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Enhancing melon production and quality through the application of '*Lithothamnium*'

Melhorando a produção e a qualidade de melão através da aplicação de '*Lithothamnium*'

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ABSTRACT - In Brazil, melon production is distinguished by its superior quality. One of the major challenges in this sector lies in the use of fertilizers, particularly due to import dependencies. In this context, *Lithothamnium*, a seaweed derivative that supplies calcium and magnesium and enhances the physical, chemical, and biological properties of the soil, presents a viable solution. This study aimed to assess the impact of varying doses (whole [W] or fractional [F]), intervals, and application modes of *Lithothamnium* on melon yield and quality. The experimental investigation was carried out at Fazenda Dina - *Dinamarca Industrial Agrícola*, located in Mossoró, Brazil. An experimental design consisting of randomized blocks with 11 treatments and four replications was implemented. Melons were harvested 75 days post-sowing. Results revealed no significant differences for most variables as per the Scott Knott test (5% probability). However, noteworthy statistical differences were observed concerning productivity, peel thickness, pulp firmness, pH, and total sugar content. All treatments involving the use of *Lithothamnium* demonstrated an increase in productivity (25.6 to 29.8 t ha^{-1}) and peel thickness (0.80 to 1.02 cm). In terms of pulp firmness, treatments using *Lithothamnium* in nanoparticle form and as a concentrated suspension with application times of 10-20-30 and 30-50 exhibited higher values (25.66 to 27.81 N). Except for the micronized powder variant, all *Lithothamnium* treatments yielded the highest pH values (6.84 to 6.94). Total sugar content was found to be highest in treatments T3, T4, and T5 (11.58%, 12.50%, and 11.78%, respectively).

Keywords: Calcareous algae. *Cucumis melo*. Postharvest.

RESUMO - No Brasil, a produção de melão se destaca pelo alto padrão de qualidade, sendo o uso de fertilizantes um dos grandes gargalos do setor produtivo. *Lithothamnium* é um produto derivado de algas marinhas e contribui para o fornecimento de cálcio e magnésio, bem como para a melhoria física, química e biológica do solo. O objetivo deste trabalho foi avaliar o rendimento e a qualidade do melão produzido por diferentes doses (inteiro [W] ou fracionado [F]), intervalos e modo de aplicação de *Lithothamnium*. O trabalho experimental foi conduzido na Fazenda Dina - Dinamarca Industrial Agrícola, Mossoró, Brasil. Utilizou-se o delineamento em blocos casualizados com 11 tratamentos e 4 repetições. As plantas foram colhidas aos 75 dias após a semeadura. Os resultados para a maioria das variáveis não diferiram pelo teste de Scott Knott a 5% de probabilidade. No entanto, houve diferença estatística para as variáveis produtividade, espessura da casca, firmeza da polpa, pH e açúcares totais. Todos os tratamentos com *Lithothamnium* apresentaram maior produtividade (25,6 a 29,8 t há$^{-1}$) e maior espessura de casca (0,8 a 1,02 cm). Em relação à firmeza da polpa, os tratamentos que utilizaram *Lithothamnium* em nanopartículas e em suspensão concentrada com tempos de aplicação de 10-20-30 e 30-50 apresentaram maiores valores (25,66 a 27,81 N). Para pH, todos os tratamentos com *Lithothamnium*, exceto o em pó micronizado, apresentaram os maiores valores (6,84 a 6,94). A quantidade de açúcares totais foi maior nos tratamentos T3, T4 e T5 (11,58, 12,50 e 11,78%, respectivamente).

Palavras-chave: Algas calcárias. *Cucumis melo*. Pós-colheita.

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INTRODUCTION

Brazil, ranking twelfth in global melon (*Cucumis melo* L.) production (589,900 t) and third in fresh fruit production, boasts a wide array of cultivated species. The leading producers of melon are China (14,071,555.28 t), Turkey (1,638,638 t), and Iran (676,318.43 t). Melon is the second most produced fruit worldwide. In 2021, Brazil achieved a melon yield of 607,047 t across 23,858 hectares (FAOSTAT, 2021).

Approximately 95% of Brazil's melon production is concentrated in the northeastern states, with Rio Grande do Norte (361,649 t), Bahia (86,866 t), and Ceará (70,665 t) as the key contributors (IBGE, 2021). Given the increasing global demand for fruits, there is a growing emphasis on technological advancements to boost productivity and postharvest fruit quality. Effective crop management, environmental considerations, and cost reduction are integral components of this advancement (CHATTERJEE et al., 2017).

Fruit postharvest quality, reflecting product excellence, has transitioned from being a distinguishing attribute to a mandatory market requirement (PEINADO; GRAEML, 2007; KLEE, 2010). Given the significant capital required for melon cultivation, the refinement of adopted technologies is crucial to optimize the cost-benefit ratio of applied inputs.

Organic sources in agriculture are gaining traction as economical and eco-friendly alternatives to synthetic chemical fertilizers. One potential solution for reducing synthetic inputs is the use of calcareous algae as a fertilizer (CHATTERJEE et al., 2017). Historically, calcareous algae have been applied for correcting acidic and/or calcium-deficient soils in France, England, and Ireland (LE BLEU, 1983). Since the 1960s, Brazil has also reported extensive occurrences of limestone algae on the N-NE continental shelf (KEMPF, 1970).

Lithothamnium, a seaweed derivative, is noteworthy for its high calcium (Ca) and magnesium (Mg) contents, essential plant nutrients. It also provides over 20 trace elements such as iron (Fe), manganese (Mn), boron (B), nickel (Ni), copper (Cu), zinc (Zn), molybdenum (Mo), selenium (Se), and strontium (Sr) in varying amounts (MELO; FURTINI NETO, 2003). *Lithothamnium* enhances productivity, optimizes input utilization, improves nutrient absorption, and increases resistance to pests and diseases. Furthermore, it balances microbial flora, neutralizes soil acidity, and boosts photosynthetic activity, thereby elevating fruit production and quality (DIAS, 2000).

Moreira et al. (2011) demonstrated that the addition of *Lithothamnium* bioclastic granules improved the quality of red pitaya fruits, resulting in an average Brix of 12.03, an average fruit weight of 249 g, and a pulp yield of 61.94%. Similarly, Silva (2010) found that the use of *Lithothamnium* increased guava fruit production by 88% and productivity by 75% compared to control groups.

In light of the economic importance of melon, this study aimed to assess the impact of different doses, intervals, and application modes of *Lithothamnium* on melon production and quality.

MATERIALS AND METHODS

General experiment data

The experiment was conducted from June to November 2014 at Fazenda Dina - Dinamarca Industrial Agrícola LTDA, located at Rod. BR 304, Km 07, Sítio Branco, Countryside, Mossoró - RN, Brazil (coordinates: 4° 54' 28" S and 37° 24' 06" W).

The regional climate is classified as 'BSwh' under the Köppen climate classification, indicating hot, dry conditions with irregular rainfall averaging 675.8 mm annually, mainly occurring from February to April. The average annual temperature is around 27ºC, and the average annual relative humidity is 69% (CARMO FILHO; OLIVEIRA, 1995).

Soil samples were collected at a depth of 0-20 cm, air-dried, and sieved through a 2-mm mesh before the experiment. These samples were then sent to the Instituto Campineiro de Análise de Solo e Adubo LTDA in Campinas-SP for analysis. The soil had the following properties: pH in water (1: 2.5) = 7.7; pH in $CaCl_2$ = 6.8; organic matter (OM) = 10 g kg^{-1}; sum of bases (SB) = 36.7 cmolc dm^{-3}; cation exchange capacity (CEC) = 44.7 cmolc dm^{-3}; Ca = 2.4 cmolc dm^{-3}; Mg = 0.7 cmolc dm^{-3}; K = 0.36 cmolc dm^{-3}; Na = 49 mg dm^{-3}; and P = 100 mg dm^{-3}.

The *Lithothamnium*-based product used in the study was obtained from VALEAGRO in Petrolina-PE, Brazil, in both concentrated suspension (CS) and powder-micronized (PM) formulations. Some of the product was processed at the Physics Laboratory of the *Universidade Federal do Rio Grande do Norte* (UFRN) to produce nanometric particles.

The high-energy grinding process was carried out using a planetary ball mill (Fritsch, Pulverisette 7), at room temperature, with a 45 mL tungsten carbide container and 4 spheres of the same material, each with a 15 mm radius and 25g weight. The weight ratio of ball to powder was 10:1. The grinding was done at 300 RPM for 20 hours, with 25g of the product processed per cycle.

Before grinding, the container and spheres were cleaned with acetone and alumina, then rotated at 400 RPM for 30 minutes to remove impurities. Following this, the micronized *Lithothamnium* powder was added to the container.

The chemical analysis of the product revealed the following component ratios: 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.

Conduct of experiment

The experiment was conducted in a melon production area, specifically an experimental field, following a randomized block design with 11 treatments and four replications (Table 1). The spacing between plants was 2.0 x 0.4 m, with each plot consisting of 12 plants.

Melon seeds of the hybrid type 'Goldex' from Fitó seed company were sown in expanded polystyrene trays with 128 cells, supplemented with organic compound Pole®. This hybrid variety has a harvesting period ranging from 64 to 75 days after sowing, with productivity exceeding 20 t ha^{-1}. The plants are vigorous and have a high content of soluble solids, making them ideal for export.

Eight days after sowing, the seedlings were transplanted to the field. The transplantation was conducted under a double-sided plastic mulch cover, with the upper part white and the lower part black. Nonwoven fabric weighing 15 g m^{-2} was used to cover the seedlings and remained in place until 28 days after transplantation.

All standard management practices and cultural treatments were implemented for melon cultivation in Rio Grande do Norte. Soil preparation involved plowing, harrowing, and furrowing in rows spaced 2.0 m apart with a depth of approximately 20 cm.

Table 1. *Lithothamnium* (*Lit.*) treatments and formulations applied to melon cv. 'Goldex' plants using different application modes and doses (whole or fractional).

Treatment	Formulation[1]	Time of application[2]	Dose (kg or L) ha^{-1}
T1	Producer standard	-	-
T2	*Lit.* micronized powder	10	50
T3	*Lit.* micronized powder	10 - 20	25 - 25
T4	*Lit.* concentrated suspension	10	10
T5	*Lit.* concentrated suspension	10 - 20	5 - 5
T6	*Lit.* nanoparticles	10	1
T7	*Lit.* nanoparticles	10 - 20	0.5 – 0.5
T8	*Lit.* nanoparticles	10	1
T9	*Lit.* nanoparticles	10 - 20	0.5 – 0.5
T10	*Lit.* concentrated suspension	10 - 20 - 30	1 - 1 - 1
T11	*Lit.* concentrated suspension	30 - 50	1.5 – 1.5

[1]T1 = producer standard; T2, T3, T4, T5, T6, and T7 - product applied by fertigation; T8, T9, T10, and T11 - product applied by spraying. [2]days after sowing.

The total fertilization included 138.5 kg ha^{-1} of urea, 4.5 kg ha^{-1} of phosphorus pentoxide, 5.1 kg ha^{-1} of potassium oxide, 534 kg ha^{-1} of potassium sulfate, 411 kg ha^{-1} of potassium nitrate, 8.8 kg ha^{-1} of boric acid, 45.0 kg ha^{-1} of KSC, 9 kg ha^{-1} of KSC Mix fertilizer, 29 kg ha^{-1} of Pekacid fertilizer, 227 kg ha^{-1} of ammonium mono phosphate (MAP), 27.5 L ha^{-1} of Restorer, and 40 kg ha^{-1} of ExtraHumus. Fertilizers applied to the planting furrows were incorporated using a rotary hoe, while the cover fertilizers were applied through weekly fertigation based on the crop's requirements.

The irrigation system employed was high-frequency drip irrigation, with emitters spaced at 0.40 m intervals, operating at a pressure range of 1.5 kgf cm^{-2} and a flow rate of 3.5 L h^{-1}, as specified by the manufacturer. Irrigation frequency was adjusted daily to meet the melon crop's needs for the region.

Phytosanitary control measures were carried out when necessary, using registered fungicides and insecticides appropriate for the crop.

Harvesting took place 75 days after sowing, and the number of commercially viable fruits per plot was recorded. Two fruits were collected from each plot, amounting to eight fruits per treatment.

At the time of harvest, the fruits were classified based on type (number of fruits/box) for export. The fruits were manually collected using a pocketknife, properly labeled, and packed in plastic bags for subsequent transportation to the Physiology and Postharvest Technology Laboratory at the *Universidade Federal Rural do Semi-Árido*.

On the same day as harvest, the melon fruits were assessed for the following physical characteristics: the total number of fruits per plot (TNF), fruit type (FT), productivity (P) (t ha^{-1}), fresh fruit mass (FFM) (g), fruit length (FL) (cm), fruit diameter (FD) (cm), longitudinal and transverse internal cavity (LIC and TIC) (cm), peel thickness (PT) (cm), pulp thickness (PuT) (cm), and pulp firmness (PF).

Subsequently, the edible fraction (pulp) was extracted from the fruits using a stainless-steel knife, homogenized in a blender, and packed into 50 mL Falcon tubes for chemical evaluations, including soluble solids content (SS), titratable acidity (TA), the potential of hydrogen (pH), and total sugars (TS).

Evaluations of treatments

Fruit type (FT)

The type of melons produced was defined based on the size or weight of fruits, specifically by considering the number of fruits that can fit in a box (Table 2).

Table 2. Classification of yellow melon fruits in a 5 kg box, adopted by the Dinamarca Company.

Type	Weight (kg)
4	3.250
5	2.600 – 3.249
6	2.167 – 2.599
7	1.857 – 2.166
8	1.625 – 1.856
9	1.444 – 1.624
10	1.300 – 1.443
11	1.180 – 1.299
12	1.083 – 1.179
13	1.000 – 1.082
14	< 0.999

The fruits were selected based on guidelines provided by the Dinamarca Company. According to their methodology, fruits of types 8 to 12 (in a 5 kg box) can be sold domestically and internationally. Types 6 and 7 are sold only in the domestic market, while types 2 to 5 are used for processing (sliced melon). Melons weighing less than 550 grams are considered non-standard or non-commercial.

Any fruits that did not meet these classification criteria were deemed non-commercial or rejected. This includes fruits affected by diseases, deformed, with apical rot, cracked, sunburned, or having an average mass below 550 grams.

Fruit shape (FS)

This variable was derived by calculating the ratio of fruit shape (FS) obtained from the length (longitudinal diameter) and diameter (transverse diameter) of the fruit. For this analysis, the average value from eight fruits per treatment was used. The classification was based on a scale adapted by Lopes (1982), which includes the following formats: long ($FS < 0.9$), spherical ($0.9 \leq FS \leq 1.1$), oblong ($1.1 < FS \leq 1.7$), and cylindrical ($FS > 1.7$).

Total number of fruits (TNF)

This value was obtained by counting the number of fruits within the useful area of the plot, and then extrapolating it to represent the number of fruits per hectare.

Productivity (P)

This value was obtained by weighing the commercial fruits from the useful area of each treatment that met the commercial quality standards. The weight of these fruits, along with an estimation for one hectare, was used to calculate the fruit productivity in t ha^{-1}.

Fresh fruit mass (FFM)

This characteristic was determined by individually weighing eight fruits per treatment using a semi-analytical scale. The results were expressed in grams (g).

Longitudinal and transverse internal cavity (LIC and TIC)

The transverse and longitudinal dimensions of the internal cavity of fruits were measured using a digital caliper, with results being expressed in centimeters (cm). These measurements were performed on eight fruits for each treatment.

Peel and pulp thickness (PT and PuT)

Pulp thickness (PuT) was determined by dividing the fruit longitudinally into two parts. The thickness of the endocarp on each side was measured using a digital caliper, and the results were expressed in centimeters (cm). The average value for the eight fruits per treatment was calculated.

Peel thickness (PT) was measured by determining the distance between the epicarp (peel) and the mesocarp using a digital caliper. This measurement was performed on eight fruits per treatment, and the results were expressed in centimeters (cm).

To measure the pulp firmness, the fruits were cut longitudinally, and equidistant readings were taken on each equatorial half of the melon fruit (resulting in two readings per fruit). Eight fruits were used per treatment for this measurement. A Fruit Pressure Tester TR, model FT 327 (3-27 Lbs.) equipped with a conical tip probe, with a diameter of eight (8) mm, was employed. The results were initially obtained in pounds and then converted to Newton (N) by multiplying them by the conversion factor of 4.45 (GOMES JÚNIOR et al., 2001).

Potential of hydrogen (pH)

The pH measurement was performed using a Tecnopon pH meter, model mPA-210, which has automatic temperature adjustment and was appropriately calibrated with pH 7.0 and pH 4.0 buffer solutions. Aliquots of 5 g of the fruit extract were diluted in 50 mL of distilled water. Once the pH readings on the equipment panel stabilized, the measured data were expressed as the actual pH values (AOAC, 2002).

Soluble solids (SS)

The soluble solids content was determined using a digital refractometer, model IPDBR45, which features automatic temperature compensation and a scale ranging from 0 to 45%. Two samples of juice were evaluated for each repetition. The juice was obtained following the procedure described in the item CONDUCT OF EXPERIMENT. The results are expressed as a percentage (%).

Titratable acidity (TA)

This variable was determined in duplicate by titrating the melon juice with a 0.1 N NaOH solution, following the methodology of the Instituto Adolfo Lutz – IAL (1985). The results were expressed as a percentage (%) of citric acid.

Soluble Solids/Titratable Acidity (SS/TA)

The SS/TA ratio was calculated by dividing the value of soluble solids by the titratable acidity. The results were expressed as a percentage (%).

Total sugars (TS)

The total sugars were determined using the Anthrone method ($C4H10O$), following the procedure outlined by Yemn and Willis (1954). To obtain the extract, 0.5 g aliquots of each sample were diluted in a 100 mL volumetric flask and then filtered using qualitative Whatman paper No. 1. A 50 µL aliquot of the extract and 95 µL of distilled water were placed in a test tube. The tubes were placed in an ice bath, and the anthrone reagent was added. After stirring, the tubes were heated in a boiling water bath for 8 minutes and then cooled in an ice water bath until they reached room temperature. The readings were taken using a spectrophotometer at a wavelength of 620 nm. The concentrations were measured in triplicate, and the average value was calculated. The results were expressed in g per 100 g of melon pulp.

Data Analysis

The data obtained for the evaluated characteristics were analyzed through analysis of variance (ANOVA), using the ASSISTAT statistical software (SILVA; AZEVEDO, 2009). If the treatment data showed significant differences according to the F-test at a 0.05 probability level, the means were compared by the Scott-Knott test (SCOTT; KNOTT, 1974).

RESULTS AND DISCUSSION

Fruit type and shape

In this experiment, the fruits produced were classified as types 6 to 8, which are considered commercial according to the classification of yellow-type fruits by the Dinamarca Company. The analyzed fruits were classified as oblong ($1.1 < FF \leq 1.7$) according to their shape (Table 3). This is an essential quality attribute, particularly in terms of packaging, transportation, and marketing considerations.

Table 3. List of fruit shape (FS) as a function of formulation, application interval (AI) (days after sowing), application mode, and application dose (whole or fractionated) of *Lithothamnium* (*Lit.*) in melon plants.

Treatment/Formulation[1]/Application mode[2]/(AI[3])/(Dose)[4]	FS
T1. Producer standard	1.25
T2. *Lit*. mic powder (10); (50 kg ha^{-1})	1.17
T3. *Lit*. mic powder (10 - 20); (25+25 kg ha^{-1})	1.23
T4. *Lit*. CS. (10); (10 L ha^{-1})	1.19
T5. *Lit*. CS. (10 - 20); (5- 5 L ha^{-1})	1.14
T6. *Lit*. nano (10); (1.0 kg ha^{-1})	1.15
T7. *Lit*. nano (10 - 20); (0.5 – 0.5 kg ha^{-1})	1.20
T8. *Lit*. nano (10); (1.0 kg ha^{-1})	1.17
T9. *Lit*. nano (10 - 20); (0.5 – 0.5 kg ha^{-1})	1.18
T10. *Lit* CS. (10 - 20 - 30); (1 – 1 - 1 L ha^{-1})	1.18
T11. *Lit*. CS. (30 - 50); (1.5 – 1.5 L ha^{-1})	1.19
CV (%)	5.65

[1]T1 = producer standard; mic powder = micronized powder; CS = concentrated suspension; nano = nanoparticles. [2]T2, T3, T4, T5, T6, T7 (application of the product by fertigation); T8, T9, T10, T11 (application of the product by spraying); [3] (days after sowing); [4]dose of *Lithothamnium* (whole or fractionated).

According to Pan et al. (2020), there are specific indices that indicate the appropriate shape for each cultivar of melon. For yellow melons, the preferred indices range from 1.0 to 1.2, indicating a slightly elongated shape. In the presented study, only treatments T1 and T3 did not produce fruits within the preferred indices. As mentioned by Vigneault, Thompson and Wu (2009), fruits with larger dimensions and elongated shapes often require more space and pose challenges when it comes to packaging.

Number of fruits, productivity, and fresh fruit mass

A significant effect was observed in terms of productivity when using different intervals and doses of *Lithothamnium* application, as determined by the Scott-Knott test at a 5% level of probability. However, no statistical difference was found for the number of fruits and fresh fruit mass when using different intervals and doses of *Lithothamnium*, as shown in Table 4.

Melon plants fertilized with *Lithothamnium* in treatments 2 and 11 showed superior results compared to the other treatments, as determined by the Scott-Knott test at a 5% level of probability. Both treatments exhibited the same productivity of 29.8 t ha^{-1}, representing a 17% increase in melon productivity compared to the control, as determined by the Scott-Knott test at a 5% level of probability (Table 4).

The higher productivity in treatments 2 and 11 (20.16% higher than treatment 1) can be attributed to the availability of nutrients during the critical growth stages of the crop. This promotes a balanced nutrient supply to the plants and encourages plant shoots to develop nutritionally, thereby enhancing their ability to produce larger fruits. The formulations used in these treatments may have increased the contact area of the particles with the plants, leading to enhanced product absorption.

Table 4. Averages of number of fruits (NF), productivity (P), and fresh fruit mass (FM) as a function of application interval and doses (whole or fractionated) of *Lithothamnium* in melon plants.

Treatment/Formulation[1]/Application mode[2]/(AI[3])/(Dose)[4]	NF (ha)	FM (g)	P ($t\ ha^{-1}$)
T1. Producer standard	12812 a	1931.88 a	24.8 f
T2. *Lit*. mic powder. (10); (50 kg ha^{-1})	14687 a	2030.75 a	29.8 a
T3. *Lit*. mic powder (10 - 20); (25+25 kg ha^{-1})	13750 a	1936.75 a	26.6 d
T4. *Lit*. CS. (10); (10 L ha^{-1})	13750 a	2101.38 a	28.9 b
T5. *Lit*. CS. (10 - 20); (5- 5 L ha^{-1})	12812 a	2001.00 a	25.6 e
T6. *Lit*. nano (10); (1.0 kg ha^{-1})	13437 a	1915.63 a	25.7 e
T7. *Lit*. nano (10 - 20); (0.5 – 0.5 kg ha^{-1})	14375 a	1827.88 a	26.3 d
T8. *Lit*. nano (10); (1.0 kg ha^{-1})	12500 a	1929.75 a	24.1 f
T9. *Lit*. nano (10 - 20); (0.5 – 0.5 kg ha^{-1})	14687 a	1877.75 a	27.6 c
T10. *Lit* CS. (10 - 20 - 30); (1 – 1 - 1 L ha^{-1})	15625 a	1829.88 a	28.6 b
T11. *Lit*. CS. (30 - 50); (1.5 – 1.5 L ha^{-1})	14062 a	2121.00 a	29.8 a
CV (%)	6.87	14.35	29.9

[1]T1 = producer standard; mic powder = micronized powder; CS = concentrated suspension; nano = nanoparticles. [2]T2, T3, T4, T5, T6, T7 (application of the product by fertigation); T8, T9, T10, T11 (application of the product by spraying). [3](days after sowing); [4]dose of *Lithothamnium* (whole or fractionated). [*]Averages followed by the same lowercase letters in the column do not differ statistically from each other by the Scott-Knott test (1974) at 5% probability.

Melo et al. (2008) conducted a study on the use of Lithothamnium-based bioclastic granules in yellow passion fruit production and found a 20.1% increase in productivity when the product was used.

Although the number of fruits and fresh fruit mass did not differ among treatments, higher averages were observed in treatments that exhibited the best productivity results. Therefore, productivity is generally directly proportional to the number of fruits and fresh fruit mass.

Transverse internal cavity, longitudinal internal cavity, peel thickness, and pulp thickness

No statistical difference was observed for the transverse internal cavity and longitudinal internal cavity when different intervals and doses of Lithothamnium application were used, as indicated in Table 5.

Table 5. Averages of transverse internal cavity (TIC), longitudinal internal cavity (LIC), peel thickness (PT), and pulp thickness (PuT) as a function of application interval and doses (whole or fractionated) of *Lithothamnium* in melon plants.

Treatment/Formulation[1]/Application mode[2]/(AI[3])/(Dose)[4]	TIC (cm)	LIC (cm)	PT (cm)	PuT (cm)
T1. Producer standard	11.24 a	5.54 a	0.50 c	4.04 a
T2. *Lit*. mic powder (10); (50 kg ha^{-1})	12.18 a	5.18 a	0.80 b	3.88 a
T3. *Lit*. mic powder (10 - 20); (25+25 kg ha^{-1})	12.11 a	5.75 a	1.02 a	3.74 a
T4. *Lit*. CS. (10); (10 L ha^{-1})	12.49 a	5.64 a	0.98 a	3.73 a
T5. *Lit*. CS. (10 - 20); (5- 5 L ha^{-1})	11.49 a	6.39 a	0.96 a	3.59 a
T6. *Lit*. nano (10); (1.0 kg ha^{-1})	11.61 a	5.53 a	0.93 a	3.93 a
T7. *Lit*. nano (10 - 20); (0.5 – 0.5 kg ha^{-1})	12.01 a	5.30 a	0.80 b	3.83 a
T8. *Lit*. nano (10); (1.0 kg ha^{-1})	12.08 a	5.71 a	0.85 b	3.74 a
T9. *Lit*. nano (10 - 20); (0.5 – 0.5 kg ha^{-1})	12.28 a	5.35 a	0.83 b	4.04 a
T10. *Lit* CS. (10 - 20 - 30); (1 – 1 - 1 L ha^{-1})	11.93 a	5.84 a	0.91 a	4.00 a
T11. *Lit*. CS. (30 - 50); (1.5 – 1.5 L ha^{-1})	12.80 a	5.75 a	0.95 a	4.25 a
CV (%)	9.26	16.59	22.27	14.32

[1]T1 = producer standard; mic powder = micronized powder; CS = concentrated suspension; nano = nanoparticles. [2]T2, T3, T4, T5, T6, T7 (application of the product by fertigation); T8, T9, T10, T11 (application of the product by spraying). [3](days after sowing); [4]dose of *Lithothamnium* (whole or fractionated). [*]Averages followed by the same lowercase letters in the column do not differ statistically from each other by the Scott-Knott test (1974) at 5% probability.

In terms of peel thickness, all treatments receiving *Lithothamnium* exhibited greater values compared to the control group. However, there was no statistical difference in terms of pulp thickness (Table 5). This improvement was observed across all three types of formulations used. Such a difference can be explained by the fact that pulp cells, which contain large vacuolar portions, reserve organelles, and larger cytoplasmic portions, tend to have lower calcium content, as this element is incompatible with cytoplasmic functions. On the other hand, peel tissues primarily serve a protective function, having smaller cells with a higher proportion of cell wall, which justifies the observed difference between pulp and peel (ZHANG et al., 2019). Overall, an increase in peel thickness is a desirable characteristic from a commercial perspective, as it indicates improved resistance of fruits to mechanical damage and thus an extended postharvest shelf life.

Pulp firmness, hydrogen potential, and total sugars

Statistical differences were detected for the evaluated characteristics of pulp firmness, pH, and total sugars when different intervals and doses of *Lithothamnium* application were used, as determined by the Scott-Knott test at a 5% level of probability (Table 6).

Table 6. Averages of pulp firmness (PuF), potential of hydrogen (pH), and total sugars (TS) as a function of application interval and doses (whole or fractionated) of *Lithothamnium* in melon plants.

Treatment/Formulation[1]/Application mode[2]/(AI[3])/(Dose)[4]	PuF (N)	pH	TS (%)
T1. Producer standard	24.34 b	6.72 b	10.58 b
T2. *Lit*. mic powder (10); (50 kg ha^{-1})	24.06 b	6.75 b	10.94 b
T3. *Lit*. mic powder (10 - 20); (25+25 kg ha^{-1})	21.76 b	6.75 b	11.58 a
T4. *Lit*. CS. (10); (10 L ha^{-1})	21.69 b	6.87 a	12.50 a
T5. *Lit*. CS. (10 - 20); (5- 5 L ha^{-1})	23.78 b	6.94 a	11.78 a
T6. *Lit*. nano (10); (1.0 kg ha^{-1})	26.35 a	6.87 a	10.76 b
T7. *Lit*. nano (10 - 20); (0.5 - 0.5 kg ha^{-1})	25.66 a	6.88 a	10.95 b
T8. *Lit*. nano (10); (1.0 kg ha^{-1})	27.60 a	6.84 a	9.78 b
T9. *Lit*. nano (10 - 20); (0.5 - 0.5 kg ha^{-1})	26.78 a	6.90 a	11.06 b
T10. *Lit* CS. (10 - 20 - 30); (1 – 1 - 1 L ha^{-1})	25.80 a	6.94 a	10.63 b
T11. *Lit*. CS. (30 - 50); (1.5 - 1.5 L ha^{-1})	27.81 a	6.87 a	10.01 b
CV (%)	12.53	1.54	9.40

[1]T1 = producer standard; mic powder = micronized powder; CS = concentrated suspension; nano = nanoparticles. [2]T2, T3, T4, T5, T6, T7 (application of the product by fertigation); T8, T9, T10, T11 (application of the product by spraying). [3](days after sowing); [4]dose of *Lithothamnium* (whole or fractionated). *Averages followed by the same lowercase letters in the column do not differ statistically from each other by the Scott-Knott test (1974) at 5% probability.

Regarding the pulp firmness, treatments using *Lithothamnium* in nanoparticles and CS formulations with spray application showed higher values compared to other treatments (Table 6). This can be explained by the increased contact surface of *Lithothamnium* nanoparticles with the plant's root system, promoting better fertilizer use by the roots, and leading to improved solubilization and nutrient absorption. The availability of calcium and magnesium in the plant increases firmness as these elements are crucial components of the cell wall, contributing to its rigidity (TAIZ; ZEIGER, 2004). The relationship between increased pulp firmness and higher levels of Ca^{2+} has already been established (MIRANDA; MEDEIROS; LEVIEN, 2008).

Natale, Prado and Môro (2005) conducted a study on guava fruits and found that calcium application led to well-defined and structured cell walls and middle lamellae, whereas fruits without calcium application exhibited unstructured cell walls and disorganized middle lamellae. Calcium application is effective in subcellular organization and shelf-life enhancement of guava fruits.

Pulp firmness reflects the solubilization of pectic polysaccharides, which are major constituents of the middle lamella. During fruit ripening, pectin solubility, and depolymerization increase. Tissue senescence is influenced, in part, by the degradation of pectic polymers in the cell wall, and fruits with higher calcium levels tend to soften more slowly (PEREIRA et al., 2002; PAIVA; LIMA; PAIXÃO, 2009). Therefore, the use of *Lithothamnium*, rich in calcium, can positively impact fruit quality during postharvest, extending the storage period or shelf life.

Firmness is a crucial attribute that determines the quality and acceptability of fresh fruits and processed products in the market. Studies on the molecular events responsible for fruit changes during ripening demonstrate that firmness can have cooperative effects on other sensory attributes such as aroma, color, and flavor. It also influences acceptability, shelf life, transportability, resistance to shear, and susceptibility to insects, bacteria, and fungi (PAIVA;

LIMA; PAIXÃO, 2009).

In terms of pH evaluation, all *Lithothamnium* treatments, except the MP formulation, resulted in higher pH values compared to the control group, as determined by the Scott-Knott test at a 5% level of probability (Table 6). The difference between the highest average pH (6.94) obtained in T5 and T10, and the lowest average (6.72) observed in T1, was only 0.2, which is considered negligible.

Previous studies by Fitzgerald, Pereira and Souza (2001) on stored melon fruits reported an increase in pH with diverse sources and doses of calcium. Comparable results were obtained by Bissoli Junior (1992) in mangoes and Fernandez (1996) in postharvest-treated melon fruits.

The pH is widely used in determining the postharvest quality of fruits due to its ease and speed of analysis (FERNANDEZ, 1996). The relatively small variation observed in pH values can be attributed to the nature of the predominant acids in the vacuolar sap of fruit cells. These acids are di- and tri-basic, exhibiting multiple pH values and buffering capacity over a wide range. In intact cells, acids are mainly located in the vacuole, separated from most enzymes in the cytoplasm or cell wall, which are maintained at higher pH values than the vacuole (MENEZES, 1996).

According to Chitarra and Chitarra (2005), pH is a parameter that generally measures the acidity of fruits and food, serving as an indicator of the required treatment to preserve food. An increase in pH is directly associated with decreased acidity and fruit ripening progression.

In terms of total sugars, treatments 3, 4, and 5 showed superior results compared to other treatments, as determined by the Scott-Knott test at a 5% level of probability. These treatments exhibited percentages of total sugars at 11.58%, 12.50%, and 11.78%, respectively (Table 6). This represents approximately 83%, 85%, and 77% of the total sugars concerning soluble solids.

The findings regarding total sugars in this study are consistent with those reported by Grangeiro et al. (1999), who studied the quality of yellow melon hybrids. They found that the total sugar content accounted for an average of 81.60% of the soluble solids content.

The higher doses of calcium provided by *Lithothamnium* may have facilitated increased potassium absorption, as observed by Bissoli Junior (1992) in mangoes treated with calcium before harvest. Potassium is responsible for the translocation of photoassimilates from leaves to fruits, resulting in higher sugar accumulation.

In melons, the content of total sugars (glucose, fructose, and sucrose) represents a significant percentage of the soluble solids content, constituting approximately 65% to 85% of the total soluble solids content (CHITARRA; CHITARRA, 2005).

Soluble solids, titratable acidity, and soluble solids/titratable acidity ratio

For the evaluated characteristics of soluble solids, total acidity, and the SS/TA ratio, no statistical difference was observed when different intervals and doses of *Lithothamnium* application were used, as determined by the Scott-Knott test at a 5% level of probability (Table 7). The average values for soluble solids, total acidity, and the SS/TA ratio were 14.49, 0.139, and 107.63%, respectively.

Table 7. Averages of soluble solids (SS), total acidity (TA% of citric acid), and SS/TA ratio as a function of application interval and doses (whole or fractionated) of *Lithothamnium* in melon plants.

Treatment/Formulation[1]/Application mode[2]/(AI[3])/(Dose)[4]	SS	TA	SS/TA
T1. Producer standard	14.45 a	0.177 a	84.33 a
T2. *Lit*. mic powder (10); (50 kg ha^{-1})	14.58 a	0.163 a	90.36 a
T3. *Lit*. mic powder (10 - 20); (25+25 kg ha^{-1})	13.93 a	0.141 a	100.88 a
T4. *Lit*. CS. (10); (10 L ha^{-1})	14.74 a	0.130 a	115.02 a
T5. *Lit*. CS. (10 - 20); (5- 5 L ha^{-1})	15.21 a	0.134 a	116.98 a
T6. *Lit*. nano (10); (1.0 kg ha^{-1})	14.76 a	0.131 a	114.65 a
T7. *Lit*. nano (10 - 20); (0.5 - 0.5 kg ha^{-1})	14.33 a	0.128 a	117.96 a
T8. *Lit*. nano (10); (1.0 kg ha^{-1})	14.24 a	0.124 a	116.98 a
T9. *Lit*. nano (10 - 20); (0.5 - 0.5 kg ha^{-1})	14.46 a	0.133 a	111.12 a
T10. *Lit* CS. (10 - 20 - 30); (1 – 1 - 1 L ha^{-1})	14.30 a	0.141 a	104.57 a
T11. *Lit*. CS. (30 - 50); (1.5 - 1.5 L ha^{-1})	14.38 a	0.137 a	111.13 a
CV (%)	3.19	19.40	8.88

[1]T1 = producer standard; mic powder = micronized powder; CS = concentrated suspension; nano = nanoparticles. [2]T2, T3, T4, T5, T6, T7 (application of the product by fertigation); T8, T9, T10, T11 (application of the product by spraying). [3](days after sowing); [4]dose of *Lithothamnium* (whole or fractionated). [*]Averages followed by the same lowercase letters in the column do not differ statistically from each other by the Scott-Knott test (1974) at 5% probability.

Our findings for soluble solids, titratable acidity, and SS/TA ratio are consistent with those of Pereira et al. (2002). These authors evaluated the effect of different calcium application sources and doses on melon fruit production and quality and found no statistical difference in soluble solids. Faria, Carrijo and Moretti (2004) also conducted a study on calcium sources in melon cultivation under protected conditions and reported no significant differences in soluble solids, titratable acidity, and the SS/TA ratio.

Similar results were observed by Silva (2010) in a study on the use of bioclastic granules (*Lithothamnium*) in guava production and quality. No statistically significant differences were found between treatments with *Lithothamnium* and the control (calcium-free treatment) regarding soluble solids, titratable acidity, and the SS/TA ratio.

Soluble solids content indicates the amount of sugar in the fruit. In this study, the soluble solids results were higher than those reported by Grangeiro et al. (1999) for yellow melons, and they met the desired standards for the international market (above 9%).

In most fruits, higher acidity levels play a significant role in flavor as its acceptance depends on the balance between acids and sugars. However, in melons, the variation in acidity levels has minimal significance due to their low concentration, and acidity does not have a significant impact on flavor (MORAIS et al., 2009).

The SS/TA ratio is widely used to evaluate flavor as it provides a more comprehensive measure than measuring sugars or acidity individually. This ratio represents the balance between sugars and acidity, with specific minimum soluble solids content and maximum acidity to achieve a more accurate understanding of flavor (CHITARRA; CHITARRA, 2005).

CONCLUSION

The use of *Lithothamnium* micronized powder (T2) and concentrated suspension (T11) had a positive impact on melon yield, with both treatments achieving a yield of 29.8 t ha^{-1}. The peel thickness in all *Lithothamnium* treatments (ranging from 0.80 to 1.02 cm) was higher compared to the control (0.50 cm). Furthermore, treatments using *Lithothamnium* in nanoparticles (25.66 to 27.60 N) and concentrated suspension with spray application (25.80 to 27.81 N) exhibited superior pulp firmness compared to the other treatments (ranging from 21.69 to 24.34 N). In conclusion, *Lithothamnium* can be used as a replacement for synthetic calcium and magnesium-based products, leading to improvements in the postharvest quality of melon fruits.

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