Revista Mexicana de Ciencias Agrícolas

DOI: https://doi.org/10.29312/remexca.v16i2.3538

Article

Production of tomato with application of salicylic acid and seaweed under shade cloth

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Abstract

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetables for human consumption due to its contribution of vitamins, minerals, and antioxidants; therefore, it is necessary to look for environmentally friendly management alternatives. Seaweed and acetylsalhasic acid have been shown to improve plant nutrition, promote growth, and confer resistance against biotic and abiotic factors. The objective of the study was to determine the effect of the application of seaweed and acetylsalicylic acid on the production and quality of tomatoes under shade cloth in 2022. Tomato plants received foliar application of extracts of *Ascophyllum nodosum*, *Ecklonia maxima*, *Sargassum vulgare*, and acetylsalicylic acid, alone and in combination: *Ascophyllum nodosum* + acetylsalicylic acid, *Ecklonia maxima* + acetylsalicylic acid, *Sargassum vulgare* + acetylsalicylic acid, and the control. It was found that the treatments did not modify the fruit yield or yield components. The lycopene content increased in the fruits with seaweeds and with *Sargassum vulgare* + acetylsalicylic acid and the firmest fruits were recorded with *Ascophyllum nodosum*, so the application of seaweeds and acetylsalicylic acid, under the conditions in which the plants were grown, despite not improving the production variables, increased the lycopene content and firmness with some treatments, parameters that improve the quality of the fruit as a functional food in human health and that make it better withstand transport and marketing.

Keywords:

biostimulants, fruit yield, lycopene.

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Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetables worldwide. Knowing the proper management of its nutrition and its interaction with agronomic yield is considered relevant (Santis *et al*., 2019), among other aspects, it is sought to promote its consumption, production, and yield (Vargas-Martínez *et al*., 2023). In its production, temperatures above 35 °C reduce fruit growth and quality and decrease the number and viability of pollen grains; on the other hand, the stems elongate, which causes the bunches to appear late and the spaces between bunches to be very long. All this reduces productivity and economic profitability (Florido-Bacallao and Álvarez-Gil, 2015).

It is important to find and evaluate environmentally friendly alternatives to reduce the negative impact of high temperatures. Recently, the use of certain seaweeds and acetylsalicylic acid has been mentioned, which also offer benefits in the crop as growth promoters, adjuvants in the absorption of nutrients, and contributors to mitigate both biotic and abiotic stresses. For example, applying seaweed extracts at temperatures as high as 30 and 32 °C promotes the assimilation of nutrients in plants and increases the growth, yield, and quality of tomato plants (Sutharsan *et al*., 2014). It has been reported that salicylic acid supplied to plants has been shown to be a good reliever of stress, mainly due to high and low temperatures (Khan *et al*., 2015; Zhang *et al*., 2020).

In the hot land of the Apatzingán Valley, Michoacán, it is a challenge to produce nightshades, mainly tomatoes, at temperatures around 40 °C. Therefore, the present work was carried out under climatic conditions of high temperatures with the aim of evaluating the foliar application of seaweeds and acetylsalicylic acid on the production and quality of tomatoes under plastic mesh structures and covers called shade houses.

Materials and methods

Experiment location and establishment

The study was established at the Faculty of Agricultural Sciences of the Michoacán University of San Nicolás de Hidalgo in Apatzingán, Michoacán at an altitude of 325 m, rainfall of 750 mm, with temperatures of 20 to 40 °C, with a dry climate (García, 2004).

On February 3, 2022, tomato seedlings of determinate habit, of the saladette type, Primux max variety, which is early resistant to Fusarium, with firm fruits and intense red coloration, from the United Genetics Company (Hortalizas AMBA, 2017), were transplanted under a cover of shade cloth. One seedling was placed per hole at distances between plants of 40 cm and 1.2 m between rows, each row on a bed. The following had been carried out previously: the preparation of the land (a fallow and double harrowing), the formation of 30 cm high beds, the placement of the irrigation system with a 5/8” tape, 1.01 LPH/dripper, with drippers every 10 cm, and silver/black plastic mulch. To know the physical and chemical characteristics of the soil of the experimental site, subsamples were taken at depths of 0-30 to form a composite sample that was dried, sieved, and sent to Fertilab for analysis.

Irrigation and fertigation

It was irrigated with deep well water every third day throughout the crop cycle, the duration and amount of water supplied varied depending on the environmental conditions, it was always sought to have the soil in conditions of field capacity. To find out the chemical characteristics of the water, a water sample was sent to Fertilab for analysis. The application of nutrients was with Steiner’s universal nutrient solution, the mineral concentration of which was adjusted according to the soil and water analysis and the application was based on the stage of development of the crop: it was supplied at 100% in the establishment and vegetative development, at 150% at flowering and fruit set, and at 200% at ripening and harvesting (Steiner, 1961).

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Phenology and climate

The maximum and minimum temperatures (ten-day average) and the evaporation of the environment (ten-day sum) outside the shade house were obtained, which are those reported by the agrometeorological station of the experimental field of the Faculty of Agricultural Sciences, Apatzingán, Michoacán during the development of the crop. In the crop, the time to occurrence of the phenological stages was recorded, which were: flowering, beginning of fruiting, beginning of harvest, end of harvest and physiological maturity.

Treatments under study and experimental design

Three seaweeds were evaluated: two extracts, one of *Ascophyllum nodosum* (AN) and the other of *Ecklonia maxima* (EM), at the concentration of 34.2%; and 100% pure *Sargassum vulgare* (SV) powder, as well as acetylsalicylic acid (ASA) powder at 99% active ingredient of Sigma-Aldrich. Five applications were made every 14 days starting six days after transplantation (dat). The doses of seaweed were 1.5 and 2 ml L^{-1} in the first and second applications and 3 ml L^{-1} was administered in the last three applications. In the case of acetylsalicylic acid, it was applied at 0.18 g L^{-1}.

The algae species were applied individually and in combination with the ASA, which generated seven treatments: AN, EM, SV, ASA, AN+ASA, EM+ASA, SV+ASA plus a control treatment (control), which were distributed in the field in an experimental design of randomized complete blocks with four replications, which generated 32 experimental units. Each unit corresponded to a row of 4.32 m in length. The useful plot was made up of four plants located in the central part of each experimental unit in order to have greater representativeness of the experimental unit and avoid the edge effect.

Seaweed and acetylsalicylic acid were dissolved in distilled water and the Inex-A surfactant was added to all treatments at a dose of 1 ml L^{-1}. Eight solutions were prepared, one for each treatment. The following laboratory equipment was used: a 1 L cylinder, a beaker, stirring rod, graduated pipette, and an analytical digital balance. The applications were carried out in the morning with 1 L capacity atomizers (318055 Pacto/Swissmex®) up to the dropping point (fully impregnated plants, which were determined with the fall of the first drop that drains from the plant).

Response variables

At harvest maturity, in the plants of the useful plot of each experimental unit, the following was determined with all the cuts: fruit yield (kg m^{-2}, the distance between plants and between rows was considered for its estimation), the equatorial and polar diameters of the fruits, the average weight of fruits, and the number of total fruits. Firmness and lycopene content were also measured in five fruits taken at random from the total harvested from the useful plot in the third cut, according to the protocol described by Fernández *et al*. (2007) and both determinations were in the same fruits.

Statistical analysis

The data for each treatment were subjected to an analysis of variance and Tukey's test at 5% probability of error with the SAS statistical package, version 9.4 (SAS, 2019).

Results and discussion

Soil and water characteristics

According to the results provided by the laboratory, the soil where the crop was established presented the following physical characteristics: medium texture (loam), bulk density of 0.96 g cm^{-3}, moderately low hydraulic conductivity (2.59 cm h^{-1}), high saturation point (56%), high field capacity (30%), high permanent wilt point (17.9%), moisture percentages given based on soil volume.

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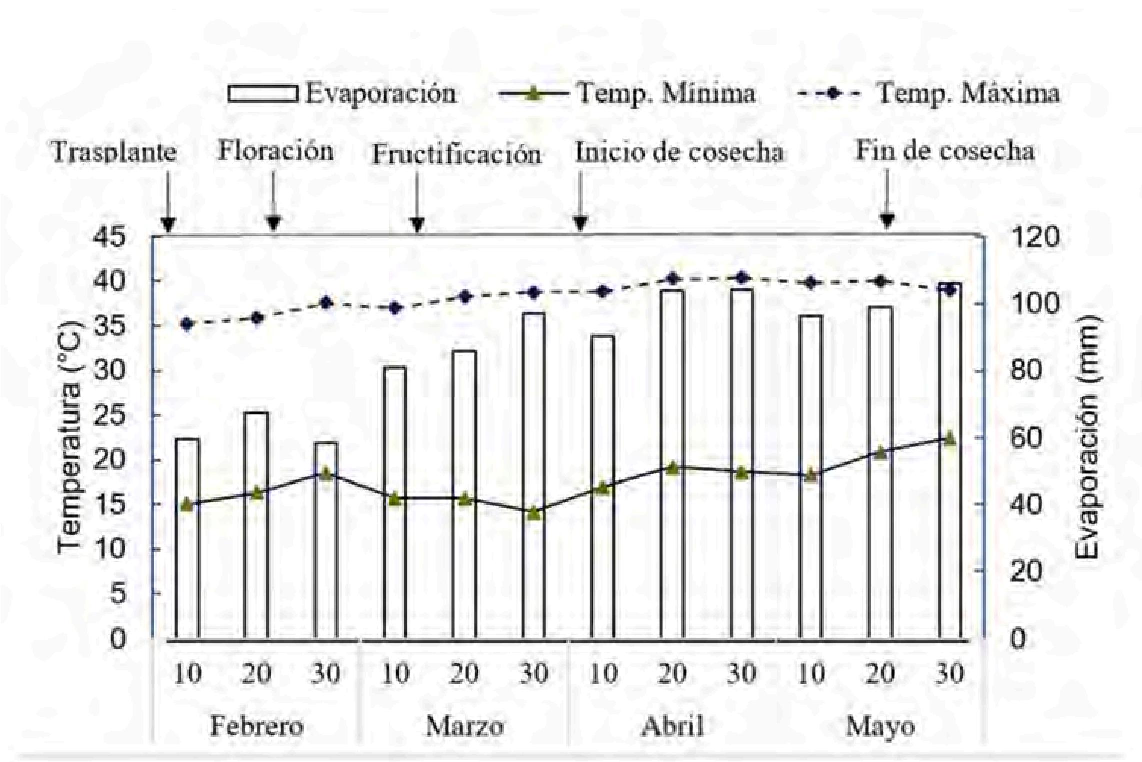
For their part, the chemical characteristics were: moderately alkaline pH (7.11), moderately low in carbonate, low in salts, very high in organic matter (4.22%), CEC of 38.5 meq 100 g^{-1}, and content (ppm) of 153 ($N\text{-}NO_3^{-}$), 34.9 (P-Olsen), 1 374 (K^{+}), 4 935 (Ca^{++}), 1 215 (Mg^{++}), 2.79 ($Mn^{=}$), 43.7 (SO_4^{-2}), 4.61 ($Fe^{=}$), 3.64 ($Zn^{=}$), 2.25 (Cu^{++}), and 47.6 (Na^{+}). On the other hand, the water presented a pH of 7.17 (optimal), an electrical conductivity of 0.31 mS cm^{-1} (adequate), a SAR of 0.27 (optimal), with low levels of carbonates, chlorides (2.63 and 0.44 meq L^{-1}, respectively), and content (meq L^{-1}) of 0.21 ($N\text{-}NO_3^{-}$), 0.01 (PO_4^{3}), 0.24 (SO_4^{-2}), 0.03 (K^{+}), 0.72 (Ca^{++}), 2.53 (Mg^{++}), and 0.34 (Na^{+}).

Climate and phenology

During the development of tomato crops, the highest temperatures occurred in April and May, which ranged from 38.8 to 40.4 °C, 14.46% higher than at the beginning of the crop cycle (transplantation). Meanwhile, in February and March, there were minimum temperatures between 14.1 and 16.3 °C, which increased 27.6% in April in the harvest phase of the crop (Figure 1).

Figure 1. Maximum temperature, minimum temperature (ten-day average), and evaporation (ten-day average) during the tomato crop cycle.



According to Wahid *et al*. (2007), the optimal average temperature for this crop is 21 to 24 °C and Chaves-Barrantes and Gutiérrez-Soto (2017) indicate that excess radiation and high temperatures affect crop growth and yield by causing leaf and fruit burns, senescence, early leaf abscission, loss of vigor, inhibition of stem and root growth, loss of pollen viability, abortion of flowers, small fruits, and discoloration of fruits.

The highest environmental evaporation recorded was in the days of April 20 to 30, with 104.37 mm, which increased up to 75.2% compared to the beginning of the crop (59.57 mm). Because of this increase in evaporation from the environment, sufficient irrigation was provided to supply the crop during the most critical days. Based on the above data, it is inferred that, in the present study, environmental conditions may have limited the productive potential of the crop.

DOI: https://doi.org/10.29312/remexca.v16i2.3538

In relation to phenological behavior, the plants of the different treatments presented similar times to the beginning of flowering, fruiting, harvest, and end of harvest (22, 48, 58, 116 dat, respectively) with any treatment (Figure 1).

Yield and yield components of tomato fruits

The fruits did not present statistically significant differences in polar and equatorial diameters or in the average weight of fruits perhaps due to the foliar application of acetylsalicylic acid and seaweed. The fruits showed polar diameters between 4.88 and 5.2 cm, equatorial diameters were from 4.08 to 4.26 cm, and fruits had an average weight between 24.57 and 30.19 (Table 1).

Table 1. Level of significance and tests of comparison of means of polar diameter (PD), equatorial diameter (ED), average fruit weight (AFW), and total fruits (TF) of tomato according to seaweed and acetylsalicylic acid applications.

Treatment	PD (cm)	ED (cm)	AFW (g fruit^{-1})	TF (fruits m^{-2})
AN	5.2 ±0.39 a¶	4.23 ±0.2 a	27.79 ±5.01 a	91.82 ±20.43 ab
EM	5.14 ±0.21 a	4.2 ±0.07 a	24.57 ±1.43 a	109.72 ±6 a
SV	4.92 ±0.63 a	4.08 ±0.4 a	27.46 ±5 a	83.87 ±24.45 b
ASA	5.09 ±0.5 a	4.14 ±0.25 a	27.85 ±4.23 a	93.44 ±17.72 ab
AN+ASA	5.08 ±0.32 a	4.17 ±0.19 a	26.31 ±1.99 a	104.75 ±27.61 a
EM+ASA	4.88 ±0.29 a	4.11 ±0.15 a	26.82 ±3.18 a	104.1 ±6.25 a
SV+ASA	5.12 ±0.39 a	4.16 ±0.29 a	25.74 ±3.7 a	106.89 ±12.44 a
Control	5.22 ±0.2 a	4.26 ±0.15 a	30.19 ±3.04 a	96.53 ±23.61 ab
Overall mean	5.08	4.17	27.09	98.89
Pr> F	NS	NS	NS	*
$MHSD_{0.05}$	0.78	0.53	8.26	41.46
CV (%)	6.5	5.37	12.86	17.68

¶ = means with equal letters within each column do not differ statistically (Tukey, $p \leq 0.05$); * = $p \leq 0.05$; NS= not significant ($p \geq 0.05$); MHSD0.05= minimum honestly significant difference; ± standard deviation; CV= coefficient of variation; AN= *Ascophyllum nodosum*; EM= *Ecklonia maxima*; SV= *Sargassum vulgare*; ASA= acetylsalicylic acid.

According to Sariñana-Aldaco *et al*. (2020), under protected greenhouse conditions in hydroponic tomato plants with foliar applications of salicylic acid at the dose of 0.025, the polar diameter increased by 18.7% (6.7 cm) compared to the control (5.6 cm), whereas the equatorial diameter of the fruit also increased by 13.3% compared to the control. These results differ from those found in the present study, possibly due to the different doses used between the two experiments.

Likewise, the small size of the fruits recorded in the present study can be attributed to the high temperatures that occurred, which were around 40 °C, which, according to Chaves-Barrantes and Gutiérrez-Soto (2017), reduce the vigor of the plant, limit the size and weight of the fruits and consequently the final yield. The total number of fruits showed statistically significant differences (*p*# 0.05) due to the treatments (Table 1).

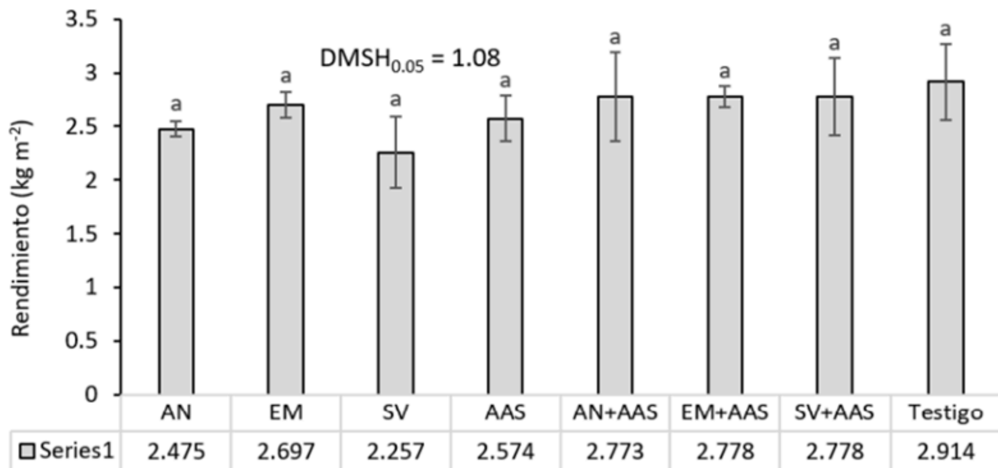
Plants with the supply of *E. maxima* extract produced the highest number of fruits, with 109.72 fruits m^{-2}, followed by plants with supply of *S. vulgare* in combination with acetylsalicylic acid, which registered 104.73 fruits m^{-2}. For their part, plants with foliar application of *S. vulgare* presented the lowest number, with 83.87 (Table 1).

Results similar to this study were found by Silva *et al*. (2022), who, with foliar applications of salicylic acid to cherry tomato plants, at the dose of 1 mM, achieved increases of 41.31% in the number of fruits compared to the control. On the other hand, in tomato plants of determinate habit grown under protected agriculture conditions, Gorni *et al*. (2021) carried out exogenous spraying of salicylic acid at the dose of 1 mM, resulting in an increase in the number of fruits of 70.2% compared to the fruits harvested from the control plants (water).

Revista Mexicana de Ciencias Agrícolas
REMEXCA
DOI: https://doi.org/10.29312/remexca.v16i2.3538

In a previous study, Vázquez-Díaz *et al*. (2016) found that the foliar application of acetylsalicylic acid and salicylic acid has a significant effect on increasing the number of fruits. However, this study showed the best results when acetylsalicylic acid was applied in conjunction with the seaweed *S. vulgare*. In relation to fruit yield (kg m^{-2}), according to the analysis of variance, there were no significant differences (Figure 2).

Figure 2. Comparison test of means of tomato fruit yield (kg m^{-2}) with applications of seaweed and acetylsalicylic acid. $DMSH_{0.05}$= minimum honestly significant difference at 5% probability of error; AN= *Ascophyllum nodosum*; EM= *Ecklonia maxima*; SV= *Sargassum vulgare*; AAS= acetylsalicylic acid.



The results of this research differ from those found by Sariñana-Aldaco *et al*. (2020), who, in hydroponic tomato plants grown under greenhouse conditions with foliar applications of salicylic acid at the dose of 0.05 mM, increased yield by 1.72 kg m^{-2} compared to the control. For their part, Shinwari *et al*. (2018), with applications of acetylsalicylic acid at doses of 0.12 mM, recorded fruit yields (3.091 kg m^{-2}) significantly higher than that achieved with the control (2.061 kg m^{-2}).

As noted by Ali *et al*. (2019), there was a positive response in the yield of fruits of tomato and sweet pepper (*Capsicum annuum*) to foliar applications of *A. nodosum* at the concentration of 0.5%, with increases of 40% compared to the control treatment for both crops, which was related to a greater number of flowers and fruits per cluster in tomato and sweet pepper. The difference in response from this study could be attributed to the different doses used between studies or also to the different environmental conditions in which the experiments were conducted.

Lycopene

In plants with the supply of *S. vulgare* in combination with acetylsalicylic acid, highly significant statistical increases ($p\leq 0.01$) were recorded in the lycopene content of tomato fruits (Figure 3).

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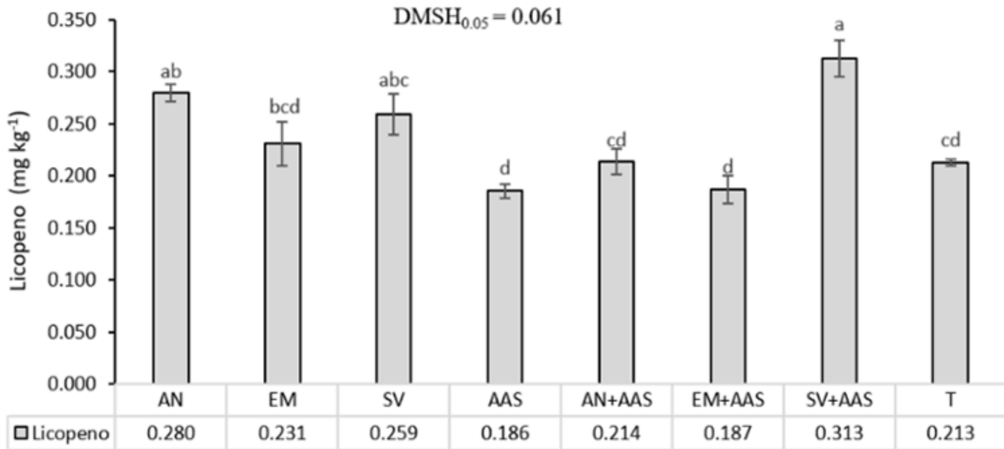
Figure 3. Comparison test of means of tomato fruit lycopene content with applications of seaweeds and acetylsalicylic acid. $DMSH_{0.05}$= minimum honestly significant difference at 5% probability of error; AN= *Ascophyllum nodosum*; EM= *Ecklonia maxima*; SV= *Sargassum vulgare*; AAS= acetylsalicylic acid.



Lycopene content increased by 47.2% with the foliar application of *S. vulgare* in combination with acetylsalicylic acid compared to fruits harvested from the control treatment plants. On the other hand, with the application of acetylsalicylic acid alone and in combination with *E. maxima*, the content decreased by 12.6% and 12.2%, respectively, compared to the control.

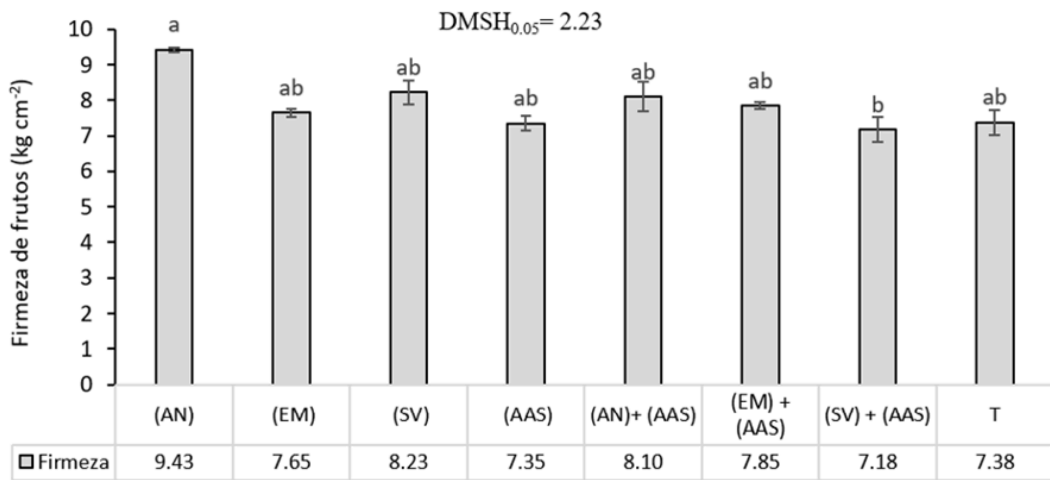
A study by Zahirul *et al*. (2018) showed negative responses of lycopene content compared to the control in cherry tomato fruits with applications of salicylic acid at doses of 0, 0.13, 0.25, 0.5, and 1 mM grown in greenhouse conditions. For their part, with exogenous sprays of salicylic acid at the dose of 1 mM in tomatoes of determinate habit under protected conditions, Gorni *et al*. (2021) managed to increase the coloration of tomato fruits by 62.25% compared to the control. In our study, acetylsalicylic acid showed improvements in this variable only when it was co-administered with *S. vulgare* extract.

Fruit firmness

Statistically significant differences (*p*# 0.05) were found in the firmness of tomato fruits due to the foliar application of seaweeds and acetylsalicylic acid. Plants sprayed with *A. nodosum* presented the fruits with the highest firmness, showing values of 9.4 kg cm^{-2}, whereas the fruits of plants with *S. vulgare* in combination with acetylsalicylic acid had the lowest value with 7.18 kg cm^{-2} (Figure 4).

DOI: https://doi.org/10.29312/remexca.v16i2.3538

Figure 4. Comparison test of means of tomato fruit firmness with applications of seaweeds and acetylsalicylic acid. $DMSH_{0.05}$= minimum honestly significant difference at 5% probability of error; AN= *Ascophyllum nodosum*; EM= *Ecklonia maxima*; SV= *Sargassum vulgare*; AAS= acetylsalicylic acid.



Regarding the use of seaweed, the results of this study are similar to those found by Ahmed *et al*. (2023), who, when *A. nodosum* was sprayed in the tomato crop, the firmness of the fruits increased by 41% compared to the control. Nonetheless, Zahirul *et al*. (2018) recorded similar responses with applications of acetylsalicylic acid at the dose of 0.5 mM, with firmer fruits than the control, so it was expected that the combination with some seaweed would favor the firmness of the fruits more; however, this did not happen in our study.

The positive response of the application of *A. nodosum* on fruit firmness can be attributed to the fact that, according to Ali *et al*. (2019), the extract acts in oxidative and metabolic processes and it is also a source of macros and micronutrients that could have favored the firmness of tomatoes. The application of seaweed and acetylsalicylic acid individually and in combination did not have a significant effect on the polar and equatorial diameters of the fruits. The total number of fruits increased with *E. maxima*, and with any combination of seaweed with acetylsalicylic acid. Nevertheless, the yield of fruits was not modified.

In relation to the quality of production, lycopene content increased in plant fruits with the application of any of the three seaweeds and with *S. vulgare* + acetylsalicylic acid, and the firmest fruits were recorded with the supply of *A. nodosum*. The lack of response in fruit yield could be attributed to the dose used of the treatments since higher doses may be required for the environmental conditions of production. This is because the answer depends on the type of cultivar, the environmental conditions, and the application rate (Larqué-Saavedra *et al*., 2010). The high temperatures that occurred during the production cycle (above 40 °C) could also have had an influence.

In this regard, Chaves-Barrantes and Gutiérrez-Soto (2017) indicate that excess radiation and high temperatures affect growth, crop yield, cause leaf and fruit burns, early leaf senescence and abscission, loss of vigor, inhibition of stem and root growth, loss of pollen viability, abortion of flowers and young fruits, and discoloration and damage of fruits, and generally negatively affect yield and profitability of the crop (Florido-Bacallao and Álvarez-Gil, 2015).

Results obtained by Rieu *et al*. (2017) mention that high temperatures affect floral abortion and cause floral abortion (80%) in tomato plants, which leads to a decrease in fruit production. With heat stress, respiratory activity and photorespiration are accelerated, therefore, energy losses are high and consequently affect crop yield (Zhao *et al*., 2015). Thus, the lack of increase in yield in the present research could be attributed to an imbalance in growth, flowering, and acceleration in the ripening of tomato fruits that none of the treatments tested managed to reverse significantly.

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Conclusions

The foliar supply of *S. vulgare* plus acetylsalicylic acid and the application of *A. nodosum* alone increased the lycopene content of the fruits, and the latter treatment produced the firmest fruits. The application of *E. maxima* increased the number of fruits, but none of the treatments promoted the increase in yield, polar and equatorial diameters, and average weight of the fruits.

Acknowledgements

The authors thank the Coordination of Scientific Research of the Michoacán University of San Nicolás de Hidalgo for the financial support granted to the project approved in 2022, and the National Council of Humanities, Sciences, and Technologies (CONAHCYT), for its acronym in Spanish for the master's scholarship.

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DOI: https://doi.org/10.29312/remexca.v16i2.3538

Production of tomato with application of salicylic acid and seaweed under shade cloth

Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Article/Issue Information
Date received: 01 December 2024
Date accepted: 01 February 2025
Publication date: 14 April 2025
Publication date: Feb-Mar 2025
Volume: 16
Issue: 2
Electronic Location Identifier: e3538
DOI: 10.29312/remexca.v16i2.3538

Categories

Subject: Articles

Keywords:

Keywords:

biostimulants

fruit yield

lycopene

Counts

Figures: 4

Tables: 1

Equations: 0

References: 23

Pages: 0