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Evaluation of physiological quality and vigor of corn seeds coated with chitosan

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ABSTRACT: In favor of better cultures development and productivity, new studies are seeking different alternatives, efficient technologies, and lower environmental impact to achieve such purposes, thus, the present study aimed to evaluate the application effect of a chitosan-based product in the germination and vigor of corn. The study was carried out at the Ceará State University, Campus Itaperi. A completely randomized design was adopted with four replications of 50 seeds, except for the mass, length tests and image analysis carried out in five replications of 20 seeds. Seeds of the cultivar SM 996 were used and submitted to six concentrations of chitosan-based product: 0.0% (control); 0.5%; 1%; 2.5%; 5%; and 10%. It evaluated the following parameters: first count, germination test, radicle, shoot and seedling length and fresh mass, chlorophyll and carotenoid content, electrolyte extravasation, image computerized analysis by Vigor-S®, emergence, and length, fresh and dry mass of the seedlings in a bed. The use of coating with the bioproduct in corn seeds significantly increased the germination test results, the shoots' first count emerged in a bed, as well as, root and seedlings fresh mass, fresh and dry mass in the field, length of the seedlings in the field, seedlings total length and growth index obtained by the Vigor-S®. It is concluded that the bioproduct presents as an essential bio-stimulant for corn seeds favoring germination parameters, vigor, and development of the seedlings.

Keywords: biostimulant; chitosan; coating; germination; *Zea mays* L.

Avaliação da qualidade fisiológica e vigor de sementes de milho revestidas com quitosana

RESUMO: *Em prol de um melhor desenvolvimento e produtividade das culturas, novos estudos estão buscando diferentes alternativas e tecnologias de caráter eficiente e menor impacto ambiental para alcançar tais finalidades, assim, a presente pesquisa objetivou avaliar o efeito da aplicação de um produto à base de quitosana na germinação e vigor de milho. O trabalho foi realizado na Universidade Estadual do Ceará, Campus Itaperi. Foi adotado um delineamento experimental inteiramente casualizado com quatro repetições de 50 sementes, com exceção dos testes de massa, comprimento e imagem,*

realizados em cinco repetições de 20 sementes. Foram utilizadas sementes da cultivar SM 996 submetidas a seis concentrações do produto à base de quitosana: 0,0% (testemunha); 0,5%; 1%; 2,5%; 5%; e 10%, sendo avaliados parâmetros de primeira contagem, teste de germinação, comprimento e massa fresca de radícula, parte aérea e plântula, teores de clorofila e carotenoides, extravasamento de eletrólitos, análise computadorizada de imagem pelo Vigor-S®, emergência, e comprimento, massa fresca e seca da parte aérea das plântulas em canteiro. O uso do revestimento com o bioproduto no milho aumentou significativamente os resultados do teste de germinação, a primeira contagem de plântulas emergidas em canteiro, assim como massa fresca de radícula e plântula, massa fresca e seca em campo, comprimento das plântulas em campo, comprimento total da muda e índice de crescimento obtidos pelo Vigor-S®. Conclui-se que o bioproduto se apresenta como importante bioestimulante para as sementes de milho, favorecendo parâmetros de germinação, vigor e desenvolvimento das plântulas.

Palavras-chave: *bioestimulante; germinação; quitosana; revestimento; Zea mays L.*

1 Introduction

Recent studies have sought new alternatives that favor the development and productivity of crops, such as corn, since Brazil is the third largest producer of this grain globally, behind the United States and China, and corn is the second most produced cereal in the country, as shown in data from ABIMILHO (2023) and Silva *et al*. (2020). Such relevance is due to its use for human and animal food, as well as for the production of beverages, polymers and fuels (Silva *et al*., 2020).

In favor of the success of the culture, the high quality of the seeds is a crucial factor, requiring adequate sanitary, genetic, physical and physiological characteristics (Costa; Campos, 1997). Among the physiological factors, seed vigor is a set of characteristics that determine its physiological performance, thus vigorous seeds favor rapid and uniform germination, cooperating with seedling growth (Soares *et al*., 2019).

The use of new technologies in the agricultural sector is of great value considering the population exponential increase, and consequently, the growing crop demand, and it is of interest that these techniques aim at the use of products of lower impact on the environment, seed quality and higher productivity (Shang *et al*., 2019).

The use of biopolymer coatings has been highlighted in the agricultural branch, whether its application is associated or not with natural products, fungicides, bioactive, or substances that favor the physiological seed quality and its use in large cultures, acting as an alternative to agrochemicals and environmentally harmful techniques (Godínez-Garrido *et al*., 2022; Malerba; Cerana, 2018; Sikder *et al*., 2021).

Among the several biopolymers, chitosan stands out as a biostimulant, since it favors germination and vigor parameters (Mahdavi; Rahimi, 2013), the shoot length and plant height (Mesa; Pedroso; Arrebato, 2015; Pedroso *et al*., 2017; Pedroso *et al*., 2019). It also provides the production and yields increase in corn crops (Choudhary *et al*., 2019) and rice (Zerpa *et al*., 2017), and activates defense mechanisms fighting phytopathogens (Freddo *et al*., 2012; Zerpa *et al*., 2017).

Chitosan is a chitin derivative, the second most abundant biopolymer in nature, obtained from the marine animal exoskeleton, arthropods and microorganisms (green

and brown algae, yeast, fungi and spores cell wall) (Korbecka-Glinka; Piekarska; Wiśniewska-Wrona, 2022; Sarmento *et al*., 2011). Non-toxicity, biodegradability, biocompatibility, low cost, easy acquisition, and renewability, among other characteristics, give chitosan a wide range of applications and studies (Martins *et al*., 2018).

It is expected that the application of chitosan products in corn seeds potentializes its physiological qualities, and the seedlings germinated with vigor and development. Thus, the present research aimed to evaluate the application effect of a chitosan-based product in corn germination and vigor. The use of the bioproduct in corn seed technology is part of the strategies that take advantage of the properties of chitosan, and its performance was evaluated in the present study through vigor, biochemical, field and image tests.

The efficiency of the FTSeed bioproduct in improving the physiological quality and vigor of corn seeds was evaluated through biochemical and physiological studies and comparison of images in the laboratory and field, the results of which were analyzed and interpreted through regression models, in order to list the best treatments.

2 Material and methods

The study was conducted in the Vegetable Ecophysiology Laboratory (ECOFISIO) at the Ceará State University (UECE), Itaperi, located in the State of Ceará, Brazil. It used the corn (*Zea mays* L.) cultivar SM 996. The applied product was the FTSeed, supplied and developed by the Fertsan Company, whose main components are soluble salts of chitosan polymeric derivatives, polysaccharides mix, urea, saccharides, organic acid mix, preservative and water.

Before starting the sows, the seeds were disinfected with 5% sodium hypochlorite commercial solution (NaClO) (2.5% a.i.) for five minutes. Then they were dried on towel paper and subsequently submitted to the treatments by imbibition in 30 minutes in the FTSeed solution, with the recommendation of 10 ml/kg, according to the treatments: T1 (control – water immersion), T2 (FTSeed at 0.5%), T3 (FTSeed at 1%), T4 (FTSeed at 2.5%), T5 (FTSeed at 5%) and T6 (FTSeed at 10%).

The following evaluations were performed in the laboratory in the treatments mentioned above.

2.1 Germination and first count

Four repetitions of 50 seeds were distributed in two germiest paper sheets and covered by a third and moistened with 2.5 times the weight of the paper and made into rolls that were maintained in biochemical oxygen demand germinator (BOD) in a constant temperature of 25 ºC and 12 hours photoperiod. The first count was performed on the fourth day after sowing (DAS) and the final count on the seventh DAS (Brasil, 2009), and the results were expressed in average percentages of normal seedlings by repetition.

2.2 Biochemical tests

Performed in conjunction with the above tests, after the germination final count, the a and b chlorophyll and carotenoid levels were determined using 0.1 g of fresh primary leaves, macerated with 0.08 g of calcium carbonate and 2.8 mL of acetone at 80%, after

filtered directly in a volumetric balloon of 10 mL the volume was completed with acetone at 80%. With this extract the absorbance readings were performed in the spectrophotometer at 648.6 nm and 663.2 nm, to estimate the "a" (Ca) and "b" (Cb) chlorophyll content. The carotenoid content has performed the readings in 646.8 nm, 663.2 nm and 470 nm, according to Lichtenthaler (1987). "A" and "b" chlorophyll and carotenoids values were calculated through the Equations 1, 2 and 3, established by Lichtenthaler (1987):

$$achlorophyll = 12.25 \times A\,663.2 - 2.79 \times A\,646.8 \quad (1)$$

$$bchlorophyll = 21.50 \times A\,646.8 - 5.10 \times A\,663.2 \quad (2)$$

$$Carotenoids = \frac{1000 \times A\,470 - (1.82 \times Ca - 85.02 \times Cb)}{198} \quad (3)$$

2.3 Electrolytes extravasation

It was performed in conjunction with the germination and biochemical tests, after the final germination count, 0.1 g of fresh leaves placed in test tubes containing 10 mL of distilled water were used. Then, the tubes were closed and maintained at rest for 24 h in BOD at 25 ºC. After this period, the reading of the initial conductivity (C1), was by a benchtop conductivity meter, soon after, the same was placed in a water bath at 80 ºC for 60 minutes, and when cooled the final conductivity was measured (C2). The relative permeability (RP) (Equation 4) was calculated, according to Tarhanen *et al*. (1999):

$$RP(\%) = \left[\frac{C1}{(C1+C2)}\right] \times 100 \quad (4)$$

2.4 Length and mass

Five repetitions of 20 seeds were used by treatment distributed in two rows of 10 seeds intercalated in two germiest paper sheets and covered with a third sheet. All the leaves were previously moistened with water in a quantity 2.5 times the weight of the dry paper. Rolls were created with the germiest sheets and placed in polyethene bags and were maintained in a biochemical oxygen demand germinator (BOD) at a constant temperature of 25 ºC and 12 hours photoperiod. For the determination of the normal seedlings' length, the measurement was performed at the seventh DAS of the shoot length (SL) in the limit region between hypocotyl and radicle, and of the radicle (RL) and its sum obtaining the value of the seedlings length (SeL) (Krzyzanowski *et al*., 2020).

Along with this test, the measurement of the shoots (SFM), the radicles (RFM) and the normal seedlings (SeFM) fresh mass were performed, obtaining the average weight of fresh matter by seedlings, expressed in g/seedlings of each repetition (Krzyzanowski *et al*., 2020).

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2.5 Field test

Performed in beds, the seeds were distributed in four repetitions (rows) of 50 seeds for each treatment, with a safety border of 20 cm established, spacing between treatments of 10 cm to 15 cm and the rows spaced in 10 cm with the aid of a stick the seeds were buried at the depth of 3 cm. The seedlings were treated with an application of Malathion 50CE, due to the presence of ants in the beds. The irrigation was performed daily with the equivalent of 10 mm of water per bed, except for rainy days. During the seven days of the experiment, the seedlings that emerged for the evaluation of the emergency speed (ESI), first emergency count (FEC) (fourth DAS) and emergency in the bed (EB) (seventh DAS) were accounted for. In the seventh DAS, the plants without leaf damage were sectioned close to the soil and the measurements of length, fresh and dry mass of the shoot were performed (Krzyzanowski *et al*., 2020).

2.6 Image test

It was performed with five repetitions of 20 seeds by treatment distributed in two rows of 10 seeds intercalated in two germiest paper sheets and covered with a third paper sheet. All the leaves were previously moistened with water in a quantity 2.5 times the weight of the dry paper. Rolls were created with the germiest paper sheets and placed in polyethylene bags and were maintained in a biochemical oxygen demand germinator (BOD) at a constant temperature of 25 ºC and 12 hours photoperiod and by three DAS. At the end of the period, the seedlings were transferred from the paper roll to a blue color vinyl acetate-ethylene sheet (VAE) with an area of 30 cm × 20 cm, according to Castan, Gomes-Júnior and Marcos-Filho (2018). Then, the seedlings' images were scanned by a HP Deskjet F4280 scanner adjusted for a resolution of 300 dpi and connected to a Core i5 computer in a box with its interior covered with aluminum.

The Vigor-S® software, for the determination of the following variables, processed the images individually: hypocotyl length, primary root length, total seedlings length, growth index, uniformity and vigor index. The root of each seedling was marked in red, while the hypocotyl was marked in blue. Manual corrections were performed for errors in marking the seedlings' structures, using the key numbers 1 (hypocotyl correction) and 2 (root correction) and a computer mouse (Figure 1).

Figure 1 ▶
Vigor-S® Analysis System Window with corn seedlings sample (cultivar SM 996) at the three days of germination testing.
Source: research data

Hypocotyl weight and the primary root weight were adjusted at 10% and 90%, respectively, for the calculation of the growth index. The contribution of the growth and uniformity parameters used to calculate the vigor index was of 70% and 30%, respectively.

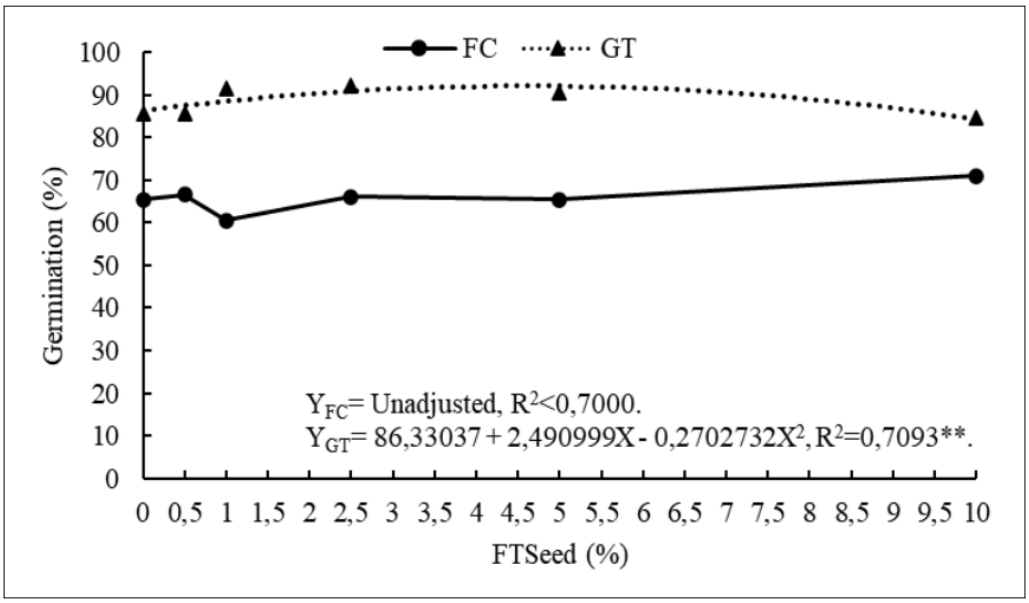
2.7 Experimental design and statistical analysis

The experiment was performed in a completely randomized design, and the results were submitted to the analysis of variation observing the significance by the F test, which when significant and with determination coefficients higher than 0.70, adjustments were performed by means of polynomial regressions of up to 3° degree. The ESTAT software (Statistical analysis system) was used for these calculations.

3 Results and discussion

The evaluation of the first count (FC) had significant statistical variation among the evaluated treatments (Figure 2), although the determination coefficient was lower than 0.70 ($R^2 = 0.5107$), presenting fluctuations among the treatments, and the application of FTSeed at 10% with higher germination percentage (71%).

Figure 2 ▶
Corn first count (FC) and germination test (GT).
Source: research data



T1 – Control (FTSeed at 0%). T2 – FTSeed at 0.5%. T3 – FTSeed at 1%. T4 – FTSeed at 2.5%. T5 – FTSeed at 5%. T6 – FTSeed at 10%. **Significant $p < 0.01$ of probability, by the F test. ns Non-significant

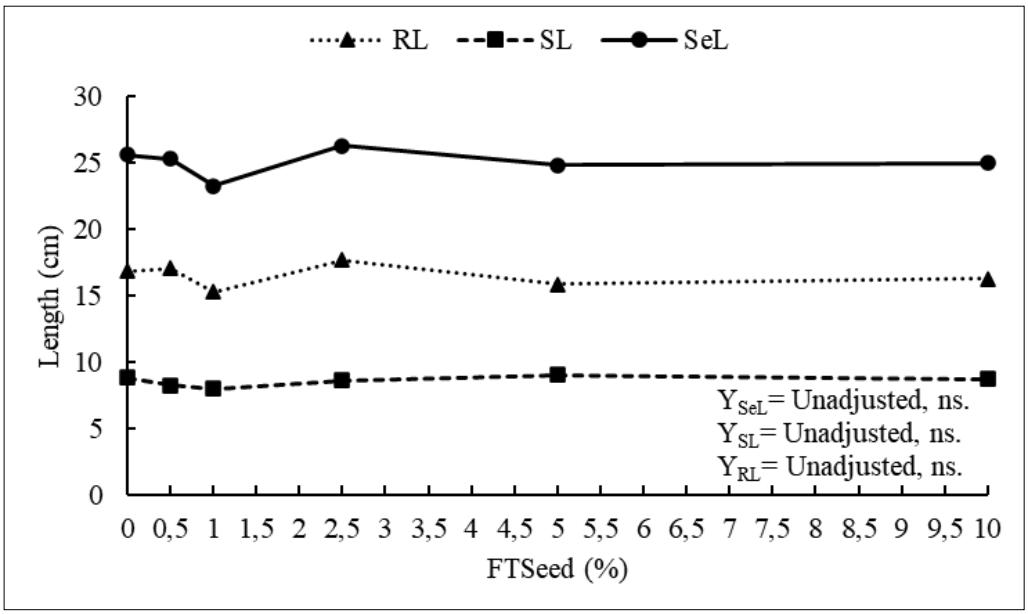
The germination test (GT) increased quadratically according to the evaluated treatments (Figure 2), presenting a higher percentage of germinated seedlings under the FTSeed estimated concentration at 4.5% (92.06%). However, in the estimated FTSeed concentrations at 9.25% (86.24%), 9.5% (85.60%), 9.75% (84.92%) and 10% (84.21%) it presented a deleterious effect on seed germination, reaching percentages lower than the control (86.33%).

According to Makhaye *et al*. (2021), the germination process is composed of a complex network of several signs, whether intrinsic or extrinsic, and the production of phytohormones is a fundamental step for the realization of this process, for example,

the gibberellic acid. Some chemicals end up inhibiting the gibberellins synthesis, delaying germination, however, Martins *et al*. (2018) suggest that chitosan does not belong to this product group, as observed in the results of the FTSeed application in concentrations below 9.25% in this research, although the concentrations above this percentage were deleterious.

The evaluation of the average radicle (RL), shoot (SL) and seedlings (SeL) lengths were not statistically significant, as it can be observed in Figure 3. However, an increase in the length of the radicle and seedling can be observed in the treatment of FTSeed at 2.5%. While, in both tests, the treatment FTSeed at 1% showed a shorter length, inferior to the control.

Figure 3 ▶
Corn radicle (RL), shoot (SL) and seedlings (SeL) length.
Source: research data

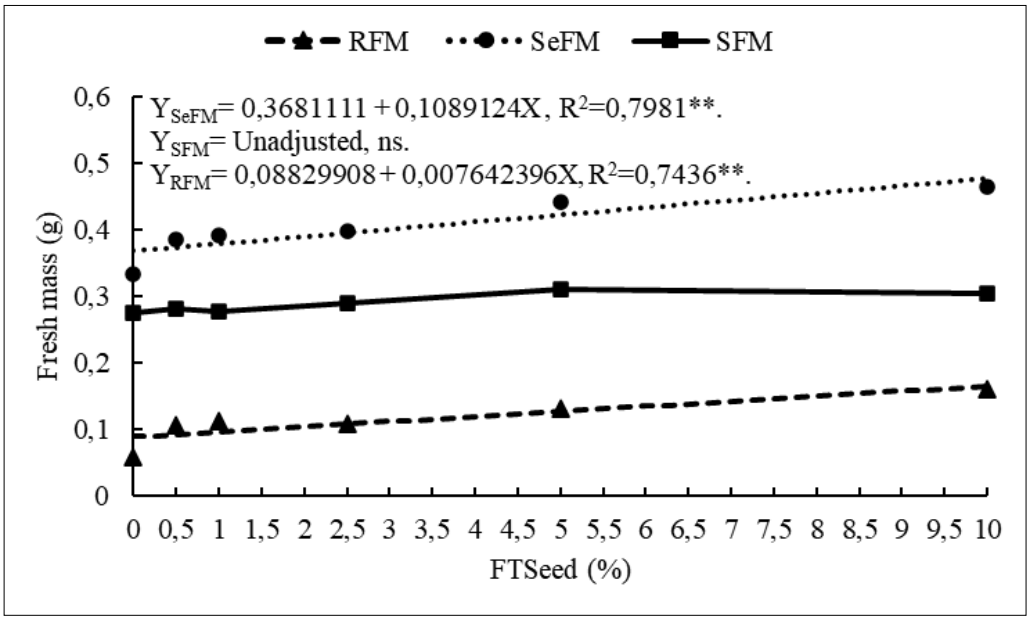


T1 – Control (FTSeed at 0%). T2 – FTSeed at 0.5%. T3 – FTSeed at 1%. T4 – FTSeed at 2.5%. T5 – FTSeed at 5%. T6 – FTSeed at 10%. ns Non-significant

Currently, the main studies on seed coatings are dedicated to the search for new active principles that improve the physiological response in the early stages of crop development. Similarly, in the application of Quitomax® on rice seeds in two varieties, it did not present difference among the treatments, but in both studies the authors highlight that the combined use of seed soaking and leaf aspersion stimulates higher cultures yields (Pedroso *et al*., 2017; Pedroso *et al*., 2019). Ziani, Ursúa and Maté (2010) applied a chitosan-based bioactive coating on artichokes, showing increased plant growth and antifungal action. The germination percentage, plant height and soybean dry weight improved under chitosan treatment (Zeng; Luo; Tu, 2012). Corn plants treated with Zn-chitosan nanoparticles (NPs) showed an increase in plant height and root length (Choudhary *et al*., 2019). The results of the study demonstrate the ability of chitosan to stimulate seedling growth.

The average corn shoot fresh mass (SFM) was not statistically significant, but the evaluation of the radicle fresh mass (RFM) grew linearly from the control (0.08 g) at the FTSeed estimated concentration at 10% (0.16 g), presenting the double of the mass with the application of 10% of the bioproduct compared to the control. The evaluation of the seedling's fresh mass (SeFM) had a linear increase, reaching its maximum point in the FTSeed concentration at 10% (0.47 g) (Figure 4).

Figure 4 ▶
Corn radicle (RFM), shoot (SFM) and seedlings (SeFM) fresh mass.
Source: research data

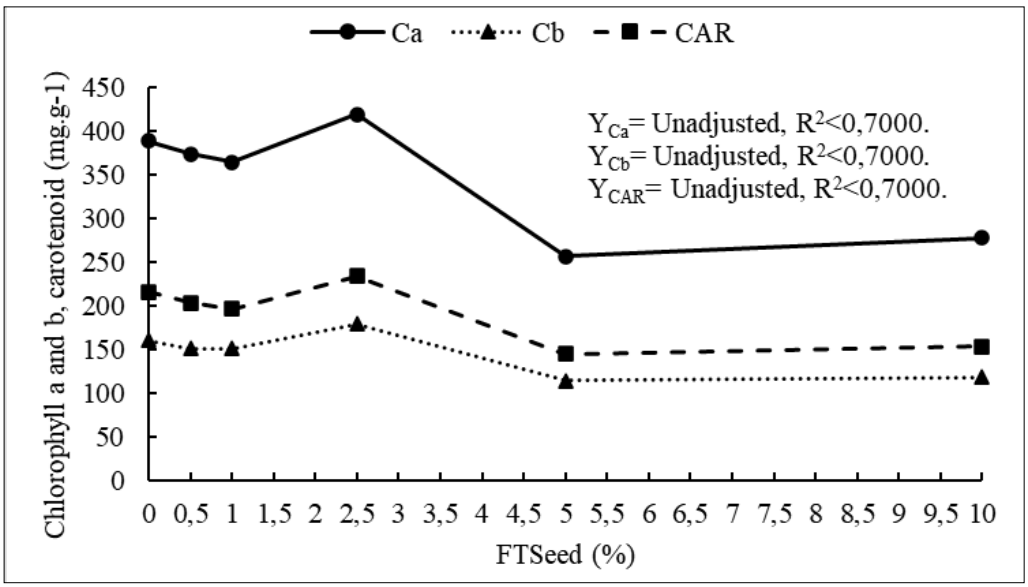


T1 – Control (FTSeed at 0%). T2 – FTSeed at 0.5%. T3 – FTSeed at 1%. T4 – FTSeed at 2.5%. T5 – FTSeed at 5%. T6 – FTSeed at 10%. **Significant at the level of $p < 0.01$ of probability, by the F test. ns Non-significant

Supporting these results, Saharan *et al*. (2016) in their studies in India with the application of Cu-chitosan nanoparticles (NPs) in corn seeds, obtained promising and statistically positive results for the seedlings, radicle and shoot length, as well as fresh mass using 0.04% of Cu-chitosan in seeds application for 4 hours. Immersion of wheat seeds in chitosan (CS) and chitosan nanoparticles (CSNPs) treatments resulted in an increase in fresh mass, by 50 µg/mL and 5 µg/mL, respectively (Li *et al*., 2019). Chitosan has a positive result in the development of corn at higher concentrations, probably due to the tegument, as observed in the study with wheat.

Chlorophyll levels (Ca and Cb) and carotenoids (CAR) evaluated had statistically significant variation (Figure 5), although the determination coefficient was lower than 0.70 (R^2 = 0.5697, R^2 = 0.5090 and R^2 = 0.5449, respectively). In both pigments, the maximum values reached were under the FTSeed concentration at 2.5%.

Figure 5 ▶
Corn a (Ca) and b (Cb) chlorophyll, and carotenoid (CAR).
Source: research data

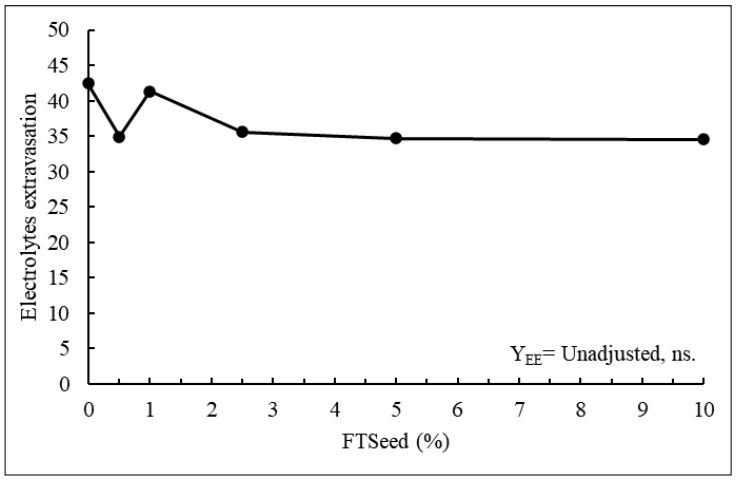


T1 – Control (FTSeed at 0%). T2 – FTSeed at 0.5%. T3 – FTSeed at 1%. T4 – FTSeed at 2.5%. T5 – FTSeed at 5%. T6 – FTSeed at 10%

Studies point out that products application developed with chitosan enable the increase of the photosynthetic capacity of the seedlings acting in their growth (Zeng; Luo, 2012). Corroborating with the results indicated, on the application of NPs, higher levels of clophoryl a and b were obtained in corn seeds (Choudhary *et al*., 2019).

According to Figure 6, the evaluation of the electrolytes extravasation (EE) did not present statistically significant variation.

Figure 6 ▶
Corn electrolytes extravasation (EE).
Source: research data

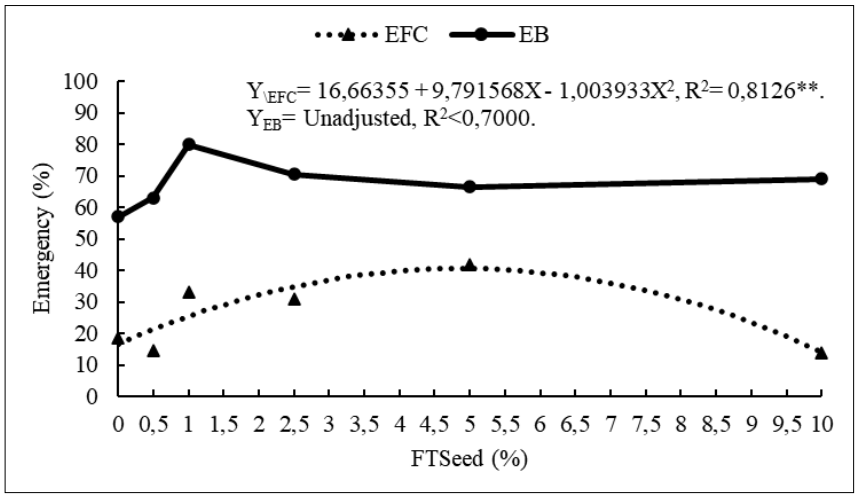


T1 – Control (FTSeed at 0%). T2 – FTSeed at 0.5%. T3 – FTSeed at 1%. T4 – FTSeed at 2.5%. T5 – FTSeed at 5%. T6 – FTSeed at 10%. ns Non-significant

As observed in Figure 6, two peaks of increase in the control and in the treatment of FTSeed at 1%, reveal greater extravasated intracellular content, and in the other treatments there is linearity, indicating that both presented the same level of stress, since the analysis of electrolyte leakage indicates the level of oxidative stress of the plants (Souza; Martins; Gaion, 2021).

In the tests beds, the emergence first count (EFC) had a quadratic increase, according to the evaluated concentrations, reaching its estimated maximum point with the FTSeed application at 5% (40.5%). For the emergence in bed (EB) there was statistically significant variation, despite the determination coefficient was lower than 0.70 (R^2 = 0.5728). It is observed that there was a higher percentage of seedlings emerged with the FTSeed concentration at 1% (80%) (Figure 7).

Figure 7 ▶
Corn first emergency count (EFC) and emergency in the bed (EB).
Source: research data

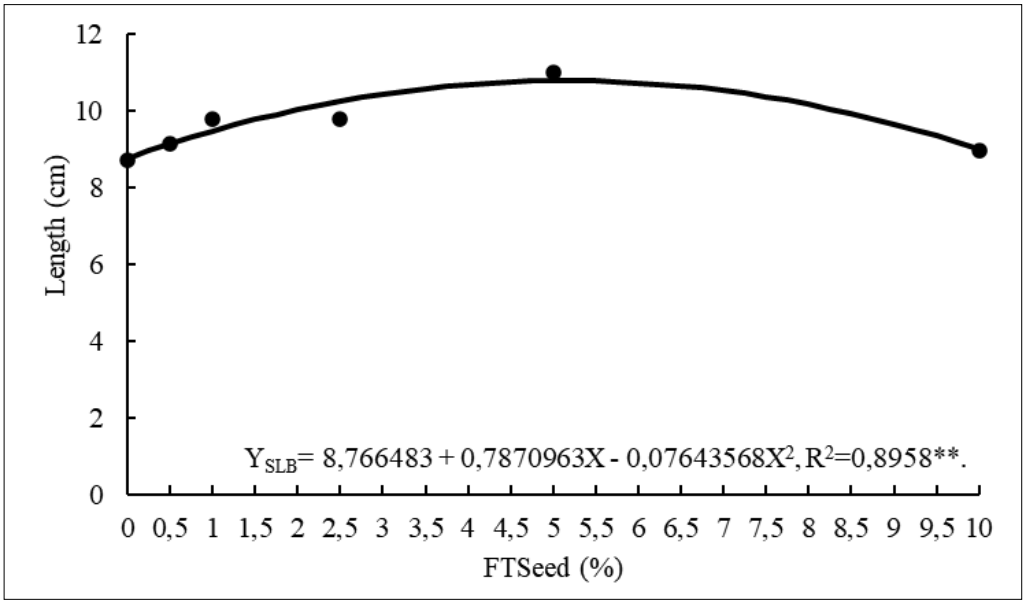


T1 – Control (FTSeed at 0%). T2 – FTSeed at 0.5%. T3 – FTSeed at 1%. T4 – FTSeed at 2.5%. T5 – FTSeed at 5%. T6 – FTSeed at 10%. **Significant at the level of $p < 0.01$ of probability, by the F test

Chitosan-based products applied in seeds for no-till can improve field emergence, the gel product application at 2.5% in rice seeds resulted in 87% of germinated seedlings and promoted an increase in the production of 16.21%, as well as, observed in studies with different varieties of rice, cultivar INCA LP 5 and J-104, corn and melon (Choudhary *et al*., 2019; Pedroso *et al*., 2017; Pedroso *et al*., 2019; Tovar *et al*., 2018; Zerpa *et al*., 2017). The contact of chitosan with the soil can promote the action of chitinases and other enzymes, which facilitate the interaction of roots with mycorrhizae in the soil (Tovar *et al*., 2018).

The average shoot length that emerged in beds (SLB) (Figure 8) increased quadratically, presenting as the estimated maximum point of the FTSeed concentration at 5.25% (10.79 cm), reducing shortly thereafter.

Figure 8 ▶
Corn shoot length (SLB) emerged in bed.
Source: research data

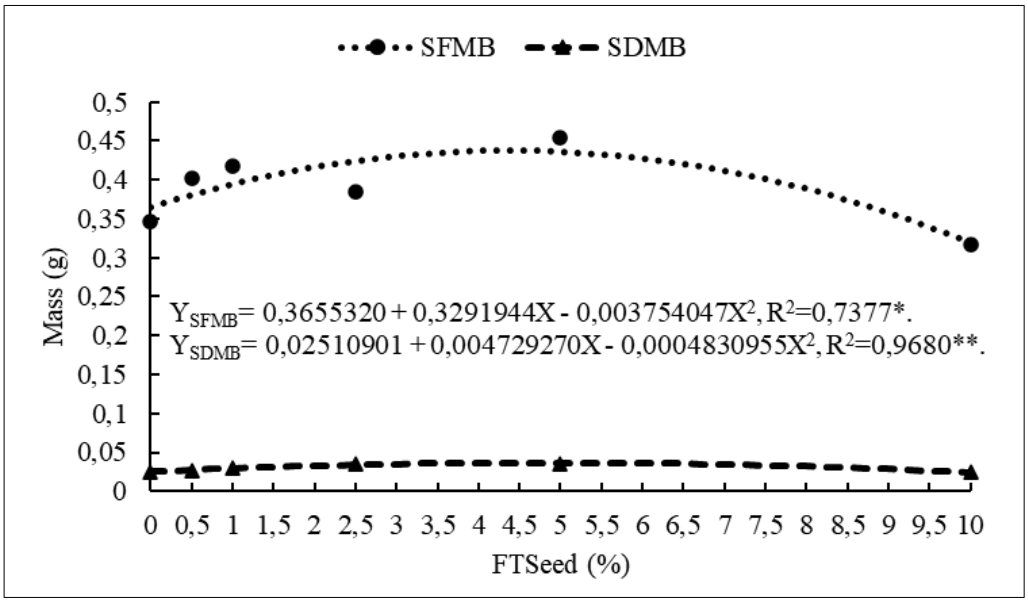


T1 – Control (FTSeed at 0%). T2 – FTSeed at 0.5%. T3 – FTSeed at 1%. T4 – FTSeed at 2.5%. T5 – FTSeed at 5%. T6 – FTSeed at 10%. **Significant at the level of $p < 0.01$ of probability, by the F test

Studies show similar results, in which the use of chitosan-based products, chitosan biofilms, or chitosan nanoparticles, perform important increase in seedling length, as in rice and corn cultivars, reaching an increase of 30% compared to controls in studies with beans and sesame (Mesa; Pedroso; Arrebato, 2015; Godínez-Garrido *et al*., 2022; Guan *et al*., 2009). Authors still report, that with the application of Cu-chitosan NPs in corn seeds, there was a significant and visual increase in plant growth compared to the control group (Choudhary *et al*., 2017). The increase in growth parameters under the action of chitosan can be attributed to the fertilizing characteristics of its compounds, acting as a biostimulant (Malerba; Cerana, 2018).

When analyzing Figure 9, we observe a quadratic behavior of the average shoot fresh (SFMB) and dry mass (SDMB) that emerged in the beds. With the increase of the FTSeed concentrations, there was an increase of the masses reaching the estimated maximum point in the concentrations of 4.5% (0.43 g) and 5% (0.36 g) of the bioproduct, respectively, followed by a reduction of all lengths.

Figure 9 ▶
Corn shoot dry (SDMB) and fresh (SFMB) mass, emerged in bed.
Source: research data

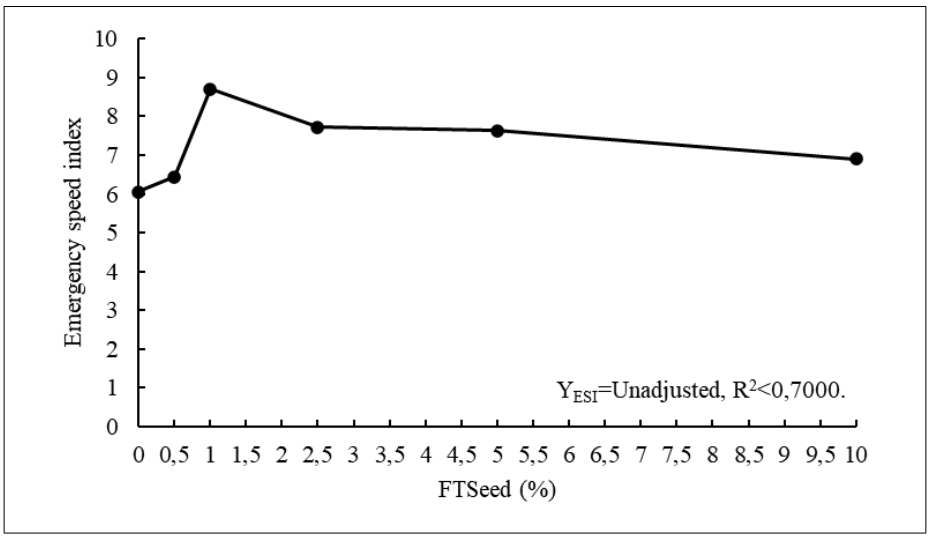


T1 – Control (FTSeed at 0%). T2 – FTSeed at 0.5%. T3 – FTSeed at 1%. T4 – FTSeed at 2.5%. T5 – FTSeed at 5%. T6 – FTSeed at 10%. *, **Significant, respectively, at the level of $p < 0.05$ and $p < 0.01$ of probability, by the F test

Vigorous seeds provide higher dry matter transfer from the reserve tissues to the embryonic axis in development, resulting in seedlings with higher mass, due to the dry matter accumulation and higher growth rate (Krzyzanowski *et al.*, 2020), as observed in the results with the application of the bioproduct in the present study.

The emergence speed index (ESI), as observed in Figure 10, had statistically significant variation, although the determination coefficient was lower than 0.70 ($R^2 = 0.5745$), and the FTSeed concentration at 1% was responsible for presenting higher vigor, corroborating with the results found in the EB, since the daily values obtained in the emergence of the seedlings are considered for obtaining the ESI.

Figure 10 ▶
Corn emergency speed index (ESI).
Source: research data



T1 – Control (FTSeed at 0%). T2 – FTSeed at 0.5%. T3 – FTSeed at 1%. T4 – FTSeed at 2.5%. T5 – FTSeed at 5%. T6 – FTSeed at 10%

At the concentration of FTSeed at 1%, there was a better performance of seedlings in the field, but at higher concentrations, there was a decline in ESI, and there may be

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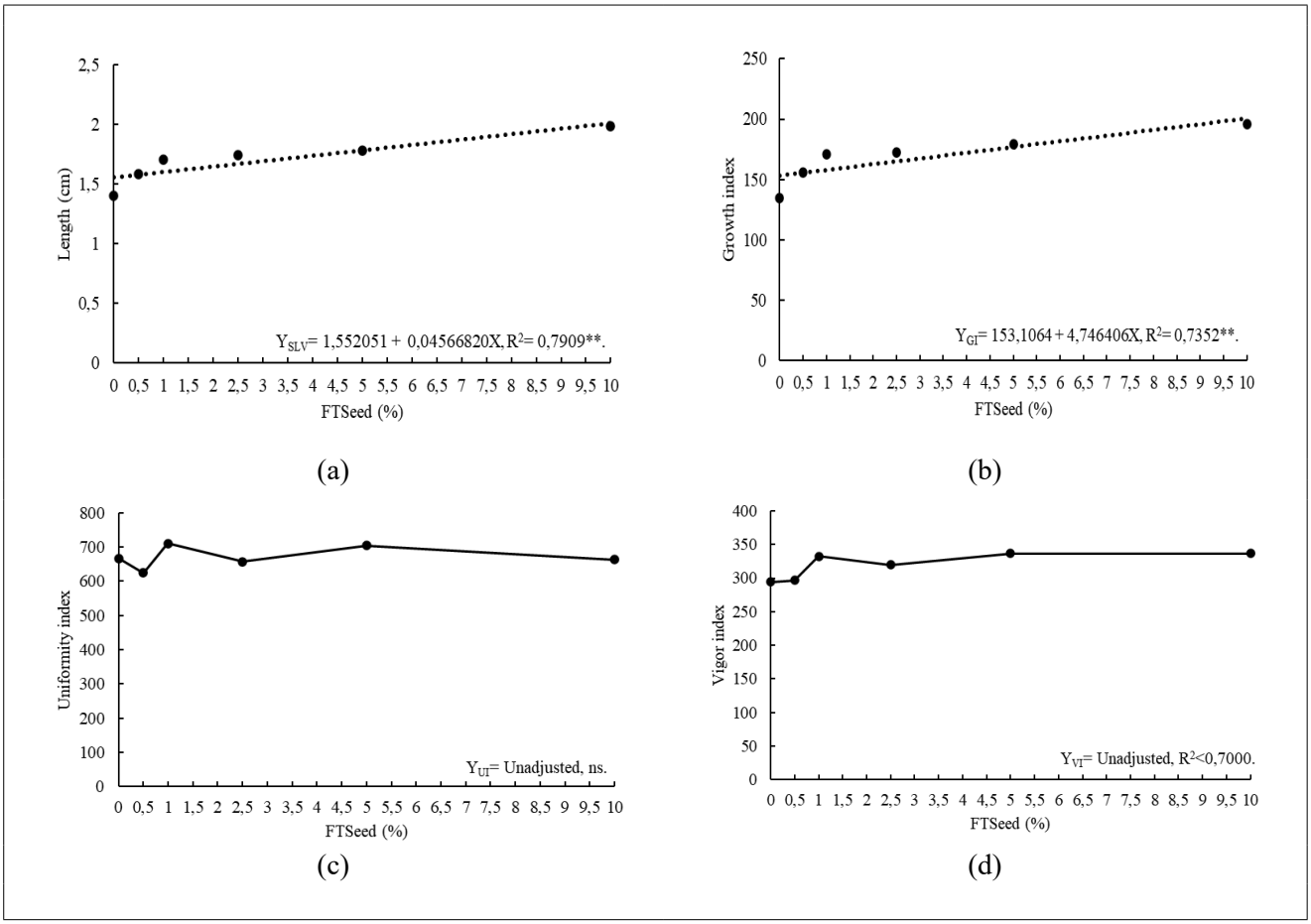
a delay due to the coating with chitosan, as well as in the coating of corn seeds with chitosan associated with cyanobacterial biomass, where in both treatments there was a reduction in ESI (Zacharias *et al*., 2022). Lizárraga-Paulín *et al*. (2013) studying the use of chitosan at 2% for 12 hours in maize seeds of Normal and QPM varieties, found that this treatment did not differ from the control regarding the seedling's emergence speed. In *Eucalyptus saligna* seeds, it was observed that the chitosan treatment at 0.94%, also in low concentration, provided higher ESI values, but as the concentration increased there was a reduction of this index (Freddo *et al*., 2012).

The analysis of data variation obtained by image by Vigor-S® had linear growth for the average seedlings length variable (SLv), reaching the estimated maximum value with the FTSeed concentration at 10% (2 cm) (Figure 11a). The growth index (GI) also increased linearly until the FTSeed estimated maximum concentration at 10% (200.57) (Figure 11b). In both growth variables, higher values were observed with bioproduct application in higher concentrations.

Figure 11 ▼
a) Corn average seedlings length (SLV). b) Corn seedlings growth index (GI). c) Corn seedlings uniformity index (UI). d) Corn seedlings vigor index (VI) analyzed by Vigor-S®.
Source: research data



T1 – Control (FTSeed at 0%). T2 – FTSeed at 0.5%. T3 – FTSeed at 1%. T4 – FTSeed at 2.5%. T5 – FTSeed at 5%. T6 – FTSeed at 10%. **Significant at the level of $p < 0.01$ of probability, by the F test. ns Non-significant

The uniformity index (UI) did not present a statistically significant difference (Figure 11c), inferring that there was no variation in the uniformity of seedling development (Castan; Gomes-Junior; Marcos-Filho, 2018). There was statistically significant variation for the vigor index (VI), although the determination coefficient was lower than 0.70 (R^2 = 0.4875) (Figure 11d), presenting a higher value of the FTSeed concentration at 10% (336.5).

The computerized analysis of images by Vigor-S® is an alternative for evaluating the vigor of seeds in a shorter time, however, the results of Vigor-S® were not compatible with the results presented in the traditional method (Oliveira *et al*., 2021).

The results of the study pointed to the potential of chitosan on the development and vigor of corn, it is also of great relevance to complementary research on this product, aiming at a better understanding of its functionalities and action, mainly in large cultures, besides being an alternative for agrochemicals that impact the environment.

4 Conclusion

Corn seed coating with FTSeed bioproduct was presented as a biostimulant on the germination, seedlings development and fresh and dry mass, providing better results in the estimated concentrations at 4.5% to 10% and with higher determination coefficient in the seedlings dry mass emerged in bed ($R^2 = 0.9680$, $p < 0.01$).

Although an ideal concentration has not been established, the study showed beneficial results with the use of the bioproduct, therefore, it is necessary to carry out more tests between the most advantageous concentrations, in order to establish one that provides greater vigor to the seeds.

That way, the bioproduct in the study presents itself as an interesting alternative to agrochemicals used in large cultures, reducing the environmental and economic damage to the crops.

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Conflict of interests

The authors declare no conflict of interest.

Contributions to the article

LIMA, Y. C.: conception or design of the study/research; data analysis and/or interpretation; final review with critical and intellectual participation in the manuscript. **ALMEIDA, A. R. L. S.:** data analysis and/or interpretation; final review with critical and intellectual participation in the manuscript. **JACINTO JUNIOR, S. G.:** data analysis and/or interpretation. **BONILLA, O. H.:** conception or design of the study/research. **LUCENA, E. M. P.:** conception or design of the study/research; final review with critical and intellectual participation in the manuscript. All authors contributed to the writing, discussion, reading, and approval of the final version of the article.

Nota

These results are derived from the Master's dissertation of Yasmin Chagas Lima, available at: https://siduece.uece.br/siduece/publico/resultadosPesquisarItemPublicoResumido/ppgcn/7/2022. In Portuguese.

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