that both pH and acidity are distinguishing features for the fresh market and for industrial processing in the region of Mossoró.

Regarding total sugars, all treatments with *Lithothamnium* applied via spraying exhibited the highest values, i.e., 8.08% in T8, 7.91% in T11, 7.70% in T10, and 7.58% in T9 when compared with that of 6.24% of T1, the control. Similar findings were reported by Barros et al. (2012) and Silva (2016), who observed approximate values of total sugars in watermelon with the application of a nitrogen fertilizer and a biofertilizer composed of *Lithothamnium*, respectively.

In terms of soluble solids, the values obtained for the fruits of the plants fertilized with *Lithothamnium* nanoparticles applied at the full rate either via fertigation (T6 = 10.38%) or via spraying (T9 = 10.10%) did not differ significantly from that of the control (T1 = 10.81%). Soluble solids are an important criterion for evaluating watermelon quality, representing an indirect measure of the concentration of sugars in the fruit pulp (Barros et al., 2012). The results obtained for soluble solids in the present study were similar to those above 9.0%, within the acceptable standard for the foreign market, reported by Silva (2016) when applying different rates and forms of a biofertilizer to watermelon. Therefore, all of these values align with the ideal range for the consumer market.

Total acidity was higher in the treatment with *Lithothamnium* applied in concentrated suspension at a fractional rate via spraying, that is, in T11 (0.227% of citric acid). The presence of organic acids and their acidity levels are fundamental attributes that influence fruit flavor. De Paula et al. (2018) found that this acidity typically decreases as the fruit ripens, due to either the respiratory process or its conversion into sugars.

Table 3. Means and mean test results for pulp thickness (PuT), pulp firmness (PuF), potential of hydrogen (pH), total sugars (TS), soluble solids (SS), total acidity (TA), and the SS/TA ratio as a function of the application interval and whole or fractioned rates of *Lithothamnium* in 'Crimson Sweet' watermelon (*Citrullus lanatus*) plants[(1)].

Treatment[(2)]	PuT (cm)	PuF (N)	pH	TS (%)	SS	TA (% of citric acid)	SS/TA ratio
T1	14.62a	8.07b	5.78a	6.24abc	10.81a	0.165bcde	43.63a
T2	13.76a	8.69ab	5.61b	3.96e	9.33c	0.136de	73.25a
T3	14.16a	9.04ab	5.54b	4.10de	9.46c	0.130e	46.00a
T4	13.84a	10.78a	5.59b	4.72cde	9.61bc	0.177bcde	56.00a
T5	13.46a	9.18ab	5.54b	5.08cde	9.58c	0.195ab	59.13a
T6	14.75a	8.50ab	5.61b	6.03bcd	10.38ab	0.177bcde	66.25a
T7	14.58a	9.25ab	5.46b	6.01bcd	9.76bc	0.146cde	69.50a
T8	14.62a	9.32ab	5.46b	8.08a	9.98bc	0.159bcde	54.50a
T9	14.44a	9.32ab	5.54b	7.58ab	10.10abc	0.188abc	54.50a
T10	13.94a	9.11ab	5.51b	7.70ab	9.44c	0.185abcd	55.38a
T11	14.25a	8.55ab	5.53b	7.91ab	9.44c	0.227a	48.63a
LSD[(3)]	2.25	2.31	0.15	1.96	0.78	0.05	37.25
CV[(4)] (%)	9.54	15.33	1.67	13.12	4.78	12.00	39.42

[(1)]Means followed by equal lowercase letters, within the column, do not differ statistically from each other by Tukey's test, at 5% probability. [(2)]T1, producer's standard (control); T2, T3, T4, T5, T6, T7, product applied by fertigation; and T8, T9, T10, T11, product applied by spraying. [(3)]Least significant difference. [(4)]Coefficient of variation.

Although the treatments did not differ significantly from each other, those with the addition of *Lithothamnium* showed the highest averages for the SS/TA ratio. This ratio is widely recognized as a crucial tool for evaluating fruit flavor, surpassing simple measurements of sugars or acidity alone. The SS/TA ratio provides a balanced assessment between these two elements, establishing a minimum level of soluble solids and a maximum level of acidity to offer a more accurate perception of flavor (Chitarra & Chitarra, 2005).

Conclusion

The application of *Lithothamnium* does not influence the production of watermelon (*Citrullus lanatus*), but improves the postharvest quality of the fruits and, therefore, can be a substitute for synthetic calcium- and magnesium-based inputs.

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