

Application of QuitoMax[®] to tomato cultivation under NaCl stress conditions: scientific model experiments for an efficient education

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ABSTRACT

This experiment was conducted at the Plant Production Laboratory of the Instituto Tecnológico del Valle del Yaqui, located at 27° 24' 46" N and 110° 07' 59" W, under semi-controlled conditions.

Objective: This research aimed to evaluate the response of tomato plants of the Amalia variety to the application of different doses of QuitoMax[®] under saline conditions.

Design/Methodology/Approach: This study aimed to evaluate the response of tomato plants of the Amalia variety to the application of different doses of QuitoMax[®] under saline conditions.

Results: The results indicate that the application of QuitoMax[®] under salinity stress conditions (ECe of 6 dS m⁻¹) promotes plant development, enhances the normalized difference vegetation index (NDVI), improves gas exchange parameters, and increases chlorophyll content.

Findings/Conclusions: The application of 350 mg ha⁻¹ yielded the best results under saline conditions, with an increase of 0.40 kg per plant compared to the control treatment.

Keywords: *Solanum lycopersicum*; salinity; biostimulant.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is among the most important horticultural crops worldwide due to its extensive cultivation, high demand, and diverse applications in the food industry. It can be consumed fresh or processed into a wide range of products (Ji *et al.*, 2023; Al-Roshdi *et al.*, 2023).

Tomato cultivation is a priority in the agricultural sector, as it ranks among the most widely consumed vegetables and serves as an important source of raw material for the food



industry (Serrano and Caballero, 2022b). However, its yield can be significantly affected by abiotic and biotic factors, which often lead to substantial reductions in harvests (Carvalho *et al.*, 2020; Rodrigues *et al.*, 2020; Ávila *et al.*, 2023).

In northwestern Mexico, a significant proportion of soils are affected by salinity (Cital *et al.*, 2025), often exhibiting very high concentrations in the saturation extract, which restricts the physiological and productive performance of tomato plants (Boorboori & Li, 2025).

When tomato is cultivated in saline soils, yield declines because it is a glycophytic species moderately susceptible to salt stress. According to Alam *et al.* (2021), the greatest sensitivity to salinity in tomato crops occurs when the electrical conductivity of the saturated extract (EC_e) exceeds 2.5 dS m⁻¹. In general, salinity exerts diverse effects on plants, including morphological, physiological, and biochemical alterations, which can significantly reduce yield (Bacha *et al.*, 2017).

Completely eliminating soil salinity is practically impossible; therefore, it is necessary to implement alternative strategies that mitigate the negative effects caused by salt accumulation in the soil (Serrano & Caballero, 2022a). Given the increasing prevalence of this stressor, rapid and precise solutions are required to sustain agricultural production (Serrano & Caballero, 2022b).

Additionally, bioactive products can exert various beneficial effects on plants, including the induction of defense mechanisms and the stimulation of growth. These compounds offer the advantage of being non-toxic to plants and environmentally safe (Terry *et al.*, 2017; Alzate *et al.*, 2022; Gedeon *et al.*, 2022; Chanthini *et al.*, 2022; Abdelhamid *et al.*, 2022; Ikuyinmin *et al.*, 2022; Sotolongo *et al.*, 2025).

QuitoMax[®] is a liquid formulation based on chitosan that stimulates seed germination and plant growth by accelerating metabolic processes during tomato cultivation (Reyes *et al.*, 2020). Its use has demonstrated positive effects on the yield of vegetables, grains, and tubers (Morales *et al.*, 2015, 2016; Falcón *et al.*, 2021). This biostimulant has been validated as an activator of growth, yield, and crop protection for species of agricultural interest, showing promising results (Falcón *et al.*, 2015b; Jiménez, 2015; Morales *et al.*, 2015, 2016; Rodríguez *et al.*, 2017; Pedroso *et al.*, 2019; González *et al.*, 2021). However, previous studies with QuitoMax[®] have not sufficiently addressed the response of tomato crops under saline conditions.

Addressing the challenges facing agriculture at global, national, and regional levels depends not only on technological innovations but also on the conscious, critical, and motivated training of students in agronomic sciences. Their academic preparation must be closely linked to practical experiences and active participation in research projects with real applicability in rural contexts. In particular, agricultural biostimulants formulated from plant extracts, algae, and other natural compounds represent effective and sustainable alternatives to mitigate the effects of abiotic stress—such as salinity—and to promote plant growth and overall health (Parra, 2022).

The use of these products not only benefits plant development but also promotes nutrient absorption, improves stress tolerance, and enhances physiological efficiency, thereby reducing the reliance on conventional chemical inputs (Parra, 2022).

Within this educational and scientific context, the objective of this study was to evaluate the response of tomato plants (Amalia variety) to different doses of QuitoMax[®] under saline conditions, with the participation of students from the Engineering in Sustainable Agricultural Innovation program at the Technological Institute of the Yaqui Valley (Bácum, Sonora, Mexico). Student collaboration enabled the integration of academic training with the generation of useful and locally relevant knowledge, contributing to biodiversity and productivity in fragile, degraded ecosystems such as those of the Yaqui Valley.

Addressing agricultural challenges at global, national, and regional levels requires the conscious and motivated preparation of students, particularly those in agronomic disciplines. This preparation should be complemented by rigorous research that demonstrates the effectiveness of agrobiological products with biostimulant properties capable of mitigating the effects of abiotic stress in crops such as tomato. Furthermore, studies conducted with active student participation contribute to enhancing species biodiversity and continuously improving productivity in semi-arid regions.

The objective of this study was to evaluate the response of tomato plants (Amalia variety) to different doses of QuitoMax[®] under saline conditions, with the participation of students from the Engineering in Sustainable Agricultural Innovation program at the Technological Institute of the Yaqui Valley, Bácum, Sonora, Mexico. This work establishes the current state of knowledge on the topic, its justification and relevance, as well as the study objectives, all presented concisely within a two-page limit.

MATERIALS AND METHODS

Experimental conditions

The research was conducted under semi-controlled conditions in the Plant Production Laboratory of the Tecnológico Nacional de México, Campus Valle del Yaqui. Seeds of the Amalia tomato variety were obtained from the Genetic Improvement Program of the National Institute of Agricultural Sciences (INCA). QuitoMax[®] was used for seed pre-germination at a concentration of 1 g L⁻¹ for two hours. Additionally, the biostimulant was applied foliarly using a manual atomizer, always in the early morning hours, as recommended by Terry *et al.* (2017) for tomato crops at the onset of the flowering phenophase.

The plants were cultivated under a controlled photoperiod of 12 h light and 12 h darkness, with an average temperature of 21 °C. Seeds were sown in polypropylene trays containing 128 cavities (66.4 cm in length, 33.5 cm in width, and 7.7 cm in height) at a depth of 1 cm. An inert substrate (SUMCHINE) was employed, moistened to 95% of its field capacity using tap water with an electrical conductivity of 0.22 dS m⁻¹.

Seedlings were fertilized seven days after emergence (DAE) with a complete formula fertilizer (Triple 19) at a concentration of 1 g L⁻¹. A second fertilization was applied at 14 DAE using the same fertilizer at a concentration of 5 g L⁻¹, delivering 10 mL per root ball. Irrigation was performed daily to maintain the substrate at 95% of its field capacity.

Six treatments were established, comprising doses of 0, 300, 350, and 400 mg ha⁻¹ under saline conditions (EC=6 dS m⁻¹), the recommended dose under non-saline conditions, and an absolute control without stress and without application of the biostimulant QuitoMax[®]. Each treatment was replicated five times (Table 1).

Table 1. Treatments and their descriptions.

Treatments	Description:
T1	0.0 mg ha ⁻¹ of QuitoMax [®] in a nonsaline soil
T2	0.0 mg ha ⁻¹ of QuitoMax [®] in a saline soil
T3	300.0 mg ha ⁻¹ of QuitoMax [®] in a nonsaline soil
T4	300.0 mg ha ⁻¹ of QuitoMax [®] in a saline soil
T5	350.0 mg ha ⁻¹ of QuitoMax [®] in a saline soil
T6	400.0 mg ha ⁻¹ of QuitoMax [®] in a saline soil

The treatments were distributed in a completely randomized experimental design on the basis of the homogeneity of the existing climatic conditions in the experimental area.

Filling the pots

Plastic bags with a capacity of 4.0 L were filled with Vertisol soil (Verhulst *et al.*, 2011). This classification follows the USDA Soil Taxonomy methodology (USDA-NRCS, 1998) and is correlated with the World Reference Base system (Nachtergaele *et al.*, 2000).

The soil exhibited a low organic matter (OM) content (OM=0.5%), which is characteristic of soils in the region (Peñuelas *et al.*, 2022). Base saturation was 42%, corroborating the presence of CaCO₂ with a value of 2.0 meq. Chemical analyses were performed at the Laboratory of the Forest, Agricultural and Livestock Research Institute (INIFAP), Obregón City, Sonora, Mexico, following the official Mexican standard NOM-138-SEMARNAT/SS-2003.

To prepare the bags for treatments without salt, they were washed with high-quality water. The electrical conductivity (EC) of the saturation extract was monitored using a portable digital multiparameter device (Combo brand) until it was confirmed to be below 0.9 dS m⁻¹. Soil water content was determined by the gravimetric method, based on mass difference, yielding a value equivalent to 83.55% of field capacity. This result was corroborated using a tensiometer and the tension-moisture curve characteristic of the studied soil (IRRROMETER).

Transplanting, fertilization and irrigation

Plants were transplanted into bags 28 days after emergence. Following transplantation, fertilization was applied at a rate of 450 kg ha⁻¹. Additional applications of the same fertilizer were performed prior to flowering and during fruit development, in accordance with the recommendations of the technological package for this crop (AGRINOVA, 2022). Cultural practices were implemented following the guidelines provided in the technical manual for tomato production (Gómez *et al.*, 2010).

Plant development variables

Twenty-five days after transplantation, ten plants were randomly selected from each treatment for evaluation. Plant height (PH) was measured from the stem base to the apical primordium, and root length (RL) was measured from the root collar to the tip of the

main root (cm). Stem thickness (ST) was determined 2 cm above the root collar using a TRUPER digital caliper (mm). The number of leaves per plant (LP) was recorded by direct count. The root-shoot ratio (R/T) was calculated as the ratio of root length to plant height. To determine root volume (RV, mm³), ten roots were carefully washed with distilled water to remove any substrate and then individually placed in a graduated cylinder containing water at a known volume. The volume displacement was recorded, and the difference was used to calculate the root volume for each sample.

Development dynamics were assessed in eight plants per treatment. Each plant was labeled and numbered to monitor height increments at weekly intervals. At maturation, the number of days elapsed since transplantation was recorded, and the final plant height was divided by this value. The relative growth rate (RGR) was expressed in cm day⁻¹ (Li *et al.*, 2019).

Vegetation index of normalized difference

The normalized difference vegetation index (NDVI) was measured using a portable Trimble™ sensor (Govaerts and Verhulst, 2010) between 08:00 and 09:00 during the flowering phenophase. For each treatment, 20 measurements were taken at a height of 0.60 m above the plant canopy, following the sensor specifications (Govaerts and Verhulst, 2010). NDVI values were evaluated for each treatment within the theoretical range of -1 to 1.

Photosynthesis, perspiration and stomatal conductance

Photosynthetic activity was measured in leaves during the flowering phenophase using a portable system (LI-6400XT, LI-COR, Inc.). The infrared gas analyzer (IRGA) determines CO₂ and water vapor concentrations through infrared spectrometry. Measurements were conducted between 10:00 and 11:00 on sunny days. For each plant, the three leaves most exposed to direct solar radiation were inserted by their central portion into the natural light gas exchange chamber (3.0×2.0 cm).

All measurements were performed under a light intensity greater than 1500 μmol m⁻² s⁻¹, with a CO₂ concentration of 400 μmol mol⁻¹ and a constant flow rate of 500 μmol s⁻¹. The variables recorded included maximum photosynthesis (A_{\max} , μmol CO₂ m⁻² s⁻¹), transpiration (E, μmol H₂O m⁻² s⁻¹), and stomatal conductance (g_s , mmol m⁻² s⁻¹).

Chlorophyll content

Chlorophyll concentration was measured using a SPAD-501 portable meter (Minolta Camera Co., Ltd., Osaka, Japan) during the flowering phenophase between 12:00 and 13:00. Measurements were taken at the middle portion of the leaf located in the central part of the plant. For each treatment, eight plants were evaluated, and the average of three readings per leaf was recorded.

Performance and its components

Among the performance indicators, the number of bunches per plant (NBP), number of flowers per bunch (NFB), and number of fruits per bunch (NFrB) were determined by

direct counting. Fruiting efficiency (FE) was calculated as the ratio between the number of fruits (NFrB) and the number of flowers (NFB). Equatorial fruit diameter (EFD) was measured in centimeters using a digital caliper (TRUPER). Yield (Y) was determined by weighing fruits at physiological maturity harvested from each plant using a high-precision analytical balance (Mettler Toledo GmbH, Greifensee, Switzerland) and expressed in kg plant^{-1} .

Statistical analysis

The data were analyzed using a one-way analysis of variance (ANOVA) based on a fixed-effects linear model. When significant differences among treatments were detected, Tukey's multiple comparison test was applied at significance levels of 5% and 1%. All statistical analyses were performed using the STATISTICA software package, version 14.5 for Windows.

RESULTS AND DISCUSSION.

Analysis of the variables of plant development

The application of different doses of QuitoMax[®] produced positive and significant effects on leaf number (LN), node height (NH), and stem thickness (ST). Under saline conditions, a similar trend was observed for all three variables: as the QuitoMax[®] dose increased, the values also increased, although the relationship was not linear. At 400 mg ha^{-1} , the effect plateaued, suggesting a compensatory response by the plant. Notably, plant height (PH) exhibited greater tolerance compared with LN and ST, as its response remained similar under both saline and non-saline conditions following QuitoMax[®] application (Table 2).

The application of different doses of QuitoMax[®] had a positive and significant effect on root length (RL), root volume (RV), and root growth coefficient (RGC). For these variables, a reduction in values was observed when conditions shifted from non-saline to saline. Under saline conditions, QuitoMax[®] application stimulated root development, with the best overall response obtained at a dose of 350 mg ha^{-1} (Table 3).

Table 2. Average values of Plants height (PH), leaves number (LN) and stem thickness (ST).

Treatments	Variables		
	PH (cm)	LN	ST (mm)
T1	29.63 ^{abc}	12.31 ^b	10.95 ^a
T2	27.58 ^c	9.66 ^c	8.42 ^c
T3	29.83 ^{abc}	13.31 ^a	10.90 ^a
T4	28.92 ^{bc}	12.33 ^b	9.10 ^{bc}
T5	31.00 ^{ab}	13.01 ^{ab}	10.62 ^a
T6	31.83 ^a	12.51 ^{ab}	9.52 ^b
SEx	0.31	0.21	0.18

(T1 - nonsaline; T2 - saline; T3 - nonsaline + 300 mg ha^{-1} T4 - saline + 300 mg ha^{-1} ; T5 - saline + 350 mg ha^{-1} ; T6 - saline + 400 mg ha^{-1}) Means with equal superscripts in the same column do not differ significantly according to Tukey's test for $p \leq 0.05$. SEx: standard error of the mean of the treatments.

Table 3. Average values of root length (RL) and volume (RV), root-tally relationship (r(R/S)) and relative growth rate (RGR).

Treatments	Amalia			
	RL	RV	r (R/S)	RGR
T1	25.04 ^{bc}	14.05 ^b	0.84	0.87 ^{abc}
T2	22.3 ^d	13.06 ^c	0.85	0.81 ^c
T3	25.55 ^{ab}	14.5 ^{ab}	0.82	0.88 ^{abc}
T4	25.47 ^{abc}	14.21 ^{ab}	0.86	0.85 ^{bc}
T5	26.31 ^a	14.98 ^a	0.88	0.91 ^{ab}
T6	24.46 ^c	14.56 ^{ab}	0.85	0.93 ^a
SEx	0.23	0.13	??	0.01

(T1 - nonsaline; T2 - saline; T3 - nonsaline + 300 mg ha⁻¹; T4 - saline + 300 mg ha⁻¹; T5 - saline + 350 mg ha⁻¹; T6 - saline + 400 mg ha⁻¹). Means with equal superscripts in the same column do not differ significantly according to Tukey's test for $p \leq 0.05$. SEx: standard error of the mean of the treatments.

Saline treatments significantly affected the relative growth rate (RGR), but this effect was mitigated by the application of QuitoMax[®]. The best response was observed at a dose of 400 mg ha⁻¹. Of particular note is the increase in root length (RL) following biostimulant application, which averaged more than two centimeters. These findings confirm the antistress effect of QuitoMax[®] under saline conditions.

Thus, the application of QuitoMax[®] clearly enhanced the development variables evaluated under saline conditions, as the observed responses can be attributed to the product's ability to stimulate plant growth, which is influenced by both the applied concentrations and the method of application. In this context, Falcón *et al.* (2011) reported that chitosan increases protein levels in leaves as well as enzymatic activity.

The response of plant height (PH), leaf number (LN), stem thickness (ST), root length (RL), root volume (RV), and relative growth rate (RGR) was greatest at a dose of 350 mg ha⁻¹ and declined when the dose was increased to 400 mg ha⁻¹, consistent with the findings reported by Martínez *et al.* (2015). These authors noted that biostimulants exert their effects at relatively low concentrations, and in tomato cultivation, the optimal response is typically observed at approximately 350 mg ha⁻¹.

Similar findings to those reported in this study were described by Martínez *et al.* (2015) when evaluating the imbibition of rice seeds (INCA LP-5 and INCA LP-7 varieties) at different concentrations for 24 h. They observed the greatest stimulation of seedling growth under saline conditions. Likewise, Gómez *et al.* (2024) reported optimal growth at a concentration of 100 mg L⁻¹ when QuitoMax[®] was applied to pepper (*Capsicum annuum* L.) in the absence of salts.

Ullah *et al.* (2020) investigated different doses of chitosan (0, 50, 100, and 150 mg L⁻¹) in tomato crops under semi-controlled conditions at four salinity levels (0, 5, 10, and 15 dS m⁻¹). The authors reported that biostimulant application positively influenced plant development indicators, with the best responses in plant height, leaf number, leaf area, and stem thickness observed at a dose of 150 mg L⁻¹. Furthermore, no scientific publications have examined the effect of QuitoMax[®] on growth rate under saline conditions.

Overall, the application of QuitoMax[®] under saline conditions promoted variation in the morphological variables evaluated, exhibiting a stimulatory effect as the biostimulant dose increased. However, this effect declined at doses exceeding 350 mg ha⁻¹.

Analysis of the normalized difference vegetation index

When the normalized difference vegetation index (NDVI) was evaluated, significant differences ($p \leq 0.05$) and positive effects among treatments were observed (Figure 1). The highest NDVI values occurred in non-saline treatments, with further increases when the biostimulant was applied. Under saline conditions, NDVI values were lower, particularly in the treatment without QuitoMax[®], whereas its application produced a positive effect on stressed plants. The best results under saline conditions were obtained at a dose of 350 mg ha⁻¹.

Initially, the curves exhibited a tendency toward verticality; from the second measurement onward, this trend diminished, gradually shifting to a horizontal orientation until the ninth measurement. After this point, the curve declined. This pattern reflects the crop cycle: as senescence progresses, plant canopy coverage and chlorophyll content decrease while fruit presence increases. These changes reduce reflectance, leading to a corresponding decline in NDVI values.

Notably, the saline treatments coincided in the curves until the fourth measurement. From that point onward, treatments with QuitoMax[®] application diverged from the saline control without biostimulant, a trend evident in both varieties and demonstrating the positive effect of QuitoMax[®] on this indicator under saline conditions. In particular, Fortes *et al.* (2014) reported that NDVI is an almost linear indicator of photosynthetic capacity, biomass accumulation, and overall physiological status of crops.

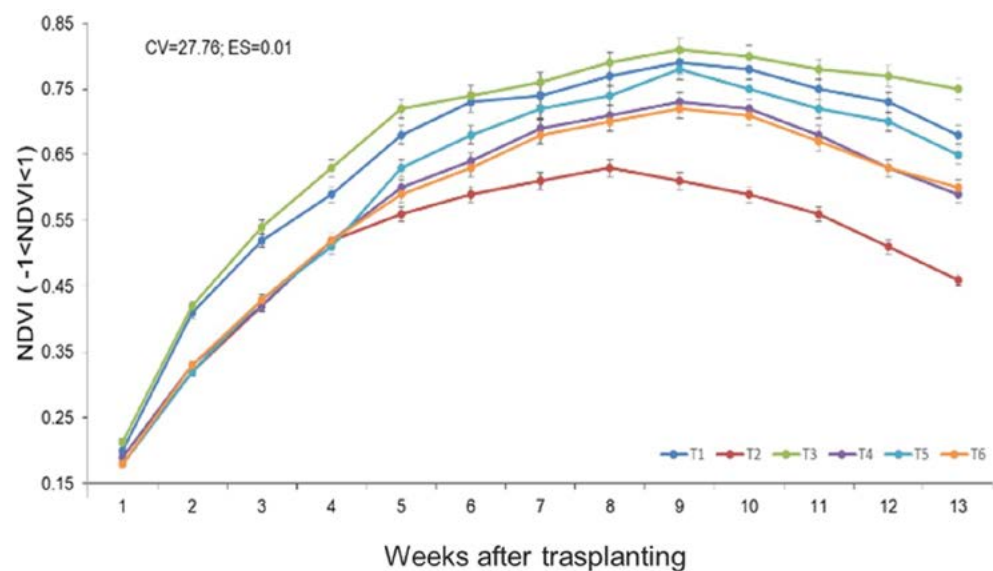


Figure 1. Effect of the QuitoMax[®] application on the normalized difference vegetation index (T1- not saline; T2- saline; T3- not saline + 300 mg ha⁻¹; T4- saline + 300 mg ha⁻¹; T5- saline + 350 mg ha⁻¹; T6- saline + 400 mg ha⁻¹). Measurements were made every seven days. The rectangular bars in the lines indicate the standard error of the mean of the treatments.

The significant effects observed in NDVI under saline conditions were associated with electrical conductivities of the saturation extract exceeding 2.5 dS m^{-1} , as previously noted. NDVI values were markedly reduced by the presence of salts in the substrate, consistent with findings reported by other authors (Fortes *et al.*, 2014; Ramos *et al.*, 2022), who documented a decline in NDVI with increasing soil salinity.

In the saline treatment without QuitoMax[®] application, the extreme value was reached seven days earlier than in the remaining treatments. This response can be attributed to the presence of salts and the tendency of plants under stress to accelerate development in order to complete seed production and ensure species perpetuation, as noted by Bhattacharya (2022).

According to the results of this study, the application of QuitoMax[®] at a dose of 350 mg ha^{-1} increased NDVI in tomato plants under saline conditions for the evaluated variety. Overall, doses above 300 mg ha^{-1} modified plant development indicators under salinity induced by NaCl at 6 dS m^{-1} .

Analysis of gas exchange and chlorophyll content

The application of QuitoMax[®] produced a significant positive effect on the parameters A_{max} and EEE across the evaluated treatments (Figure 2). Under saline conditions, increasing the dose of QuitoMax[®] was associated with higher A_{max} values; however, this relationship was not linear. Beyond a certain threshold, the response became limited, likely reflecting a compensatory mechanism in the plant, as observed at the dose of 400 mg ha^{-1} . The highest values occurred when the biostimulant was applied in the absence of salinity, whereas the lowest values were recorded under saline conditions without QuitoMax[®] application.

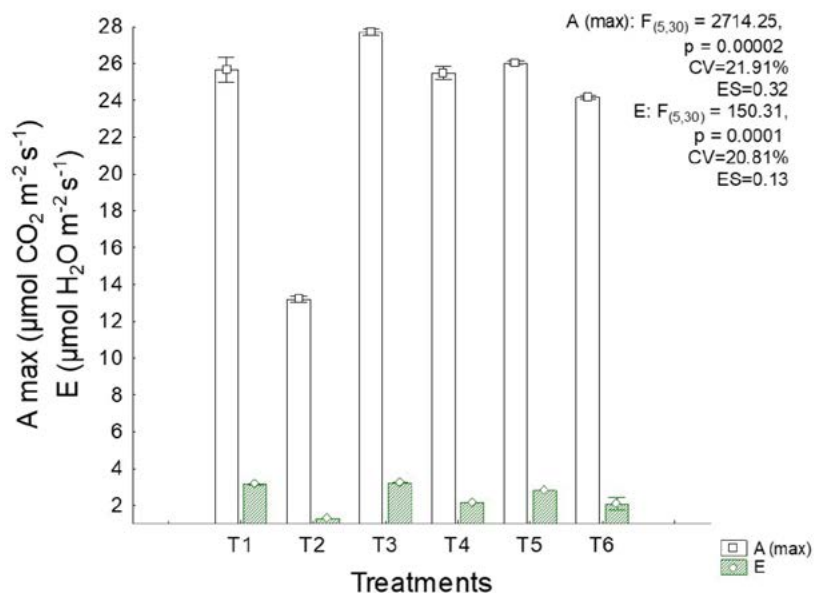


Figure 2. Photosynthesis and transpiration of tomato plants (T1- not saline; T2- saline; T3- not saline + 300 mg ha^{-1} ; T4- saline + 300 mg ha^{-1} ; T5- saline + 350 mg ha^{-1} ; T6- saline + 400 mg ha^{-1}). The rectangular bars in the columns indicate the standard error of the mean of the treatments.

Under saline conditions, the values were consistently higher when QuitoMax[®] was applied. The most favorable results were obtained with a dose of 350 mg ha⁻¹, and it is noteworthy that these values were comparable to those observed in plants grown under non-saline conditions without the biostimulant.

This finding highlights the beneficial role of QuitoMax[®] in mitigating salinity stress, enabling plants to maintain photosynthetic rates comparable to those observed under non-stress conditions. Similar results have been reported by Falcón *et al.* (2021), who demonstrated that under non-saline conditions, QuitoMax[®] enhances photosynthesis in tomato crops.

According to several authors cited by Falcón *et al.* (2021), the reduction in transpiration observed in both varieties under saline conditions may be associated with an antiperspirant effect. Researchers have reported that QuitoMax[®] induces stomatal closure by directly influencing abscisic acid levels in the guard cells. Notably, in non-saline treatments, transpiration values did not decrease following biostimulant application, likely because plants were maintained under adequate soil moisture, preventing the activation of stomatal closure.

The application of QuitoMax[®] exerted a positive and statistically significant effect ($p \leq 0.05$) on chlorophyll content and stomatal conductance (Table 4). The highest chlorophyll concentrations were recorded when the biostimulant was applied under non-saline conditions, followed by its application under saline conditions at a dose of 350 mg ha⁻¹, and finally in the control treatment without salinity.

This parameter was significantly influenced by the presence of salts in the substrate, and a positive effect of QuitoMax[®] application was evident when plants were subjected to salinity stress.

It is important to note that no significant differences were observed between non-saline and saline treatments at a dose of 350 mg ha⁻¹, underscoring the positive effect of QuitoMax[®] under the salinity conditions evaluated. These findings are particularly relevant given the critical role of chlorophyll in plant physiological processes.

Table 4. Average values of chlorophyll (CHL) content and stomatal conductance (G_s).

Treatments	CHL (SPAD Units)	G_s ($\text{mmol m}^{-2} \text{s}^{-1}$)
T1	61.03 ^a	117.33 ^d
T2	35.27 ^c	111.67 ^c
T3	62.91 ^a	168.83 ^c
T4	58.31 ^b	175.17 ^b
T5	61.13 ^a	183.00 ^a
T6	55.93 ^b	170.33 ^{bc}
SEx	1.16	1.43

(T1- nonsaline; T2- saline; T3- nonsaline + 300 mg ha⁻¹ T4- saline + 300 mg ha⁻¹; T5- saline + 350 mg ha⁻¹; T6- saline + 400 mg ha⁻¹). Means with equal superscripts in the same column do not differ significantly according to Tukey's test for $p \leq 0.05$. SEx: standard error of the mean of the treatments.

Photosynthetic pigments serve as key indicators of plant physiological performance and play an essential role in capturing light energy, which is subsequently converted into chemical energy (Vicente, 2021). Chlorophyll, in particular, enables the absorption of radiant solar energy and its transformation into chemical energy stored in organic carbon through the process of photosynthesis.

Evaluation of stomatal conductance revealed statistically significant differences among treatments ($p < 0.05$). The highest values were observed when the biostimulant was applied under non-saline conditions (T3), whereas the lowest values occurred in saline conditions without application. Under salinity stress, QuitoMax[®] exerted a positive effect on g_s , with the highest conductance recorded at a dose of 350 mg ha⁻¹ (Table 4). Plants responded favorably to biostimulant application, and the values obtained at 350 mg ha⁻¹ were comparable to those of plants grown under non-saline conditions (T1).

The results of this study indicate that the application of QuitoMax[®] enhances gas exchange in tomato plants of the Amalia variety under saline conditions.

When doses exceeding those recommended for cultivation under non-saline conditions are applied, an increase in photosynthetic activity is observed. Vicente *et al.* (2021) reported that enhanced photosynthesis is critical for crop development and productivity. In this context, low A_{max} values during the reproductive phenophase can lead to substantial yield losses (Prins *et al.*, 2016).

A morphological study conducted by Shahrajabian *et al.* (2021) demonstrated stomatal closure in plants treated with chitosan, a phenomenon attributed to its antiperspirant effect. These findings are consistent with those reported by Ullah *et al.* (2020), who evaluated different chitosan doses in tomato plants under salinity stress. The highest foliar chlorophyll content (SPAD) values were recorded when the maximum dose (150 mg ha⁻¹) was applied.

The increase in chlorophyll content observed at a QuitoMax[®] dose of 350 mg ha⁻¹ is particularly relevant, as these pigments play a crucial role in capturing light energy and converting it into chemical energy (Vicente *et al.*, 2021). Moreover, chlorophyll content is fundamental for plant growth and development (Chávez *et al.*, 2015), and its reduction is a primary cause of disruptions in the photosynthetic process (Khairi *et al.*, 2015).

The results presented in this study are significant, as greater stomatal conductance facilitates CO₂ uptake and thereby enhances photosynthetic activity (Oliveros and Caicedo, 2023). These findings align with previous reports on the effects of chitosan application (Shahrajabian *et al.*, 2021). Furthermore, evaluation of photosynthetic activity revealed a positive response in Amalia tomato plants when QuitoMax[®] was applied under saline conditions, with the most favorable outcomes observed at a dose of 350 mg ha⁻¹.

Yield components

When the number of bunches per plant (NBP) and the number of fruits per bunch (NFrB) were evaluated, statistically significant differences ($p \leq 0.05$) were observed among treatments. The highest NBP values occurred under saline conditions when QuitoMax[®] was applied at doses of 350 and 400 mg ha⁻¹ (Table 5), surpassing those recorded in saline treatments without biostimulant application and in two treatments conducted under non-saline conditions.

The results indicate a positive effect of this parameter when QuitoMax[®] was applied under NaCl-induced stress; however, under non-saline conditions, the recommended dose did not produce a significant impact.

No significant differences were observed among treatments in the number of flowers per bunch (NFIB), regardless of salinity in the substrate or the biostimulant dose applied (Table 5). These findings suggest that none of the factors studied influenced this parameter. In contrast, the number of fruits per bunch (NFrB) was significantly affected, with salinity markedly reducing this indicator compared to other treatments (Table 5). Notably, application of QuitoMax[®] at doses of 350 and 400 mg ha⁻¹ resulted in values comparable to those recorded in plants grown under non-saline conditions.

Similarly, the application of QuitoMax[®] increased fruiting efficiency (FE) under saline conditions (Table 5).

In the absence of the biostimulant, FE reached only 75% under salinity stress. However, when doses of 350 and 400 mg ha⁻¹ were applied, FE values reached 100%, equivalent to those observed under non-saline conditions.

This aspect is particularly relevant, as it demonstrates the effectiveness of QuitoMax[®] application in tomato cultivation under saline conditions, especially as a key determinant of productivity. It is also noteworthy that under the stress conditions evaluated, the recommended dose of 300 mg ha⁻¹ resulted in lower fruiting efficiency compared to doses of 350 and 400 mg ha⁻¹, suggesting that the standard dose may be insufficient to mitigate the adverse effects of salinity.

Significant differences ($p < 0.05$) were detected among treatments for fruit mass (FM), equatorial fruit diameter (EFD), and yield (Y). The lowest values were recorded in plants grown under saline conditions without biostimulant application, confirming the detrimental effects of salinity on crop performance (Table 5).

Furthermore, QuitoMax[®] application favored this parameter regardless of salinity in the substrate. At an electrical conductivity of 6 dS m⁻¹, the equatorial fruit diameter (EFD) was lower when the recommended dose of 300 mg ha⁻¹ was applied compared

Table 5. Yield components of the Amalia tomato variety.

Treatments	NBP	NFIB	NFrB	EF (%)	EFD (cm)	FM (cm)	Y (kg plant ⁻¹)
T1	14 ^b	8	8 ^a	100	5.82 ^b	150.11 ± 2.7 ^b	1.20 ± 0.4 ^{ab}
T2	11 ^c	8	6 ^b	75	4.12 ^c	143.27 ± 3.4 ^c	0.86 ± 0.3 ^c
T3	14 ^b	8	8 ^a	100	6.21 ^a	156.16 ± 3.1 ^a	1.25 ± 0.6 ^a
T4	12 ^c	8	7 ^{ab}	88	4.76 ^c	147.6 ± 3.1 ^c	1.03 ± 0.1 ^b
T5	16 ^a	8	8 ^a	100	6.72 ^a	158.26 ± 4.2 ^a	1.26 ± 0.3 ^a
T6	16 ^a	8	8 ^a	100	5.78 ^b	158.34 ± 2.9 ^a	1.26 ± 0.2 ^a
SEx	0,48	0,0002	0,08		0,09	0,41	0,46

(T1- nonsaline; T2- saline; T3- nonsaline + 300 mg ha⁻¹; T4- saline + 300 mg ha⁻¹; T5- saline + 350 mg ha⁻¹; T6- saline + 400 mg ha⁻¹). Means with equal superscripts in the same column do not differ significantly according to Tukey's test for $p \leq 0.05$. SEx: standard error. ±: mean ± standard deviation. NBP: number of bunches per plant; NFIB: number of flowers per bunch; NFrB: number of fruits per bunch; FE: fruiting efficiency; EFD: equatorial diameter of the fruits; FM: mass of the fruits; Y: yield.

to higher doses. The maximum EFD value was achieved at 350 mg ha^{-1} , which did not differ significantly from the non-saline treatment with QuitoMax[®] application and even exceeded the control under non-saline conditions.

Similarly, significant differences ($p < 0.05$) were observed among treatments for fruit mass (FM). The lowest FM values were recorded under saline conditions without QuitoMax[®] application (Table 5), highlighting the detrimental effects of salinity on crop performance and the potential of the biostimulant to mitigate these effects.

The best results were obtained with doses of 350 and 400 mg ha^{-1} , which were significantly different from those of the control treatment, without the presence of salts and without the application of the biostimulant. Similarly, although the difference was not significant, the MF values were greater in the QuitoMax[®] treatment than in the nonsaline treatment (Table 5).

Analysis of yield revealed statistically significant differences among treatments ($p < 0.05$). The most pronounced negative effects were observed in saline treatments without biostimulant application (Table 5). Conversely, a positive response to QuitoMax[®] application under saline conditions was evident, with the best results obtained at doses of 350 and 400 mg ha^{-1} , between which no significant differences were detected.

Salinity exerted adverse effects on yield and its components in tomato plants under stress conditions. Conversely, the application of QuitoMax[®] produced a positive impact, with the greatest effect observed at a dose of 350 mg ha^{-1} .

To date, no studies have been reported in the scientific literature on the use of QuitoMax[®] under NaCl-induced stress in tomato cultivation in Mexico, except for those recently published by members of the present research team (Argentel-Martínez *et al.*, 2024).

Studies conducted by Terry *et al.* (2017) reported positive effects on yield under non-saline conditions, although their findings differ from those of authors who achieved the best results at a dose of 300 mg ha^{-1} under similar conditions. Likewise, positive effects on tomato cultivation have been documented with the application of chitosan, the base compound of the biostimulant used in this study (Reyes *et al.*, 2020).

Recent studies have evaluated different chitosan doses in tomato plants under salinity stress (Ullah *et al.*, 2020). In that research, the highest yield per plant was achieved with the maximum dose applied (150 mg ha^{-1}).

Similarly, the results of this study are consistent with reports of positive effects on performance when chitosan is applied under non-saline conditions. For instance, an increase in yield components of Mara variety tomato plants and an agricultural yield improvement of 55% compared to the control treatment have been documented (Terry *et al.*, 2017). Likewise, under non-saline conditions, chitosan application to the tomato hybrid H-3108 resulted in the best yield response at a dose of 275 mg ha^{-1} , with increases ranging from 35.47% to 42.93% (Jiménez *et al.*, 2015).

Similarly, these findings are consistent with those reported by Enríquez *et al.* (2018), who evaluated a biostimulant under non-saline substrate conditions and observed a 35% increase in yield in the Florade tomato variety when QuitoMax[®] was applied. However, their results differed regarding the optimal dose, which in that study was 300 mg ha^{-1} .

The results of the present study contrast with those obtained under organoponic conditions by Reyes *et al.* (2013), who evaluated the effects of chitosan on tomato cultivation at doses of 250, 300, and 350 mg ha⁻¹. In their study, the best performance indicators were achieved with an application rate of 300 mg ha⁻¹. Comparable findings were reported by Sopalo *et al.* (2020) in protected cultivation systems using the Amalia variety.

This study provides a reflective analysis of how guided experiments, implemented as educational tools, can substantially enhance academic performance and strengthen students' competencies in the field of agricultural sciences.

Active pedagogical approaches, such as project-based learning and experimental practice, have demonstrated greater effectiveness in promoting learning compared to traditional, theory-focused instruction. A study involving tenth-grade agroecology students showed that these participatory and demonstrative strategies fostered deeper conceptual understanding, as evidenced by 135 of 180 students achieving superior results relative to those taught through lecture-based methods (Aremu, 2023).

This participatory teaching approach not only fosters the development of technical skills but also promotes student engagement, enhances interest in learning, and stimulates critical reasoning within authentic agricultural contexts.

Moreover, the integration of educational technologies —such as online laboratories, digital simulations, and interactive platforms— has proven beneficial for training in agricultural sciences. In one study, over 90% of agronomy students rated animated teaching tools that connect theoretical concepts with practical applications as “valuable,” contributing to a greater appreciation of the role of chemistry within their professional field (Ulery, 2020).

At a broader level, a review of educational technologies in agricultural training indicates that modalities such as virtual visits, flipped classrooms, and extended reality (XR) are particularly effective when aligned with clear pedagogical objectives and supported by appropriate instructional design (Xu, 2023). Within the context of this study, the direct involvement of students in agricultural experiments with tomato and the biostimulant QuitoMax[®] represents a practical and effective application of active learning methodologies. By participating in all stages of the process —from planning to the analysis of experimental trials— students can:

- Acquire technical and analytical skills by addressing specific variables such as biostimulant concentrations and salinity levels in the crop.
- Develop reflective learning through the interpretation of results, identification of potential errors or biases, and formulation of improvements.
- Deepen understanding of scientific knowledge by transferring theoretical concepts to real contexts, thereby strengthening critical thinking capacity.
- Benefit from an active, student-centered teaching model supported by research in agroecology and multimedia education demonstrating its effectiveness (Ncisana, 2023).
- Engage in a pedagogical approach with potential for expansion into digital environments, including interactive simulations or virtual laboratories as complements to face-to-face experiences (Xu, 2023).

Active participation in research—such as the tomato and QuitoMax[®] trials under saline conditions—strengthens technical and analytical skills by engaging students with real variables and field challenges. This practical approach facilitates the internalization of scientific concepts, enhances motivation, and promotes meaningful learning (Pathway, 2025).

Experimental activities are closely associated with pedagogical approaches such as land laboratories and agricultural practices, which serve as authentic learning environments. In these settings, students acquire competencies in key areas, including ecosystem restoration, biodiversity management, practical application of scientific knowledge, and the promotion of sustainability (Wikipedia, 2023).

Furthermore, implementing experiments with Agronomy students (IAS) provides dual value. On the educational side, it promotes technical, scientific, and reflective skills through active, experiential, and collaborative learning. On the environmental and social side, it addresses soil salinization through applied and innovative solutions, generating robust, sustainable proposals adapted to the local context.

These educational and innovative practices not only enrich professional training in agronomy but also foster the development of effective strategies to address global challenges such as soil degradation and salinization.

CONCLUSIONS

The application of QuitoMax[®]—at 1 g L⁻¹ for seed treatment and 350 mg ha⁻¹ on the aerial part under saline conditions (EC=6 dS m⁻¹)—yielded the best results for plant development, gas exchange, chlorophyll content, relative growth rate, and normalized difference vegetation index. These findings indicate that under saline stress (EC=6 dS m⁻¹), the optimal dose of QuitoMax[®] was 350 mg ha⁻¹. Furthermore, implementing practical experiments with students of the Engineering in Sustainable Agricultural Innovation (IAS) program not only enhances academic training but also constitutes an effective strategy for addressing global challenges such as soil salinization.

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