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Relationship between Tomato (*Solanum lycopersicum*) Nutrition and the Severity of the Vascular Fusariosis

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Abstract

The vascular fusariosis is one of the main obstacles in the tomato crop production. Currently, the management of the nutrient solution is presented as a control option for fusariosis, for such reason different nutrient solutions with nitrogen (N), phosphorus (P), potassium (K) and calcium (Ca) modifications; in four saladette tomato varieties Bony Best (BB), Manapal (M), Walter (W) and FLA were evaluated in this research, in order to analyze the damage caused by *Fusarium oxysporum* f.sp. *lycopersici* (FOL) severity. Tomato plants were inoculated with 3 FOL breeds, establishing a completely random design with a factorial arrangement with six repetitions. Disease's severity was evaluated 30 days after the inoculation using levels of (0 - 4) of the methodology established by Marlatt and Correll (1988). Afterwards, a statistical analysis was done through the Kruskal Wallis test, in which it was observed that treatments 93 (Ca 207 mg·L^{-1}, R3, variety BB), 95 (207 mg·L^{-1} Ca, R3, variety W), 81 (0Ca, R3, BB) showed less disease severity. In the foliar analysis, the best treatments were 22 (193 mg·L^{-1} N, R3, M) for N, the greatest P content was treatment 94 (207 mg·L^{-1} Ca, R3, M) for K treatment three and 93 (207 mg·L^{-1} Ca, R3, variety BB) greatest Ca content.

Keywords

Fusarium oxysporum f.sp. *lycopersici*, Nutrient Solution, Cultural Control

1. Introduction

In the present time, the tomato crop has gained economical and feeding impor-

tance worldwide, because the harvested surface worldwide exceeds 4 million ha per year^{-1}, with the mean production fluctuating around 177 million tons per year (FAO, 2019). México occupies the ninth position with a 3.35 million tons production with an export value of 2613 million dollars [1].

Although the production of this vegetable is affected by the fusariosis vascular disease, which is a cryptogamic disease caused by *Fusarium oxysporum* f.sp. *lycopersici* (FOL), being one of the factors that limit the success in the production of this vegetable, causing up to 60% of loss and in some cases total crop loss [2].

[3] mentions that the symptoms caused by the *Fusarium oxysporum* f.sp. *lycopersici* are initially observed in the plant's root system, which causes severe rotting and moves through the stem's vascular bundles to the aerial part, darkening them and obstructing water and nutrients way. The root's vascular system, stem and petioles turn brown-reddish, causing its tamponade, to cause a slight yellowness and premature aging of the lower leaves. There are 3 FOL breeds which are genetically similar and have clonal populations. In different special ways of some vegetative compatible groups (VCG) they can be found in the same polymorphism pattern of the DNA multiplied randomly, the existence of four VCG that go from 000300 to 0033 has been informed. Breeds 1 and 2 produce VCG 0030 to 0032, and breed 3 VCG 0030 and 0033 [4].

11 FOL proteins have been identified, which have been named proteins secreted in the xylem (*SIX*). Three of these proteins are opposed by the tomato *I* genes: *Avr*1 (*SIX*4) is known by genes *I* and *I*-1 non allelic, *Avr*2 (*SIX*3) is known for *I*-2 and *Avr*3 (*SIX*1) is known for *I*-3. *Avr*2, *Avr*3 as well as *SIX*6, are genuine effectors, and it has been found that they contribute to the general virulence [5].

The Fusarium species responsible for the wilting follow a similar infection pattern; penetrate through the root and colonize the plant's stem and the vascular system. Although, the colonization is restricted in resistant crops as well as susceptible ones to the region of initial entrance of the pathogen, due to the occlusion of the vessels of gels, release of callouses and tyloses. In susceptible crops, the continuous colonization (secondary distribution) when the gels and callouses are degraded by the pectolytic enzyme effect of the pathogen and the tyloses growth is inhibited. In resistant crops, catechins type flavonoids and their oxidation products deactivate the enzymes, and the secondary distribution is confined to the initial infection points [6].

Fusarium control is mainly based on the use of resistant varieties, soil fumigation and fungicide applications, among other techniques. In Sinaloa, the control of root diseases in tomato cultivation has been carried out through the use of pesticides (fungicides and soil fumigants), the most used fungicides are systémic: benzimidazoles, triazoles, contact: Imidazoles, ditiocarbamatos Benzimidazoles and triazoles are characterized by favoring the formation of resistant pathogen strains [7].

Despite the above, there is no interest about the mineral nutrition having an

important role in the plant disease control. The use of chemicals increases the negative impact in the environment and food safety. The deficiency of all essential nutrients affects plant's health and susceptibility to diseases. The plants with nutritional stress are inclined to diseases, while plants with adequate nutrition are more disease tolerant [8].

Basic scientific research has provided specific explanations about the mechanisms in which nutrition has a strong influence over the incidence and severity of the diseases of the cultivated plants. On the other hand, from this research obtained results have given the basis to add the nutritional management in commercial schemes of integrated control of the sanitary problems in several crops [9]. Also, it is pointed that the unbalances between N and K, between Ca and B and between Ca, Mg and K favor the disease's development and have shown how the comprehensive nutrition management must be part of the management strategies for the disease control [10].

The diffusion rate ant the composition of the exterior cytoplasmic exudates, are aspects that are affected by the nutrient availability. For example, the sugars concentration and amino acids is high in the leaves when there is potassium (K) deficiency, and how these substances favor the fungus development, its greater concentration favors fungous diseases [11].

It was demonstrated that the $CaCl_2$ abiotic elicitor application, decreases the damage post-harvest in pear shaped fruit, by the induction of high levels in the defense enzyme activity [12]; the high concentration of the Ca^{2+} cation shows that an important event during the interaction of the hosting pathogen that induces to immune responses innate to the plant [13].

The objective of this research investigation was to determine the effect of the nutrients (nitrogen, phosphorus, potassium and calcium) and the severity of the different *Fusarium oxysporum* f.sp. *lycopersici* breeds in tomato plants.

2. Materials and Methods

2.1. *Fusarium* Insulations Used

The insulations used in this study are the same used y [14]; who confirmed that the breeds in the insulations used through pathogenicity tests and molecular tests (**Table 1**). The insulations are placed in the insulation collection in the Phyto protection lab in the Agronomy Faculty in the Universidad Autónoma de Sinaloa.

Table 1. Origin, codes and accession numbers of the Genbank of *Fusarium* spp. insulated from tomato plants.

Species Insulation code	Origin Genbank Access num
F. oxysporum (raza 1) FOB20SINELO	Elota, Sinaloa MH298326
F. oxysporum (raza 2) FOA62SINFUE	El Fuerte, Sinaloa MH048074
F. oxysporum (raza 3) FOB25SINGUA	Guasave, Sinaloa MH463538

The insulations were obtained from commercial tomato crops (*S. lycopersicum*) in the state of Sinaloa, México in the fall-winter 2016-2017 cycle.

2.2. Sowing

The sowing of the four tomato varieties undetermined was done in peat and fine vermiculite substratum in trays of 200 cavities, placing one seed per cavity. They were kept under adequate greenhouse conditions the varieties used were Bony Best (BB) susceptible to the three FOL breeds, Manapal (M) resistant to one FOL breed, Walter (W) resistant to FOL breed 1 y 2 de FOL y FLA resistant to the three FOL breeds.

The pathogenicity tests done used the four tomato varieties. The plant's roots by genotype in the two true leaves stage in sterile peat were washed and soaked in a conidial suspension (1×10^5 UFC·mL^{-1}) of each insulation for 10 minutes and then planted into a pot that contained sandy loam soil. The suspension was obtained by gathering the spore of each insulation. 40 days after inoculation, once the 4 true leaves showed up, they were harvested for the respective analysis.

2.3. Nutritive Solution

The nutritive solution (SN) was applied after the FOL inoculation, the used concentration were based on the Steiner universal solution (1966) using sterile distilled water, but with modifications, the concentration was increased by 15% and lowered to 0 the four elements. The fertilizers used in this experiment were, potassium nitrate KNO_3, calcium nitrate $(NO_3)_2{\cdot}4H_2O$, mono potassic phosphate KH_2PO_4, potassium sulphate K_2SO_4, calcium chloride $CaCl_2$ and potassium chloride KCl (**Table 2**). According to [15], post-sowing, every plant was inoculated on day 40 (when these had two true leaves) after the sowing, by the root immersion method, this was submerged for 15 minutes with FOL with an amount of 1×10^6 conidia.

2.4. Foliar Analysis

The plants were analyzed to know each elements concentration and determine N, P, K and Ca concentrations. The samples were placed in paper bags and inserted to a forced air stove at 70˚C ± 5˚C for 24 h. Once the sample dried, it was grinded in a grinder until in went through a 1.00 mm sieve. After the grinding the sample was homogenized and separated in 5 to 10 g samples for the analysis and storage. From the homogenized sample, it is placed in a 2 g melting pot, and it's introduced in a muffle at 450˚C for two hours. The sample is retrieved and cooled down, afterwards 2 - 3 mL of distilled water is added to moist the ashes and for the estimation of each element the methodology proposed by [16] was used.

2.5. Disease's Severity

30 days past the inoculation the plants were retrieved from the trays and were

Table 2. Treatments and factor levels.

TREAT	FERT.	BREED	VAR.	TREAT	FERT.	BREED	VAR.
1	0 N	R1	BB	21	15% N	R3	BB
2	0 N	R1	M	22	15% N	R3	M
3	0 N	R1	W	23	15% N	R3	W
4	0 N	R1	FLA	24	15% N	R3	FLA
5	0 N	R2	BB	25	0P	R1	BB
6	0 N	R2	M	26	0P	R1	M
7	0 N	R2	W	27	0P	R1	W
8	0 N	R2	FLA	28	0P	R1	FLA
9	0 N	R3	BB	29	0P	R2	BB
10	0 N	R3	M	30	0P	R2	M
11	0 N	R3	W	31	0P	R2	W
12	0 N	R3	FLA	32	0P	R2	FLA
13	15% N	R1	BB	33	0P	R3	BB
14	15% N	R1	M	34	0P	R3	M
15	15% N	R1	W	35	0P	R3	W
16	15% N	R1	FLA	36	0P	R3	FLA
17	15% N	R2	BB	37	15% P	R1	BB
18	15% N	R2	M	38	15% P	R1	M
19	15% N	R2	W	39	15% P	R1	W
20	15% N	R2	FLA	40	5% P	R1	FLA
41	15% P	R2	BB	61	15% K	R1	BB
42	15% P	R2	M	62	15% K	R1	M
43	15% P	R2	W	63	15% K	R1	W
44	15% P	R2	FLA	64	15% K	R1	FLA
45	15% P	R3	BB	65	15% K	R2	BB
46	15% P	R3	M	66	15% K	R2	M
47	15% P	R3	W	67	15% K	R2	W
48	15% P	R3	FLA	68	15% K	R2	FLA
49	OK	R1	BB	69	15% K	R3	BB
50	OK	R1	M	70	15% K	R3	M
51	OK	R1	W	71	15% K	R3	W
52	OK	R1	FLA	72	15% K	R3	FLA

Continued

53	OK	R2	BB	73	0Ca	R1	BB
54	OK	R2	M	74	0Ca	R1	M
55	OK	R2	W	75	0Ca	R1	W
56	OK	R2	FLA	76	0Ca	R1	FLA
57	OK	R3	BB	77	0Ca	R2	BB
58	OK	R3	M	78	0Ca	R2	M
59	OK	R3	W	79	0Ca	R2	W
60	OK	R3	FLA	80	0Ca	R2	FLA

81	0 Ca	R3	BB
82	0 Ca	R3	M
83	0 Ca	R3	W
84	0 Ca	R3	FLA
85	15% Ca	R1	BB
86	15% Ca	R1	M
87	15% Ca	R1	W
88	15% Ca	R1	FLA
89	15% Ca	R2	BB
90	15% Ca	R2	M
91	15% Ca	R2	W
92	15% Ca	R2	FLA
93	15% Ca	R3	BB
94	15% Ca	R3	M
95	15% Ca	R3	W
96	15% Ca	R3	FLA

labeled. The severity of the disease was evaluated, according to the scale proposed by [17]; established levels from (0 - 4) where, 0 = 0%; 1 = light necrosis (1% - 33%); 2 = moderate necrosis and discoloration (34% - 66%); 3 = extreme necrosis and discoloration (67% - 100%); 4 = dead plant.

2.6. Statistical Analysis

A completely random design was established with a factorial arrangement with six repetitions obtaining a total of 96 treatments. For variables with result of disease's severity the data was analyzed by the non-parametrical test of Kruskal Whallis ($\alpha = 0.0$), which originated a dendrogram; for the variables of the foliar analysis of the elements a variance analysis was done and a comparison Tukey

mean test ($\alpha = 0.05$).

3. Results and Discussion

3.1. Disease's Severity

The severity of the vascular fusariosis caused by FOL was statistically less in treatments 93, 95 and 81. Treatments 93 (Ca at 15%, R3, variety BB) y 95 (Ca at 15%, R3, variety W), showed a decrease in disease's severity. [18] concludes that, when calcium is increased, the FOL disease decreases, because it has an adequate amount of calcium in the tomato plant's tissue which reduced the enzymes that fade in the cellular walls produced by FOL. Besides, it is reported that Ca deficiency increases cytoplasmic membrane permeability, which favors the sugars and amino acid accumulation in the apoplast [19], this limits the polymer synthesis which may have a negative effect on the development of the pathogen [20], On the other hand, Ca is fundamental in the cellular wall structure, so its deficiency may cause a stiffness loss in the cellular wall and facilitate the pathogen infection in plants [21] [22], found that nutrition with calcium is important to the tomato bacterial withering resistance, reporting that when the calcium content in plants tissue is increased, the resistance to some diseases is induced and have shown some possible mechanisms: calcium does a direct inhibition of the polygalacturonate and other pectolytic enzymes produced by the pathogen. According to [23], the calcium nitrate application reduces the incidence of the disease called southern putrescence caused by *Sclerotium rolfsii* in the carrot crop. Because of this, it can be deduced that the calcium application in the treatments may have benefited the tomato plant's health.

3.2. Foliar Analysis

Treatment 22 consists of 193 $mg{\cdot}L^{-1}$ N, R3 FOL and M variety, statistically showing a greater N content in the foliar area with a 73.5 mg concentration N g^{-1} plant (**Table 3**), this treatment had a severity level with a mean of 1, which coincides with [24], who established an N sufficient level which oscillates between 62.5 - 100 mg of plant N g^{-1}. This indicates that adequate nitrogen levels are less damage susceptible by *Fusarium*, although [25] found that nitrogen excess may promote favorable conditions for plant diseases since it encourages thinner and weaker cellular walls. On the other hand, [26] demonstrated that ammonium nitrate has no influence on the *Fusarium* growth in the fin and root as long as it has low levels, keeping a level of 10 to 100 $mg{\cdot}L^{-1}$ N.

P concentration was greater in treatment 94 as shown in **Table 4**, which is made of Ca (207 $mg{\cdot}L^{-1}$), P (31 $mg{\cdot}L^{-1}$), R3 FOL and M variety, with 62.75 mg of plant P g^{-1}, this showed a severity level of the disease with a 1.8 mean which agrees with [27], where the phosphorus content in vegetal tissue, that was observed in eight treatments, values fluctuated from 24.75 of P g^{-1} of plant in treatment 50% Steiner solution, to 52.8 mg of P g^{-1} of plant in treatment 100% Steiner solution respectively.

Table 3. Foliar analysis of Nitrogen in plant (mg).

Treat.	Mean	Group	Treat.	Mean	Group	Treat.	Mean	Group	Treat.	Mean	Group
22	**73.5**	**A**	40	36.5	K	72	31.5	R	79	26.6	X
30	63	B	54	36.5	K	94	31.5	R	55	26.6	X
18	61.25	C	83	35	M	77	30.8	S	65	26.6	X
90	49	D	14	35	M	52	30.8	S	25	26.6	X
36	43.4	E	78	35	M	44	30.8	S	13	26.6	X
80	43.4	E	76	34.25	N	71	29.4	T	27	25.9	Y
28	42	F	46	34.25	N	39	29.4	T	31	25.9	Y
50	42	F	85	33.6	O	88	29.4	T	87	25.9	Y
70	42	F	26	33.6	O	38	29.4	T	29	25.9	Y
58	41.2	G	62	33.6	O	37	28.7	U	19	25.2	Z
32	39.8	H	61	32.9	P	84	28.7	U	23	25.2	Z
73	39.8	H	20	32.9	P	95	28	V	68	25.2	Z
86	39.8	H	53	32.2	Q	69	28	V	67	24.5	A1
74	39.8	H	93	32.2	Q	96	28	V	91	24.5	A1
75	39	I	60	32.2	Q	48	28	V	17	24.5	A1
66	39	I	42	32.2	Q	33	27.3	W	51	24.5	A1
16	37.1	J	35	31.5	R	89	27.3	W	81	23.8	B1
82	37.1	J	49	31.5	R	24	27.3	W	63	23.1	C1
34	36.5	K	57	31.5	R	43	26.6	X	64	23.1	C1

Treatments with different letters show significant difference Tukey $\alpha = 0.05$.

Table 4. Foliar analysis of Phosphorus in plant (mg).

Treat.	Mean	Group	Treat	Mean	Group	Treat.	Mean	Group	Treat	Mean	Group
94	**62.7**	**A**	87	17.75	J	72	7.75	N	8	5.2	O
69	40.25	B	92	15.25	K	40	7.75	N	57	5.2	O
9	37.75	C	43	15.25	K	78	7.75	N	22	5.2	O
53	37.75	C	21	15.25	K	6	7.75	N	65	5.2	O
90	35.25	D	76	12.75	L	62	7.75	N	46	5.2	O
86	32.75	E	58	12.75	L	66	7.75	N	85	5.2	O
1	30.25	F	71	12.75	L	50	7.75	N	38	5.2	O
96	30.25	F	91	12.75	L	82	7.75	N	14	5.2	O
45	30.25	F	75	12.75	L	42	7.75	N	59	2.75	P
93	25.25	G	49	12.75	L	79	7.75	N	63	2.75	P

Continued

2	22.75	H	48	10.25	M	39	7.75	N	68	2.75	P
17	22.75	H	10	10.25	M	55	7.75	N	11	2.75	P
5	22.75	H	95	10.25	M	81	7.75	N	52	2.75	P
13	22.75	H	3	10.25	M	77	7.75	N	23	2.75	P
61	22.75	H	51	10.25	M	84	5.2	O	64	2.75	P
83	20.25	I	89	10.25	M	44	5.2	O	73	2.75	P
18	17.75	J	41	10.25	M	88	5.2	O	56	2.75	P
70	17.75	J	37	10.25	M	60	5.2	O	24	2.75	P
74	17.75	J	4	7.75	N	16	5.2	O	54	2.75	P

Treatments with different letters show significant difference Tukey $\alpha = 0.05$.

These results show that when phosphorus is added to the nutrient solution in the amount of 207 mg·L^{-1} it can reduce damage severity caused by *Fusarium* in tomato plants, as mention by [28], P applications reduce seed disease as well as fungous diseases in root, stimulating a vigorous development that allows plants to evade the diseases since P is essential for the virus' multiplication, excess of this may increase plant's susceptibility to virus' disease.

Treatment three showed a greater leave concentration of K and was statistically greater in regards of the other treatments as shown in (**Table 5**), which is composed by Steiner solution without addition of N, K (273 mg·L^{-1}) R1 FOL and W variety, such treatment showed a concentration of 110.9 mg of K g^{-1} of plant y and a mean severity of 0.8, this concentration agrees [29] publication, who concluded that element levels are sufficient for an adequate crop development, establishing a sufficient level from 75 to 125 mg of Kg^{-1} of plant. The disease's severity in this treatment was lower, this could be explained due to the adequate potassium content, since [30], mention in a study done with strawberry plants that K deficiency can promote root exudate production, especially phenolic acids, which can not only inhibit the strawberry's plant's growth, but promote the *F. oxysporum* growth.

The greatest Ca content in tomato plants was found in treatment 93 (**Table 6**) which is made of Ca (207 mg·L^{-1}), R3 FOL and BB variety, where 15 mg of Ca g^{-1} of plant were obtained, such treatment showed a disease severity of 0.8 mean, this agrees with the report done by [31], which establishes that from 10 to 30 mg of calcium g^{-1} of plant, are sufficient levels so that the plant has an optimal development. The Ca increase is reported as an important event during the pathogen-host interaction inducing immune innate plant responses [32], Ca acts as a structural element and promoter in the activation of some enzymes that participate in the defense against some pathogens and physiological disorders, according to [33], calcium also drastically inhibits the polygalacturonate's action, because the high levels of calcium in the cell apoplast generate a greater proportion

Table 5. Foliar analysis of Potassium in plant (mg).

Treat.	Mean	Group	Treat.	Mean	Group	Treat.	Mean	Group	Treat.	Mean	Group
3	110.90	A	11	86.1	Q	63	79.8	A1	17	73.5	I1
10	109.3	B	96	85.6	R	75	79.8	A1	16	70.9	J1
65	104.1	C	87	85.1	S	90	78.8	B1	72	70.3	K1
7	101.4	D	40	85.1	S	31	78.8	B1	21	69.3	L1
6	99.9	E	48	85.1	S	34	78.2	C1	36	68.2	M1
43	98.8	F	73	84	T	15	77.2	D1	28	68.2	M1
18	97.25	G	47	84	T	82	77.2	D1	85	67.7	N1
30	96.25	H	27	83.5	U	41	76.1	E1	29	66.7	O1
5	95.6	I	92	83.5	U	4	75.6	F1	79	66.7	O1
39	95.6	I	19	83	V	13	75.6	F1	68	66.7	O1
88	94.6	J	66	83	V	76	75.1	G1	67	66.1	P1
62	94.6	J	95	83	V	9	75.1	G1	89	65.6	Q1
38	93.5	K	74	82.5	W	86	74.6	H1	8	64.5	R1
35	93	L	37	82.5	W	61	74.6	H1	25	64.5	R1
23	91.4	M	80	81.9	X	70	74.6	H1	20	64	S1
2	91.4	M	91	80.9	Y	83	74.6	H1	64	64	S1
46	90.4	N	26	80.4	Z	42	74.6	H1	77	64	S1
69	88.8	O	14	80.4	Z	71	74.6	H1	94	64	S1
22	87.2	P	1	79.8	A1	78	74.6	H1	32	61.4	T1

Treatments with different letter show significant difference Tukey $\alpha = 0.05$.

Table 6. Foliar analysis of Calcium in plant (mg).

Treat.	Mean	Group	Treat.	Mean	Group	Treat.	Mean	Group	Treat.	Mean	Group
93	**15**	**A**	33	10	F	50	8	H	48	4	L
5	14	B	54	10	F	45	8	H	56	4	L
6	14	B	13	10	F	86	8	H	96	4	L
9	14	B	57	10	F	91	7	I	88	4	L
1	12	D	29	10	F	24	7	I	47	4	L
42	12	D	18	9	G	7	7	I	51	4	L
2	12	D	58	9	G	10	7	I	39	4	L
25	12	D	66	9	G	69	7	I	43	4	L
21	12	D	35	9	G	3	6	J	63	4	L
41	12	D	30	9	G	23	6	J	65	4	L
89	12	D	17	9	G	11	6	J	87	4	L

Continued

14	11	E	70	9	G	95	6	J	4	0	M
22	11	E	61	9	G	27	6	J	20	0	M
90	11	E	94	9	G	55	6	J	12	0	M
62	11	E	49	9	G	19	5	K	36	0	M
37	11	E	85	9	G	31	5	K	40	0	M
38	11	E	92	8	H	67	5	K	83	0	M
53	11	E	26	8	H	71	5	K	81	0	M
80	0	M									

Treatments with different letters show significant difference Tukey $\alpha = 0.05$.

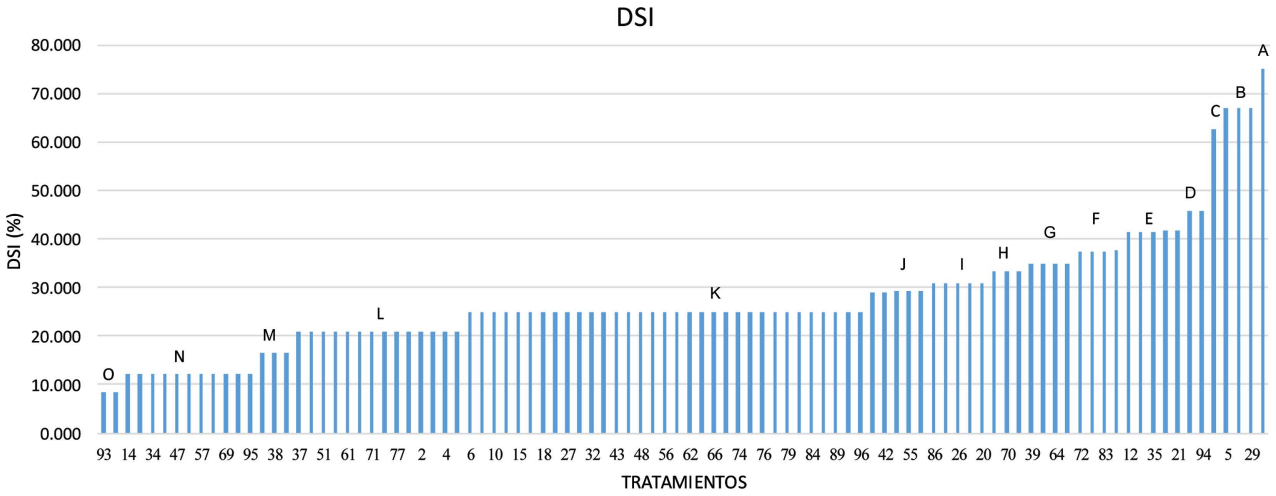

Figure 1. Disease severity index DSI (%). Treatments with different letters show significant difference Tukey $\alpha = 0.05$.

of pectates and therefore greater resistance to the wall disintegration; the Ca may act as amplifier of certain defense signals against the maturity spot and increase the speed response of the plant facing the incidence. Different scientific reports show the close relationship between the disease with the calcium deficiencies in drought seasons. The fertilization and the calcium behavior against the other soil nutrients are also incidental factors in the maturity spot, incidence that is reduced with calcium nitrate fertilizations [34].

3.3. Disease's Severity Index DSI

As it is observed in **Figure 1** treatments 93 and 81 are made of 207 $mg \cdot L^{-1}$ Ca, R3 of FOL, BB variety, 0Ca, R3 and BB variety presented an 8.5% value of low severity index, this agrees with the results obtained by [35], which found low severity levels of 10%, applying low levels of N 15 $mg \cdot L^{-1}$, while Delgado *et al.* (2016), obtained similar results in garlic showing that severity indexes oscillated between 2.25% to 3.5%. [36] obtained a severity index of 5% in chickpea that were inoculated with breed 5 of *Fusarium oxysporum* f.sp. *ciceris*.

4. Conclusion

Bonnie Best and Walter varieties presented lower severity of de disease with 0.5 levels, with a 207 $mg \cdot L^{-1}$ Ca concentration; it is convenient to apply such Ca doses to reduce the disease's severity caused by FOL. The Bonnie Best variety is susceptible to the 3 FOL races, but with optimal nutrition, it has the capacity that when attacked by microorganisms capable of activating defensive mechanisms, these mechanisms include the increase in the activation of enzymes, such as phenylalanine ammonium lyase (PAL), which is key in the synthesis of important defensive metabolites. While R2 of FOL showed greater disease severity, it is worth mentioning that the research will continue to obtain an adequate nutrient dosage to decrease the disease's severity.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Angulo, C.A. (2017) Biotecnología microbiana en el manejo del chile pimiento (*Capsicum annuum* L.). Ph.D. Thesis, Institución Ensenanza E Investigacion Ciencias Argicolas Campus Montecillo, México.

[2] Cachinero, J.M., Hervás, A., Jiménez-Díaz, R.M. and Tena, M. (2002) Plant Defence Reactions against *Fusarium* Wilt in Chickpea Induced by Incompatible Race 0 of *Fusarium oxysporum* f.sp. *ciceris* and Nonhost Isolates of *F. oxysporum*. *Plant Pathology*, **51**, 765-776. https://doi.org/10.1046/j.1365-3059.2002.00760.x

[3] Castellanos, J.Z., Uvalle, B.J.X. and Aguilar, S.A. (2000) Manual de interpretación de análisis de suelos y aguas. Editorial Trillas, México.

[4] Chakraborty, N., Chandra, S. and Acharya, K. (2017) Biochemical Basis of Improvement of Defense in Tomato Plant against *Fusarium* Wilt by $CaCl_2$. *Physiology and Molecular Biology of Plants*, **23**, 581-596. https://doi.org/10.1007/s12298-017-0450-y

[5] Dangl, J.L., Dietrich, R.A. and Richberg, M.H. (1996) Death Don't Have No Mercy: Cell Death Programs in Plant-Microbe Interactions. *The Plant Cell*, **8**, 1793-1807. https://doi.org/10.2307/3870230

[6] Delgado, O.J.C., Ochoa, F.Y., Cerna, C.E., Beltran, B.M., Rodríguez, G.R., Aguirre, U.L.A. and Vázquez, M.O. (2016) Patogenicidad de especies de *Fusarium* Asociadas a la pudrición basal del ajo en el centro norte de México. *Revista Argentina de Microbiología*, **48**, 222-228. https://doi.org/10.1016/j.ram.2016.04.003

[7] Díaz, A., Cayón, G. and Mira, J.J. (2007) Metabolismo del calcio y su relación con la mancha de madurez del fruto de banano: Una revisión. *Revista Agronomía Colombiana*, **25**, 280-287.

[8] Doyle, J.J. and Doyle, J.L. (1987) A Rapid DNA Insulation Procedure from Small

Quantities of Fresh Leaf Tissue. *Phytochemical Bulletin*, **19**, 11-15.

[9] Duffy, B.K. and Défago G. (1999) Macro- and Microelement Fertilizers Influence the Severity of *Fusarium* Crown and Root Rot of Tomato in a Soilless Production System. *Revista Hortscience*, **34**, 287-291. https://doi.org/10.21273/HORTSCI.34.2.287

[10] Faithfull, N.T. (2005) Métodos de análisis químico agrícola. Editorial Acribia. Zaragoza.

[11] FAO (2019) Organización de las Naciones Unidas para la Alimentación y la Agricultura. FAO. http://www.fao.org/faostat/es/#data

[12] García, J. (2001) Importancia del Ca en la resistencia de las plantas a enfermedades. In: Sliva, F., Ed., *Los elementos secundarios* (*Ca*, *Mg*, *S*) *y el silicio en la agricultura*, Sociedad Colombiana de la Ciencia del Suelo, Bogotá, 72-84.

[13] González, I., Arias, Y. and Peteira, B. (2012) Aspectos generales de la interacción *Fusarium oxysporum* f.sp. *lycopersici*-Tomate. *Revista Protección Vegetal*, **27**, 1-7.

[14] Jahanshir, A. and Dzhalilov, F.S. (2010) The Effects of Fungicides on *Fusarium oxysporum* f.sp. *lycopersici* Associated with *Fusarium* Wilt of Tomato. *Journal of Plant Protection Research*, **50**, 172-177. https://doi.org/10.2478/v10045-010-0029-x

[15] Jones, J.P., Engelhard, A.W. and Woltz, S.S. (1989) Management of *Fusarium* Wilt of Vegetables and Ornamentals by Macro and Microelements. In: Engelhard, A.W., Ed., *Soilborne Plant Pathogens*: *Management of Diseases with Macroand Micro-elements*, APS Press, Saint Paul, 18-32.

[16] Lawrence, E. (2007) Mineral Nutrition and Plant Disease. American Phytopathological Society, Saint Paul.

[17] Marlatt, M. and Correll, J.C. (1998) The Ocurrence of Race 3 of *Fusarium oxysporum* f.sp. *lycopersici* in Arkansas. *Phytopathology*, **83**, 1345.

[18] Motsara, M., and Roy, R.N. (2008) Guide to Laboratory Establishment for Plant Nutrient Analysis. Food and Agriculture Organization of the United Nations.

[19] Munévar, M.F. (2004) Relación entre la nutrición y las enfermedades de las plantas. *PALMAS*, **25**, 171-178.

[20] Motsara, M.R. and Roy, R.N. (2008) Guide to Laboratory Establishment for Plant Nutrient Analysis. FAO Fertilizer and Plant Nutrition Bulletin 19. Food and Agriculture Organization of the United Nations.

[21] Ngosong, C., Clovis, B.T., Cyril, A.N., Mfombep, P.M., Okolle, J.N., Njock, T.E., Nkongho, R.N. and Tening, A.S. (2018) Importance of NPK Foliar Fertilization for Improving Performance of Tomato *Solanum lycopersicum* L., Managing diseases and Leafminer (*Tuta absoluta*). South West Region, Cameroon. *Journal of Experimental Agriculture International*, **20**, 1-14. https://doi.org/10.9734/JEAI/2018/39034

[22] Quiroga, M.R., Rosale, E.M., Rincón, E.P., Hérnandez, G.E. and Garrido, R. (2007) Enfermedades causadas por hongos y nematodos en el cultivo de Tomate (*Lycopericon esculentum* Mill.). Chiapas, México. *Revista Mexicana de Fitopatología*, **25**, 114-119.

[23] Rodriguez, D.A. and Montilla, J.O. (2002) Disminución de la marchitez causada por *Fusarium* en tomate con extracto de *Citrus paradisi*. Manejo Integrado de plagas, Costa Rica.

[24] Rodriguez, M.A. (2009) Caracterización de proteínas con actividad anti fúngica producidas por Penicillium Chrysogenum. Ph.D. Thesis, Universidad de Extremadura, Badajoz.

[25] Rodríguez, F.H. (2015) Métodos de análisis de suelos y plantas. Editorial Trillas, Mexico City.

[26] Sepúlveda, C.G. (2006) Enfermedades de las plantas y nutrición mineral. Proyecto INNOVA CORFO 08CT11IUD-22, México.

[27] SIAP (2017) Servicio de Información Agroalimentaria y Pesquera. https://www.gob.mx/siap

[28] Steiner, A.A. (1966) The Influence of the Chemical Composition of a Nutrient Solution on the Production of Tomato Plant. *Plant and Soil*, **24**, 454-466. https://doi.org/10.1007/BF01374052

[29] Stevens, M.A. (1974) Varietal Influence on Nutrition Value. In: White, P.L. and Selvey, N., Eds., *Nutritional Qualities of Fresh Fruits and Vegetables*, Futura Publications, New York.

[30] Tello, J.C. and Lacasa, A. (1988) "La podredumbre del cuello y de las raíces", causada por *Fusarium oxysporum* f.sp. *radicis-lycopersici*, nueva enfermedad en los cultivos de Tomate (*Lycopersicum esculentum* Mill.) españoles. *Boletín de Sanidad Vegetal-Plagas*, **14**, 307-312.

[31] Tian, S.P., Qin, G.Z. and Xu, Y. (2006) Induction of Defense Responses against *Alternaria* rot by Different Elicitors in Harvested Pear Fruit. *Applied Microbiology and Biotechnology*, **70**, 729-734. https://doi.org/10.1007/s00253-005-0125-4

[32] Vega, G.T.A., López, O.C.A., López, U.G.A., Velarde, F.S., Amarillas, B.L.A., Martínez, C.A.R. and Allende, M.R. (2019) Foot Rot and Wilt in Tomato Caused by *Fusarium falciforme* (FSSC 3+4) in Mexico. *Plant Disease*, **103**, Article No. 157. https://doi.org/10.1094/PDIS-06-18-1001-PDN

[33] Velasco, V.V. (1999) Papel de la nutrición mineral en la tolerancia a las enfermedades de las plantas. *Terra Latinoamericana*, **17**, 193-200.

[34] Woltz, S.S., Jones, J.P. and Scott, J.W. (1992) Sodium Chloride, Nitrogen Source and Lime Influence *Fusarium* Crown Rot Severity in Tomato. *HortScience*, **27**, 1087-1088. https://doi.org/10.21273/HORTSCI.27.10.1087

[35] Yamazaki, H. and Hoshina, T. (1995) Calcium Nutrition Affects Resistance of Tomato Seedlings to Bacterial Wilt. *Hortscience*, **30**, 91-93. https://doi.org/10.21273/HORTSCI.30.1.91

[36] Cao, Z.-Q., Fan, T.-F., Bi, Y.-M., Tian, G.-L. and Zhang, L.-S. (2016) Potassium Deficiency and Root Exudates Reduce Root Growth and Increase *Fusarium oxysporum* Growth and Disease Incidence in Continuously Cultivated Strawberry. *New Zealand Journal of Crop and Horticultural Science*, **44**, 58-68. https://doi.org/10.1080/01140671.2016.1146306