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Effects of Elicitors on the Growth, Productivity and Health of Tomato (*Solanum lycopersicum* L.) under Greenhouse Conditions

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) production in countries like Mexico relies heavily on the use of chemical pesticides, which can be toxic to a host of other organisms including beneficial insects and human consumers. Environment-friendly methods of controlling tomato diseases include agroecological practices, organic fungicides, and biological control. Plants' resistance against pathogens is induced by applying agents called elicitors to the plants and would lead to disease prevention or reduced severity. The objective of this research was to know the effect of three elicitor; namely, Activane (1.8 g L^{-1}), Micobiol (3 mL L^{-1}) and Stemicol (2.5 g L^{-1}) plus a control on the incidence of diseases, vigor, yield and fruit quality of two cultivars of Bola tomato and Saladette in the greenhouse. Elicitors decreased the incidence and severity of presented diseases and increased plant survival. Additionally, the elicitors Micobiol® and Activane® were able to increase plant height, stem diameter, weight and fruit diameter, while Stemicol® considerably increased fruit color, °Brix and pH and Activane® increased titratable acid. In general, elicitors were able to reduce disease, increase plant survival, production and improve fruit quality. These findings provide positive directions for the possible use of these elicitors and induce resistance in plant protection.

Keywords: Bola tomato, Disease resistance, Fruit quality, Saladette.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetables in Mexico, since it occupies a prominent place within the horticultural crops that are produced under protected agriculture conditions. However, the greenhouse environment is not problem-free. The higher humidity, temperature and lush green foliage create conditions that enable certain diseases and insects to thrive (FIRA, 2019; SIAP, 2019). The crop is of greater importance nationally and internationally, due to its wide consumption, harvested area and the economic value of the product. In addition to its economic and social importance in the world's production systems, tomato has increasing nutritional relevance because it is a significant source of antioxidant substances (lycopene, beta-carotene) and vitamins (Marín, 2017; Souri and Dehnavard, 2018; Souri and Tohidloo, 2019).

The main tomato producing countries in the world are China, the United States, India, Turkey, Egypt, Italy, Iran, Spain, Brazil, Mexico, Uzbekistan, Russia, among others

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(FAOSTAT, 2018). The single most significant trend in tomato growing in Mexico is the increasing area of about 43,903 hectares coming from greenhouse (including shade house) and open field cultivation. The production is highly concentrated, with six states producing 53 percent of the national production in 2020. Moreover, it permits a large internal domestic and international market during most of the year (SIAP, 2019).

Tomato is very prone to various diseases, which cause low yield and quality and even total loss. Due to their aggressiveness, only preventive treatments show a certain degree of effectiveness, but once the symptoms appear, they no longer have an effect, which is why many applications of synthetic chemical pesticides are made (Bustamante *et al*., 2013). Most pesticides are costly and harmful to humans and the environment, so, their use should be limited to emergencies. However, it is recommended to use combined strategies of pesticides (with emphasis on biological control), organic fertilizers and associated culture management and ecological procedures (Souri *et al*., 2019; Ebrahimi *et al.,* 2021).. In these circumstances, the demand for alternatives such as organic products for disease and pest control and the use of inducing molecules also called elicitors increases (García *et al*., 2018; Simmons, 2018). Elicitors are natural or mineral substances that, when applied to plants in a preventive way, help to reduce or avoid damage caused by diseases, pests or adverse abiotic factors (INTAGRI, 2017). They are presented as the most promising method among the pathogen control alternatives that ensure better tissue vigor, better post-harvest quality (Souri and Hatamian, 2019; Souri and Bakhtiarizade, 2019), production profitability and cost reduction due to reduced use of pesticides and healthy products (Mota, 2019). For this reason, the primary aim of this work was to study the potentiality of selected elicitors to confer broad spectrum disease resistance and production of the two tomato cultivars under greenhouse conditions.

MATERIALS AND METHODS

Study Area and Plant Material

Tomato is an extremely important crop for the economy of several countries like Mexico and thus chosen as the model plant in this study, using two important cultivars, 'Bola' and 'Saladette', cultivated in greenhouse conditions. The aforementioned cultivars were cultivated under the greenhouse "Israelita" during the summer–spring 2019-2020 at the Center for Protected Agriculture (CAP) of the Faculty of Agronomy of the Autonomous University of Nuevo León (UANL), Nuevo León, Mexico. Subsequently, the analysis of the samples was conducted at the chemistry laboratory of the above-mentioned faculty.

Experimental Design and Treatments

In this study, a completely randomized experimental design with four treatments was used: T1: (Control), T2: (Activane®), T3: (Micobiol®), T4: (Stemicol®) and four replications, with a total of 256 plants, were used to evaluate the effect of the elicitors in foliar application (eight sprays) during crop growth period. The dose recommended and the information about the products by the production company, "Lida de Mexico" (Table 1) was used.

Data Analysis

Treatment comparisons according to the findings were performed using the Tukey (P≤ 0.05) test to assess the association between the variables with statistically significant differences between the treatments. Statistical analyses were performed using SPSS STATISTIC software ver. 21.0 (IBM 2015), program for Windows.

Table 1. List of the elicitors applied on leaves of the two tomato cultivars.

Elicitor	Elicitor source	Elicitor properties	Dosis applied
Activane®	Crustaceans	Chito-Oligosaccharides (COS)	1.8 g L^{-1}
	Vegetable origin	Phenols	
Micobiol®	Yeast	β-glucan	3 mL L^{-1}
Stemicol®	Crustaceans	Chito-Oligosaccharides(COS)	2.5 g L^{-1}

Parameters of Study

Vegetative Growth

The data of the variables of interest were taken at 7-day intervals at the same time for greater precision. The following agronomic variables of growth and yield were evaluated according to the methodology of Muñoz, (2009) and Urrieta-Velázquez *et al*. (2012):

A measuring tape was used to measure plant height (cm) and stem diameter was measured with a Digital Vernier Caliper in millimetre (mm). The evaluation of the SPAD units was made with a SPAD brand Minolta model 502 Plus, and the weight of the fruits from several harvest was evaluated by using an electronic scale. Meanwhile, the fruit diameter was also measured with a Digital Vernier Caliper in millimetres (mm).

Fruit Quality Variables

Evaluation of fruit quality variables was carried out with four fruits per plant, when they presented an intense and uniform red surface. Meanwhile the fruit diameter was also measured with a Digital Vernier Caliper in millimetres (mm). The pH values and total soluble solids were determined in the fruit mash with the help of a potentiometer brand "HANNA" model 211 and a digital refractometer brand Atago model Pal1, quantification of the titratable acid content was carried out by extracting 1.0 g of fruit material crushed in a tube adding 9 mL of distilled water. The mixture was titrated with 0.1N sodium hydroxide (NaOH), using 0.1% phenolphthalein as indicator, and the results were expressed as a percentage of citric acid present, fruit color was objectively evaluated where L*, a* and b* values were measured with a Chin SPEC model colorimeter previously calibrated (Ruiz and Rodríguez, 2014; Benito-Bautista *et al*., 2016).

Disease Evaluated

The incidence of the disease was evaluated considering the presence of healthy and diseased plants at 50, 100 and 150 days after transplant. The severity of the symptoms of the diseases present during the development of the crop were evaluated according to the scale proposed by Moreno *et al*. (2016), described as follows, 0= No symptoms (0%); 1= Necrotic spots (20%); 2= Necrotic lesions (40%); 3= Necrotic lesions spots on the surface of the leaf (60%); 4= Necrotic lesions distributed (80%); 5= Fully affected (wilting) or dead (100%).

Molecular Identification of Diseases

Root, stem, leaf and fruit samples were collected from the two tomato cultivars in the greenhouse. For fungi and bacteria, the samples consisted of plant roots, leaves and fruits with symptoms of pathogen attack. For the virus, the sample consisted of 2 g of the newest leaf located in the aerial apex with symptoms indicating the presence such as interveinal chlorosis, mottling and leaf deformation. The samples were taken to the Phytopathology Laboratory, where the corresponding analysis was subsequently carried out for each one as follows: (1) Isolation of bacterial and fungi strains from diseased tomato plants, (2) Obtaining of bacterial DNA and amplification with polymerase chain reaction (PCR), and (3)

RNA extraction and virus detection by generic PCR *Begomovirus*.

Sequencing and Data Analysis

The procedure for the corroboration of the identification of bacteria, fungi and viruses by comparing sequences 16S for bacteria and 18S/5.8S/28S for fungi was revised. The amplified products were sequenced and their sequences were compared with GenBank of National Center for Biotechnology Information (NCBI) (www.ncbi.nlm.nih.gov) of the quantitative values observed; only those with the greatest identity were considered.

RESULTS

Vegetative Growth

Production of tomato crop under greenhouse conditions through the applications of the elicitors in the present study showed a significant effect on vegetative growth. The highest plant height in Saladette cultivar was in treatments with Micobiol® (21.5 cm) followed by Stemicol® (20.6 cm) and Activane® (19.4 cm). Meanwhile, for stem diameter the highest records were registered in the treatments with Stemicol® (10.0 mm). Also, the variables of plant height evaluated in the Bola cultivar showed significant (P= 0.05) for these variables, registering the highest average in stem diameter with Stemicol® (10.0 mm). Leaf SPAD value showed a significant difference (P= 0.05) between the means of the Saladette cultivar, obtaining the highest value for the treatment Micobiol® (T3) with 46.99, followed by Control (T1), Stemicol® (T4) and Activane® (T2) with average values of 45.17, 4.14 and 44.33, respectively. Meanwhile, the Bola cultivar did not show a significant difference (P= 0.05) between the treatments of this variable (Table 2).

Table 2. Effect of elicitors on vegetative growth of the tomato cultivars.[A]

Treatment	Plant height (cm)	Stem diameter (mm)	Number of leaves	SPAD
Saladette cultivar				
T1 – Control	18.6875 c	8.9013 c	14.7812 a	45.1750 b
T2 – Activane®	19.4375 b	9.2125b c	15.2343 a	44.3312 c
T3 – Micobiol®	21.5000 a	9.9894 b	14.9218 a	46.9984 a
T4 – Stemicol®	20.6250 b	10.0788 a	15.0156 a	45.1406 b
Bola cultivar				
T1 – Control	28.8667 c	11.6500 a	18.4969 a	50.6870 a
T2 – Activane®	30.7500 a	11.9233 a	18.7188 a	50.0235 a
T3 – Micobiol®	30.2000 b	12.0193 a	19.1240 a	50.6258 a
T4 – Stemicol®	29.7500 b	11.7816 a	18.6563 a	49.7156 a

[A] Means with the same letter within each column do not differ statistically (P= 0.05).

Fruit Weight and Diameter

The statistical analysis for the parameters under study showed a significant difference (P= 0.05) for the variables weight and equatorial diameter of the fruits in the Saladette cultivar. Meanwhile significant difference (P= 0.05) was registered for the variables of weight and polar diameter of fruits in the Bola cultivar. For both cultivars, the highest value of fruit weight and polar and equatorial diameter were found in the treatment Micobiol® with 128.0 g, 64.1 mm, and 52.4 mm, respectively. The evaluated variables allow knowing the balance between the weight and the diameter of the fruit in the harvest of the two cultivars of tomato (Table 3).

Table 3. Fresh fruit weight, polar and equatorial diameter of the two tomato cultivars as affected by elicitors.[A]

Treatment	Fresh weight of fruit (g)	Fruit diameter (mm)	
		Polar	Equatorial
Saladette cultivar			
T1 – Control	107.13 b	60.12 a	50.69 ab
T2 – Activane®	91.46 c	60.02 a	47.23 b
T3 – Micobiol®	128.07 a	64.10 a	52.45 a
T4 – Stemicol®	111.45 b	63.33 a	51.11 ab
Bola cultivar			
T1 – Control	169.03 b	49.83 b	69.38 a
T2 – Activane®	131.01 c	52.24 ab	68.13 a
T3 – Micobiol®	176.21 a	53.16 ab	69.46 a
T4 – Stemicol®	175.20 a	54.66 a	69.46 a

[A] Means with the same letter within each column do not differ statistically (P= 0.05).

Yield

The highest fruits yield was obtained from the plants treated with elicitors in comparison with the untreated ones. The statistical analysis did not show any significant difference (P= 0.05) for the Bola cultivar. However, a significant difference (P= 0.05) was recorded for the Saladette cultivar, obtaining the highest average in the treatments Activane® (T2) with 70 fruits per square meter and 7.2 kilograms per square meter. The treatments with elicitors Control (T1) presented the lowest average for the number and weight of fruits (Figure 1).

Fruit color

The colors of the ripe fruits were deep and uniform red. Visual perception was not different between the treatments for the two cultivars evaluated during the period of the evaluations (Figure 2).

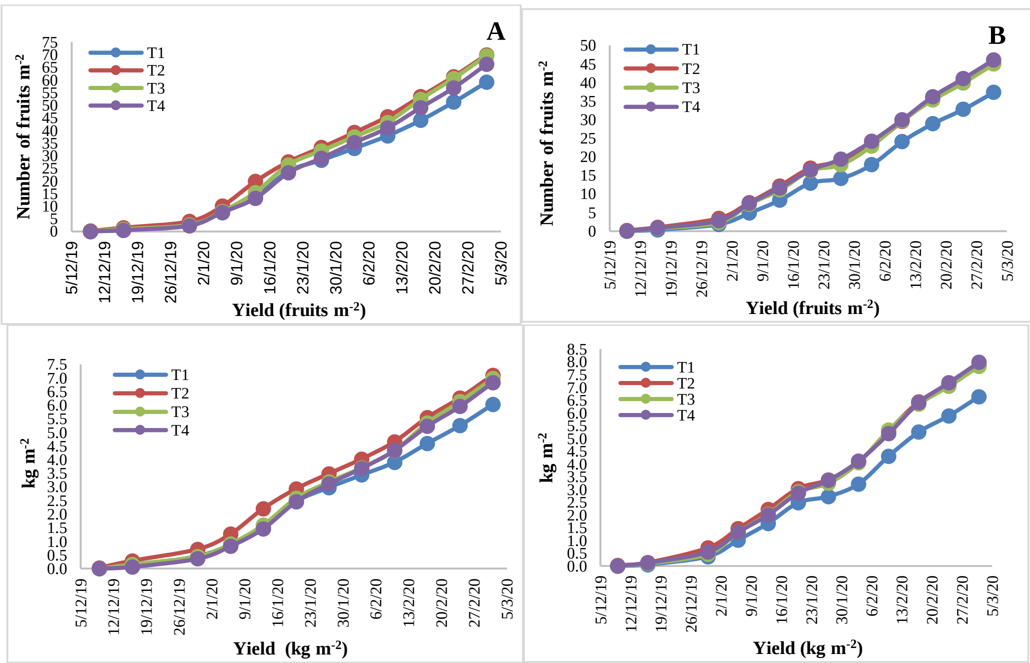

Figure 1. Effects of the elicitors on yields of the two tomato cultivars: (A) Saladette and (B) Bola under greenhouse conditions.

Figure 2. Ripe fruits of intense and uniform red color in both tomato cultivars were selected and evaluated for greater precision of this variable.

Coordinates (a*: b*: C*)

Under the study conditions, statistical analysis of the parameter a*did not show significant difference (P= 0.05) for the two tomato cultivars. However, for the parameters b* and c* showed significant difference (P= 0.05) between the means of the treatments in Saladette cultivar; treatment Stemicol® (T4) being the one that had the most influences on these coordinates. On the other hand, the Bola cultivar showed a significant difference in the Hue angle (H*) and Color Index (IC). The values of this cylindrical coordinate H* showed the highest value for the treatment Activane® (T2) in the two cultivars (54.17 and 50.38), with treatment Control (T1) as the one that presented the lowest values in both (Table 4).

Table 4. Comparison of means of the fruits color coordinates of the two tomato cultivars as affected by elicitors.[A]

Treatments	Luminosity (L*)	Hue angle (H*)	Red contribution (a*)	Yellow contribution (b*)	Chroma (C*)	Color Index (IC)
Saladette cultivar						
T1 – Control	36.57 a	46.18 a	20.70 a	21.50 b	29.84 b	27.06 a
T2 – Activane®	37.11 a	50.38 a	19.96 a	23.76 ab	31.50 ab	23.52 a
T3 – Micobiol®	34.97 a	46.19 a	21.51 a	22.41 ab	31.12 ab	27.06 a
T4 – Stemicol®	35.78 a	47.36 a	21.87 a	23.93 a	32.51 a	26.08 a
Bola cultivar						
T1 – Control	38.76 a	48.55 c	18.10 a	20.53 a	27.44 a	23.10 a
T2 – Activane®	39.16 a	54.17 a	16.13 a	22.45 a	27.79 a	18.80 b
T3 – Micobiol®	38.86 a	51.45 b	18.05 a	22.36 a	28.86 a	21.19 ab
T4 – Stemicol®	38.26 a	50.45 b	17.82 a	21.61 a	28.175 a	22.05 ab

[A] Means with the same letter within each column do not differ statistically (P= 0.05).

Total Soluble Solids (TSS), pH and Titratable Acidity of Fruits

In this study, the total soluble solids (°Brix) registered a significant difference (P= 0.05) for the Saladette cultivar, obtaining the lowest value for the treatment Micobiol® (T3) with 5.26, followed by Activane® (T2), Control (T1) and Stemicol® (T4) with values of 5.37, 5.43 and 5.52, respectively. However, for the Bola cultivar it did not show significant difference (P= 0.05) between the variables. The reported pH values are within the range (4.23-4.59) obtained for the four treatments of both tomato cultivars. The statistical analysis did not present a significant difference for the variables of the Bola cultivar. On the other hand, analysis regarding the acidity of the fruits, showed a significant difference for the two cultivars with the highest being treatment Activane® (T2) with 0.52% of citric acid, followed by the other three treatments with an average of 0.35% (Figure 3).

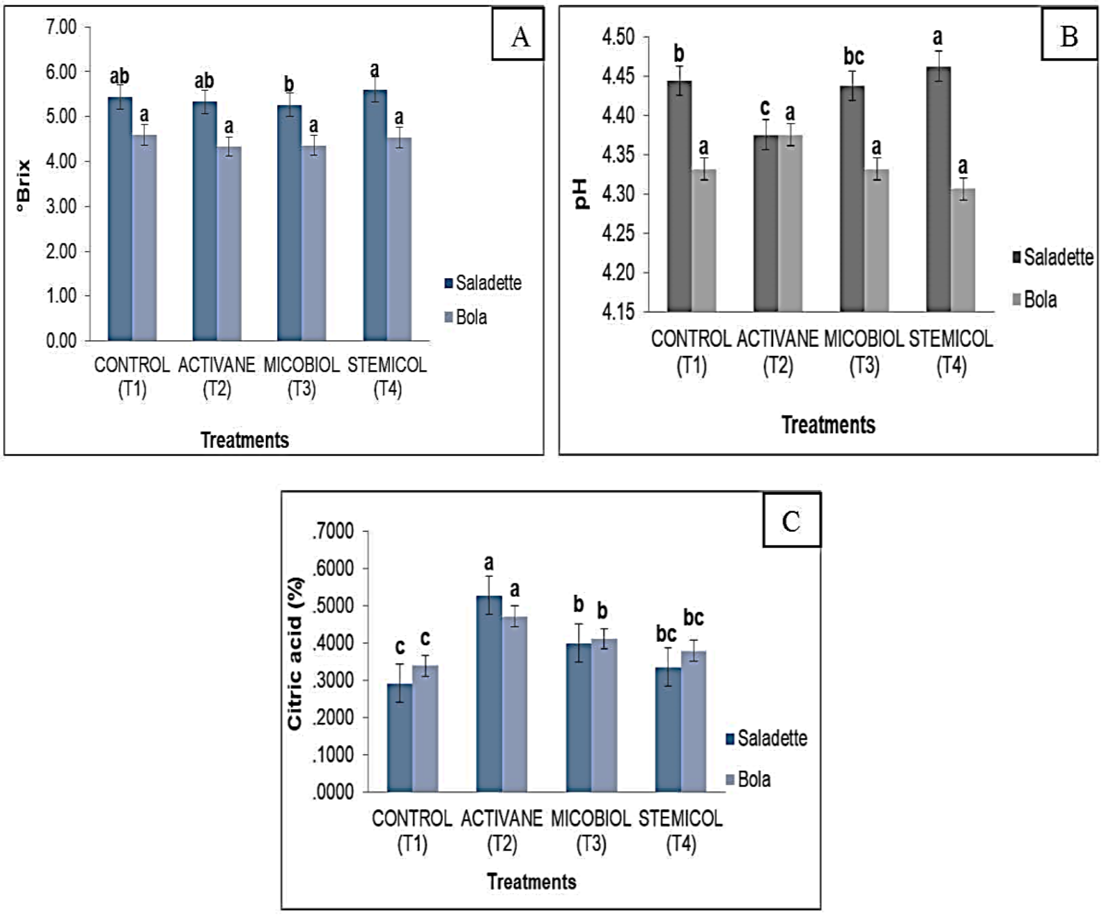

Figure 3. Effects of the elicitors on: (A) Total soluble solids (°Brix), (B) pH, and (C) Titratable acid of the two tomato cultivars.

Incidence and Severity of Diseases

The incidence of diseases was observed mainly in plants of treatment Control (T1). However, the result of the treatments T2, T3, and T4 showed an incidence of 3-17% for *Enterobacter cloacae*, 6–45% for *Oidiopsis taurica* and 3% for *Tomato Yellow Leaf Curl Virus* (TYLCV) in the Bola cultivar and 6-7% for *Oidiopsis taurica* and 3% for *TYLCV* in Saladette cultivar (Table 5).

For plant survival a significant difference (P= 0.05) was recorded for the Bola type cultivar, while for the Saladette type cultivar did not present a significant difference (P= 0.05). Saladette showed the highest averagesof plants in the treatments Micobiol® (T3) w ith (94%) and Activane® (T2) with (91%). Finally, the lowest percentages were presented in the Bola cultivar in the treatment Control (T1) with (47%) (Figure 4).

Table 5. Incidence and severity of diseases in the two tomato cultivars growing in greenhouse conditions as affected by elicitors.

	Bacteria (*Enterobacter cloacae*)				Fungi (*Oidiopsis taurica*)				Virus (TYLCV)			
	Incidence (%)			Severity (%)	Incidence (%)			Severity (%)	Incidence (%)			Severity (%)
	Days after transplant				Days after transplant				Days after transplant			
	50	100	150		50	100	150		50	100	150	
Tomate Bola												
T1	6	10	17	80	-	10	45	40	-	-	3	5
T2	-	3	3	20	-	7	20	20	-	-	-	-
T3	6	6	6	40	-	6	22	20	-	-	-	-
T4	6	6	6	40	-	6	25	20	-	-	3	5
Tomate Saladette												
T1	-	-	-	-	-	7	21	20	-	-	3	5
T2	-	-	-	-	-	6	19	10	-	-	-	-
T3	-	-	-	-	-	6	13	10	-	-	-	-
T4	-	-	-	-	-	6	16	10	-	-	-	-

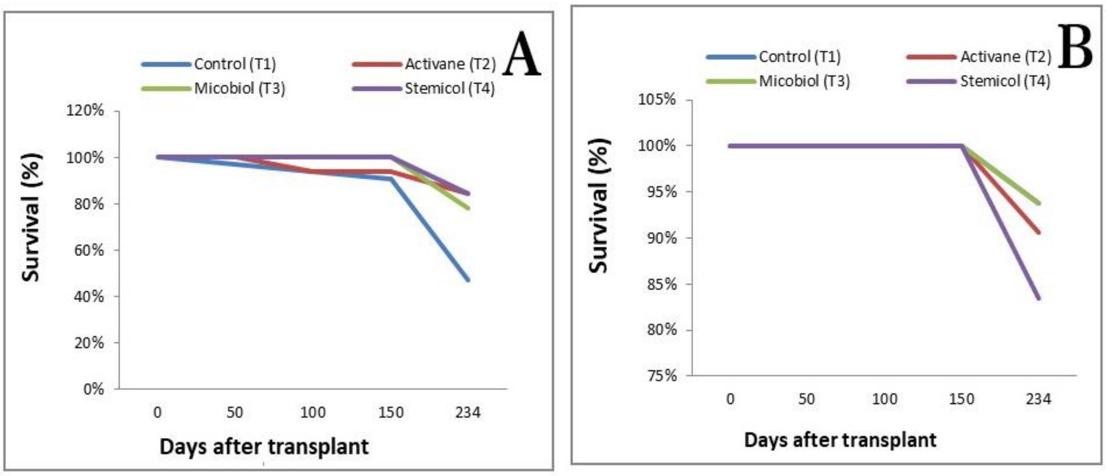

Figure 4. The plant survival trend shown in the two tomato cultivars: (A) Saladette and (B) Bola under greenhouse conditions as affected by elicitors.

Morphological and Molecular Identification of Diseases

Out of the two tomato cultivars sampled and with symptoms of necrosis on roots, stems and leaves, bacterial, fungal and viral isolations were obtained, most of which were characterized by having a white or creamy color. After sequencing them (Figure 5), the Bacteria (*Enterobacter Cloacae*) with an identity of 97.8%, Fungi (*Oidiopsis taurica*) and *Tomato Yellow Leaf Curl Virus* (TYLCV) with an identity of 99.6% were identified.

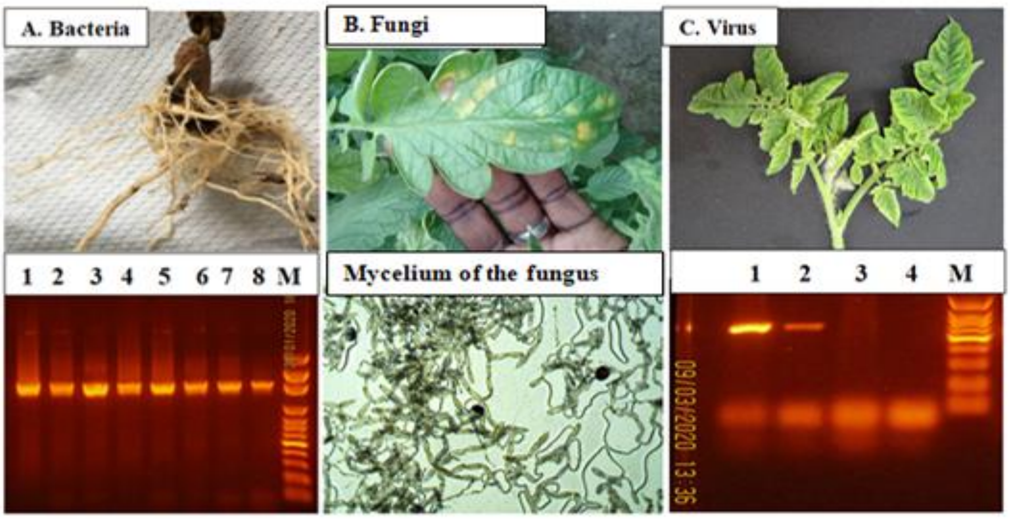

Figure 5. Amplifies fragments of the bacteria and fungi identified through PCR. (A) Amplifies fragment of the bacteria in lane 3; (B) Morphological identification of the fungus with microscopic photos of the mycelium of the fungus, and (C) Amplifies fragment of the virus DNA (TYLCV) in lanes 1-2. (M) Molecular weight marker.

DISCUSSION

Tomato is a world important vegetable crop, which is severely constrained by diseases and pests. Uncovering elicitors that may replace the genetically modified plants and the heavy use of agrochemicals in tomato agriculture grasped researchers' attention. Several elicitors were reported to induce resistance reactions in tomato (Lee *et al*., 1999). In the present scenario of food safety and sustainable agriculture, development of safe and useful strategies toward better biotic and abiotic stresses tolerance is highlighted (Souri *et al*., 2019; Hatamian *et al*., 2020; Ebrahimi *et al*., 2021). Plants need appropriate stimuli or signal to activate their array of defense mechanisms. Elicitors, the small molecules, can mimic the pathogen insight by a plant following activation of various modes of complicated defence reactions that includes hypersensitive response, antimicrobial compound synthesis, lignin accumulation in the cell wall, and over-expression of plant defense related genes (Chandra *et al*., 2014).

It was evident from our results that elicitors Micobiol®, Stemicol® and Activane®, at a specific concentration significantly improved plant growth, yield, and quality, also induced the plant defense molecules. However, Micobiol® (3 mL L^{-1}) and Stemicol® (2.5 g L^{-1}) were found to be most efficient among the tested elicitors. The values of the growth variables recorded in the present study exceed that reported in tomato cultivation by Muñoz, (2009). According to Maldonado *et al*. (2015), tomato crop presented two well-defined growth stages, one exponential in the first four weeks after transplantation and the other linear from the fourth week on. The Micobiol® (T3) was the best treatment with respect to the SPAD value after the eighth application of elicitors. These results coincide with the findings of García *et al*. (2018), who, after evaluating the effect of two elicitors on the tomato crop, found a significant difference (P= 0.05) between the treatments, after the second application and an increase in chlorophyll content during the development of the plants. With respect to treatments with the elicitors, manganese is said to participate in the synthesis of chlorophyll and assimilation of nitrates. Likewise, it has a fundamental role in photosynthesis, respiration, water photolysis, and assimilation of Carbon dioxide (CO2)

INTAGRI (2017). In the present investigation, given that these three treatments contain Mn that is related to increases in photosynthetic activity, organic treatments could be a viable option to be used as a source of nutrients for tomatoes in the greenhouse, when seeking to reduce the use of conventional fertilizers (Preciado *et al*., 2011).

In addition, Grijalva *et al*. (2009) reported the weight of the fruit of a Saladette cultivar ranged between 20–135 grams, and the diameter between 25–59 mm, while in Bola cultivar the weight of the fruit ranged between 20–220 grams, and the diameter between 25–59 mm. Regarding the titratable acid results, they coincide with Nielsen (2009), who reported that the typical amount of acidity in tomato was citric acid and ranged between 0.2-0.6. It is worth mentioning that in this study, the elicitors increased the number of fruits in the treated plants and decreased the reduction in total yield. These results coincide with García *et al*. (2018) after evaluating the effect of two elicitors on the tomato crop found that application of elicitors of natural origin from plant extracts had a positive effect on the height of the treated plants and accumulation of biomass decreased the reduction of total yield. On the other hand, Grijalva *et al*. (2009) indicated an average yield of 25.3 kg.m^2 in Bola tomato, and for Saladette as the most consistent, an average yield of 26.1 kg.m^2 during three years under greenhouse conditions. Regarding the color of the fruit, these results could be due to the different degradation times of chlorophyll in each cultivar, due to the content and activity of chlorophylase and the presence of other degrading enzymes, or to the ease of degeneration of chloroplast structures (Hornero-Méndez and Mínguez-Mosquera, 2002). On the other hand, López and Gómez (2004) report that, for tomato fruits, the C* coordinate is not an adequate indicator of maturity, since it is essentially an expression of purity for a specific color. López and Gómez (2004), reported H* values of 59.3 for fruits at maturity for consumption (red color). Similarly, Santamaría Basulto *et al*. (2009) reported value of 65 for H* when the fruit reached maturity for consumption. These results can be compared with the color index for tomato (*Lycopersicon esculentum* Mill) obtained by López and Gómez (2004), who found a direct correlation between this expression and the degree of ripening, with Color Index (CI) values around 21.8 for ripe fruits for consumption.

The Brix degree results coincide with that of Ramírez-Godina *et al*. (2013), who indicated a range from 5.95 to 6.63 °Brix, with a significant difference (P= 0.05) between the populations of different tomato cultivars. On the other hand, our data regarding fruit pH value were similar to those reported by Jiménez *et al*. (2012), who indicated a range of pH 3.51 to 4.51, between three genotypes and tomato cultivars with a significant difference (P= 0.05) due to the effect of the cut-off date.

García *et al*. (2018) found that application of elicitors was not only observed to decrease the symptoms of incidence of the disease, but also promoted accumulation of total dry biomass, the increase in height, and a lower yield loss per plant compared to the plants that were not treated. In this study, excised leaves of the two tomato cultivars when elicited with Activane® (1.8 g L^{-1}), Micobiol® (3 L L^{-1}) and Stemicol® (2.5 g L^{-1}) induced decrease in the incidence of disease symptoms compared to the control. Although, treatment of tomato leaves with other elicitors such as Micobiol® (T3) and Stemicol® (T4) showed a greater positive effect on the incidence of diseases than the Control (T1). As shown in both experiments, where the incidence of diseases and the severity of their symptoms during the evaluations were reduced by the application of elicitors, this could be due to the fact that the active compounds applied from these elicitors activated some mechanism related to the defense of the plant to face these conditions.

Mortality in the treatments was influenced by the incidence and severity of the diseases. Both cultivars presented the highest survival rates at 234 Days After Transplanting (DAT) in the plants treated with the elicitors. A probable reason for this trend is that elicitors promote the induction of resistance in the treated plants; therefore, it was possible to reduce the incidence and severity of the disease and improve survival. These results coincide with the findings of García *et al*. (2018), who evaluated the effect of two elicitors on the tomato crop and found that the incidence of the disease caused by *F. oxysporum* and the severity of its symptoms during the first evaluation were reduced by the application of the elicitors of natural origin. To explain that this could be due to the compounds applied, they activated some mechanism related to the defense of the plants to face conditions of biotic stress.

Moreover, the bacteria *E. cloacae* registered in this work was found affecting up to 4% of chili seedlings (*Capsicum annuum* L.) in greenhouses in Chihuahua, Mexico (García-González *et al*., 2018). In this study, we registered a new bacterial disease in tomato crops caused mostly in plants without elicitors. Meanwhile the powdery mildew (*Oidiopsis taurica*) registered attacking the leaves was reported by Guzmán *et al*. (2011) associated with four tomato genotypes of indeterminate habit produced in greenhouse conditions in Coahuila, Mexico. The present study also indicates the same results where attacks on the leaves appear as yellowish-green spots on the upper part of the leaves, and then the central part of the lesions dehydrates and turns brown. Also, virus *TYLCV* that belongs to the genus *Begomovirus*, family Geminiviridae, is another virus that stands out enormously for its incidence and severity in tomato crops. It is a DNA virus transmitted by the whitefly *Bemisia tabaci*. This virus has been reported under the shade houses and greenhouses of The State of Sonora, Mexico, and more recently in the agricultural area of Caborca (Guerrero *et al.,* 2016). In the present investigation, we found this virus mostly in Control plants (T1). However, Stemicol® (T4) treated plants also showed less infection of this virus over control.

CONCLUSIONS

The growth and production of these two tomato cultivars were favoured by the application of elicitors. The elicitors that had the highest influence in terms of plant height, stem diameter, weight, and fruit diameter were Micobiol and Activane, while for the variables like fruit color, °Brix, and pH it was Stemicol, and Activane had significant effect on titratable acid of both cultivars. Moreover, the incidence and severity of diseases decreased and survival increased in plants treated with elicitors. The elicitors Activane, Micobiol, and Stemicol may represent an important potential in greenhouse tomato production to counteract the negative effects of increased incidence and severity of diseases and to prevent unfavourable conditions in the development of tomato crops.

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REFERENCES

1. Benito-Bautista, P., Arellanes-Juárez, N. and Pérez-Flores M. E. 2016. Color y Estado de Madurez del Fruto de Tomate de Cáscara. *Agron. Mesoam*., **27(1):** 115-130.
2. Bustamante, J. D, Vázquez, A., Trujillo, C., Reye, R. and Escalona, F. 2013. *Manual Para el Cultivo del Jitomate en Bioespacio e Invernadero.* Libro Técnico 11, Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Centro de Investigación Regional Pacífico Sur, Campo Experimental Zacatepec, Zacatepec, Morelos, 190 PP.
3. Chandra, S., Chakraborty, N., Chakraborty, A., Rai, R., Bera, B. and Acharya. K. 2014. Induction of Defense Response against

Blister Blight by Calcium Chloride in Tea. *Arch. Phytopathol. Plant. Prot.*, **47:** 2400–2409.
4. Ebrahimi, M., Mousavi, A., Souri, M.K. and Sahebani, N. 2021. Can Vermicompost and Biochar Control *Meloidogyne javanica* on Eggplant?. *Nematology*, **(1):** 1-12.
5. FAOSTAT. 2018. *Statistics Division Food and Agriculture Organization of the United Nations Viale delle Terme di Caracalla.* Rome, Italy. http://www.fao.org/faostat/en/#home.
6. FIRA. 2019. *Panorama Agroalimentario Tomate Rojo.* Online: diees@fira.gob.mx
7. García, E., Robledo, A., Mendoza, B., Solís, G. and González, S. M. 2018. Efecto de Elicitores de Origen Natural Sobre Plantas de Tomate Sometidas a Estrés Biótico. *Rev. Mex. Cienc. Agríc. Vol. Esp.,* **(20).**
8. García-González, T., Sáenz, H. H., Silva, R., Morales, N. C., Vancheva, T., Koebnik, R. and Ávila, Q. G. 2018. *Enterobacter cloacae*, an Emerging Plant-Pathogenic Bacterium Affecting Chili Pepper Seedlings. *Plant Pathol. J.*, **34(1):** 1-10
9. Grijalva, C. L., Robles, C. F. and Macías, D. R. 2009. *Híbridos de Tomate Para la Producción en Invernadero en el Noroeste de Sonora.* Folleto Cientifico (1), Instituto Nacional de Investigaciones Forestales y Agropecuarias, Centro de Investigaciones Regional del Noroeste, Campo Experimental Caborca, Caborca, Sonora, México, PP. 1-34.
10. Guerrero, J. C., Fernández, E. and Zamora, E. 2016. Virus del Rizado Amarillo de la Hoja del Tomate (TYLCV) o Virus de la Cuchara Bajo Casas Sombra. Enfermedades de las Plantas (Cultivos Protegidos). ***ENFPL*-CP-(001)**: 1-4.
11. Guzmán, P. R., Fajardo, F. L., García, E. R., Cadena, H. M. 2011. Desarrollo Epidémico de la Cenicilla y Rendimiento de Tres Cultivares de Tomate en la Comarca Lagunera, Coahuila, México, *Agrociencia Méx*., **3(45):** 1405-3195.
12. Hatamian, M., Rezaei Nejad, A., Kafi, M., Souri, M. K. and Shahbazi, K., 2020. Interaction of Lead and Cadmium on Growth and Leaf Morphophysiological Characteristics of European Hackberry (*Celtis australis*) Seedlings. *Chem. Biol. Technol. Agric.*, **7(1):** 1-8.
13. Hornero-Méndez, D. and Mínguez-Mosquera, M. I. 2002. Chlorophyll Disappearance and Chlorophyllase Activity during Ripening of *Capsicum annuum* L Fruits. *J. Sci. Food Agric.*, **(82):** 1564-1570.
14. INTAGRI. 2017. *La Inducción de Defensa en las Plantas a Través de Elicitores.* Serie Fitosanidad Núm. 92, Artículos Técnicos de INTAGRI, México, 6 PP.
15. Jiménez, E., Robledo, A., Benavides, T. A., Ramírez, F., Ramírez, H. and De la Cruz, E. 2012. Calidad de Fruto de Genotipos Tetraploides de Tomate de cáscara (*Physalis ixocarpa* Brot.). *Uni. y Cien*., **28(2):** 153-161.
16. Lee, S., Choi, H. and Suh, S. 1999. "Oligogalacturonic Acid and Chitosan reduce stomatal aperture by inducing the Evolution of Reactive Oxygen Species from Guard Cells of Tomato and *Commelina communis*". *Plant Physiol.,* **121(1):** 147–152.
17. López, A. F. and Gómez, P. A. 2004. Comparison of Color Indexes for Tomato Ripening. *Hortic. Bras*., **(22):** 534-537.
18. Maldonado, J. A., Romenus, K. A., González, A. Z., Ramírez, H. and Mendoza, B. A. 2015. Análisis de Crecimiento del Cultivo de Tomate en Invernadero. *Rev. Mex. de Cien. Agrí.*, **6(5):** 943-954.
19. Marín, L. L. 2017. Manual Técnico del Cultivo de Tomate (*Solanum lycopersicum*) Costa Rica. Instituto Nacional de Innovación y Transferencia en Tecnología Agropecuaria. San José, C. R. *INTA*, (**126):** 978-9968.
20. Moreno, L. P., Mendoza, G. H., Celedón, B. M., Galván, Ma. F., Hernández, L. R. and Franco, A. C. 2016. Incidencia, Severidad y Detección de Virus Fitopatógenos en Lechuga, en el Estado de Querétaro, México. Ciencias Biológicas, Agropecuarias y del Medio Ambiente. *Acta. Univ*., **26(2):** 3-11.
21. Mota, J. B. 2019. Las Fitovacunas y su Efecto Vigorizante y Protector en los Cultivos. *V Congreso Nacional de Fertirrigación y Nutrición en Hortalizas*, Lida de México, SA de CV, PP. 1–83.
22. Muñoz., 2009. *Condiciones Agroclimática de Mexico y la Horticultura Protegida. Manual de Producción de Tomate en Invernadero.* Intagri, Castellano (Ed), Gto. Mexico. PP. 44- 60.
23. Nielsen, S. 2009. *Food Analysis*. Editorial Springer, Purdue University, **(4):** 587-657.
24. Preciado, P., Fortis, M., García, J. L., Rueda, E., Esparza, J. R., Lara, A., Segura, M. A.

and Orozco, J., 2011. Evaluación de Soluciones Nutritivas Orgánicas en la Producción de Tomate en Invernadero. *Interciencia,* **(36):** 689-693.
25. Ramírez-Godina, F., Robles-Torres, R., Foroughbakhch-Pournabav, A., Benavides-Mendoza, J. L., Hérnández–Piñero, M. H., Reyes-Váldez, M. and Alvarado-Vázquez, M. A. 2013. Yield and Fruit Quality Evaluation in Husk Tomato Autotetraploids (*Physalis ixocarpa*) and Diploids. *Aust. J. Crop Sci.*, **(7):** 933-940.
26. Ruiz, M. Á. and Rodríguez, M. S. 2014. Parámetros de Calidad Interna de Hortalizas y Frutas en la Industria Agroalimentaria. Negocio Agroalimentario y Cooperativo. *Fichas de Referencia Número,* **(005):** 1 – 18.
27. Santamaria Basulto, F., Duch, E. S., Espadas y Gil, F., Diaz-Plaza, R., Saavedra, A. L. and Santamaria, J. M. 2009. Postharvest Ripening and Maturity Indices for Maradol Papaya. *Interciencia*, **34:** 583-588.
28. Servicio de Información Agroalimentaria y Pesquera (SIAP). 2019. Online: https://www.gob.mx/siap/acciones-y-programas/produccionagricola-33119.
29. Simmons, E. 2018. *Biostimulants Working Group.* AAPFCO Admin Seminar, USDA, Palm Springs, CA, PP. 1-11 p.
30. Souri, M. K. and Dehnavard, S. 2018. Tomato Plant Growth, Leaf Nutrient Concentrations and Fruit Quality under Nitrogen Foliar Applications. *Adv. Hort. Sci.*, **32(1):** 41-47.
31. Souri, M. K. and Hatamian, M. 2019. Aminochelates in Plant Nutrition; A Review. *J. Plant Nut.*, **42(1):** 67-78.
32. Souri, M. K. and Tohidloo, G. 2019. Effectiveness of Different Methods of Salicylic Acid Application on Growth Characteristics of Tomato Seedlings under Salinity. *Chem. Biol. Technol. Agric.*, **6(1):** 26.
33. Souri, M. K. and Bakhtiarizade, M. 2019. Biostimulation Effects of Rosemary Essential Oil on Growth and Nutrient Uptake of Tomato Seedlings. *Sci. Hort.*, **(243):** 472476.
34. Souri, M. K., Naiji, M. and Kianmehr, M. H. 2019. Nitrogen Release Dynamics of a Slow Release Urea Pellet and Its Effect on Growth, Yield, and Nutrient Uptake of Sweet Basil (Ocimum basilicum L.). *J. Plant Nut.*, **42(6):** 604-614.
35. Urrieta-Velázquez, J. A., Rodríguez-Mendoza, M., Ramírez-Vallejo, P., Baca-Castillo, G. A., Ruiz-Posada, L. and Cueto-Wong, J. A. 2012. Variables de Producción y Calidad de Tres Selecciones de Jitomate de Costilla (*Solanum lycopersicum* L.). *Rev. Chap. Serie Hort.*, **18(3):** 371-381.

اثر محرک ها (الیسیتورها Elicitors) بر رشد، بهره وری و سلامت گوجه فرنگی (*Solanum lycopersicum* L.) در شرایط گلخانه

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چکیده

تولید گوجه فرنگی (*Solanum lycopersicum* L.) در کشورهایی مانند مکزیک به شدت به استفاده از آفت‌کش‌های شیمیایی وابسته است که می تواند برای بسیاری از موجودات دیگر از جمله حشرات مفید و مصرف کنندگان انسانی سمی باشد. روش‌های سازگار با محیط‌زیست برای کنترل بیماری‌های گوجه‌فرنگی شامل اقدامات زیست‌بوم‌کشاورزی، قارچ‌کش‌های آلی و کنترل بیولوژیکی

است. مقاومت گیاهان در برابر عوامل بیماری‌زا با استفاده از عواملی به نام محرکها در گیاهان ایجاد می شود و منجر به پیشگیری از بیماری یا کاهش شدت آن می شود. هدف این پژوهش، شناخت تأثیر سه محرک بود به نام اکتیوان (Activane) (۱٫۸ گرم درلیتر)، میکوبیول (Micobiol) (۳ میلی لیتردرلیتر) و استمیکول (Stemicol) (۲٫۵ گرم در لیتر) و یک تیمار شاهد بر کنترل بروز بیماری، بنیه، عملکرد و کیفیت میوه دو رقم گوجه فرنگی Bola و Saladette در گلخانه بود. محرک ها باعث کاهش بروز و شدت بیماریهای ارائه شده و افزایش بقای گیاه شد. علاوه بر این، محرک‌های Micobiol® وActivane® توانستند ارتفاع بوته، قطر ساقه، وزن و قطر میوه را افزایش دهند، در حالی که Stemicol® به طور قابل توجهی رنگ میوه، درجه بریکس و pH را افزایش داد و Activane® اسید قابل تیتراسیون را افزایش داد. به طور کلی، محرک‌ها قادر به کاهش بیماری، افزایش بقای گیاه، تولید و بهبود کیفیت میوه بودند. این یافته‌ها سمت‌گیری‌های مثبتی را برای استفاده احتمالی از این محرک‌ها ارائه می کنند و باعث ایجاد مقاومت در حفاظت از گیاه می‌شوند.