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Response of tomato varieties (*Solanum lycopersicum* L.) to water stress

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ABSTRACT

Background and Objectives: Water scarcity is limiting for tomato (*Solanum lycopersicum* L) production, due to its sensitive to drought in the different phases of development, so irrigation should be done in an optimal way; because of this, the objective was to evaluate four levels of irrigation in greenhouse tomato varieties.

Methods: A completely randomized experimental design with factorial arrangement was used and various agronomic variables, fruit quality and biomass were measured as response variables.

Results: Tomatoes were significantly affected ($P \leq 0.05$) by variety factors (V), irrigation (R), and their interaction. 100% of variety P presented fruits of greater weight (122 g); while weight decreased to 84, 90, 34 and 18 g when reducing water up to 25%, in varieties Cid, P, E and C, respectively. However, in terms of yield and leaf area, 100% of the Cid variety presented the highest values, around 3.3 kg/plant and 8.6 m^{-2}.

Conclusions: Variety c was tolerant to water stress and also does not present apical rotting (calcium deficiency) in the fruit.

Keywords: leaf area, apical rotting, yield, *Solanum lycopersicum* L.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is of paramount economic importance worldwide, and adverse climate conditions generate abiotic stress which is one of the principal limiting factors for production (Grayson, 2013). Drought affects 64% of the global land surface (Mittler, 2006). Tomato crops demand 23 to 30 liters of water per kilogram of fresh fruit (Medrano *et al*., 2007).

During its different development phases, this crop is sensitive to water stress, duration, severity and environmental factors which provoke it (Florido and Bao, 2014). Regarding stress severity and duration, the plants activate defense mechanisms at a molecular, morphological, physiological and cellular level, which can result in higher stomatal resistance (Witcombe *et al*., 2008; Peleg *et al*., 2011). Apical rotting is a common physiological disorder in fruits, which can reduce commercial yield by up to 50% (Taylor *et al*., 2004), and it is related to diverse factors such as temperature, transpiration, relative humidity and low calcium content (Matthew *et al*., 2004). Based on the aforementioned, four varieties of tomato were studied with four levels of irrigation during greenhouse plant growth.

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MATERIALS AND METHODS

The study was carried out in a polyethylene greenhouse at the Superior Technological Institute in Guasave, Sinaloa, located at 25° 52' N and 108° 37' W at an altitude of 15 m. Two varieties of Roma tomato were studied (E=1001 and P=1007), one Bola tomato (C=1006) from the company Mar-seed®, and the Cid control (T) F1 (Harris Moran®).

The four varieties were evaluated in four water humidity regimes in substrate during 150 days after transplanting. These irrigation regimes were based on information from Flores *et al*. (2007), who reported that water consumption of tomatoes ranges from 0.2 L per plant in initial seedling phases to 1.5 L in the adult phase with maximum water demand in substrate. For this experiment, a minimum of 0.3 L was used (25% = 300 mL d^{-1}) for treatment 1 (T1); T2 (50% = 600 mL d^{-1}); T3 (75% = 900 mL), and a maximum of 1.2 L (100% = 1200 mL d^{-1}) of water per plant for T4. Irrigation started 30 days after transplantation. In order to achieve this, two drip irrigation systems were installed, one with Steiner solution at 100% three times concentrated (Steiner, 1961). To avoid confusion, the same amount of nutrients and water levels were applied to the plants in all four treatments and water was added to complement the amounts in each watering, except for T1 which did not receive any additional water.

In order to compare treatments (four levels of irrigation × four varieties of tomatoes), a completely random experimental design was used with factorial arrangement, with four repetitions (one plant per repetition). The sowing of seeds took place on August, 25, 2019, in polystyrene trays with 200 cavities of 9 mL with peat. After 30 days, the seedlings were transplanted in 40 × 36 black polyethylene bags which contained 10 L of river sand with a diameter of 2-5 mm. The plants were managed at one stem and strung individually with raffia.

The agronomic varieties evaluated during the cycle were: 1) plant height (m), measured with a flex meter from the plant's base to the apex, 2) leaf area (m^2) was determined in all fresh leaves, sampled with a portable laser leaf area meter (Licor, Inc. Lincoln, NE, USA), 3) number of fruits, 4) fruit weight (g), and 5) fruit yield (kg/plant), which were weighed in each cut and added to obtain the total weight.

The fruit quality variables measured in four fruits randomly selected from each treatment were: 1) number of locules, 2) total soluble solids (%) measured with a digital refractometer ATAGO PR-100® (Japan) (A.O.A.C., 1990), and 3) number of fruits with apical rotting counted by sampling.

The biomass variable was performed with a random destructive sample 150 days after transplant; two plans were taken from each experimental unit. The plants and each organ were dissected in the laboratory in a stove (Riossa®, Mexico) at 70 °C for 72 hours in order to measure total dry matter, until constant weight.

All of the variables were subjected to a variance analysis through a completely random design with factorial arrangement of two factors, varieties by regimes, and a means test using Tukey's method (P≤0.05). The analyses were carried out with the SAS statistics software (version 9.0) and the tables with Microsoft Excel 2010® software.

RESULTS AND DISCUSSION

The results show that the tomato varieties were significantly (P≤0.05) affected by the factors variety (V) and irrigation (I), and by the interaction V × I in all the variables studied: agronomic, biomass and fruit quality (Tables 1 and 2). However, the interaction between variables is different.

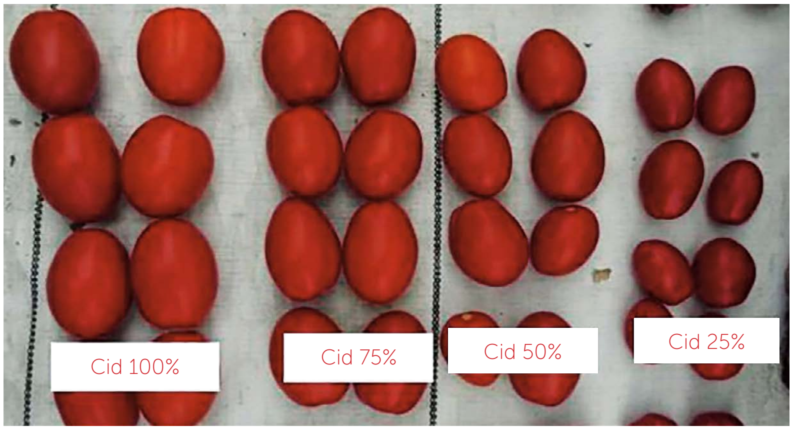
Of the agronomic variables (Table 1), only the number of fruits had an effect on V with 77% compared to the total variation due to treatments. Meanwhile, I caused more of an effect on plant height (57%), leaf area (61%), fruit weight (54 %) and

Table 1. Sum of squares of the agronomic variables measured in tomato plants cultivated in greenhouses with four levels of irrigation in Guasave, Sinaloa, Mexico.

FV	GL	Plant Height (m)	Leaf area (m^2)	Number of fruits	Weight Per Fruit (g)	yield (kg/plant)
		Sum of squares				
Trats	15	7.9**	339**	6008**	60712**	43.1**
V	3	2.7**(34)	105**(31)	4630**(77)	15108**(25)	1.4**(3)
R	3	4.5**(57)	207**(61)	953**(16)	32486**(54)	28.5**(66)
V × R	9	0.7**(9)	25**(8)	423**(7)	13117**(21)	13.2**(31)
Error	48	0.13	0.6	192	1080	0.4
Total	63	8.03	339.6	6200	61792	43.5

**: Statistically significant with P≤0.01; FV: source of variation; GL: degrees of freedom, Trats: treatments, V: variety, R: Irrigation, V × R: variety × irrigation. (Initials based on Spanish terms).

yield (66%). For its part, the interaction between V and I had slightly significant effects of 1 to 9%, although in fruit weight (21%) and yield (31%) it was high. Fruit quality (Table 2) affected by V were: fruits with calcium deficiency (76%) and number of locules (99%). Meanwhile, total biomass and total soluble solids were affected by I (64 and 54 %). Also a slight significance was seen in the V × I interaction, which oscillated between 1 and 17% in all the variables evaluated.



The Cid variety.

Plant height decreased as the availability of water for the plants was reduced, so that the lowest were the ones that received the least volume of irrigation. The Cid variety (control) with 100% and 75% had the tallest plants, and with complete irrigation (100%), the C variety was lower. The plants that received 25% water treatment, E and C varieties, were less affected with 0.4 and 0.3, respectively; Cid and P lost 1 m of height. The leaf area of Cid at 100% (8.6 m^{-2}) is 60% of E variety at 100% (3.3 m^2); in the four varieties water reduction generated a decrease in leaf area such that Cid, P, C and E at 25% treatment had leaf area decreased by 6.3, 6.7, 3.6 and 2.6 m^2/plant with the E variety being the least affected (Table 3). In terms of number of fruits, the highest amount was shown by the C variety in contrast with the P variety. Reduction in irrigation by 25% caused a reduction in number of fruits: Cid (6), P (9), E (4) and C (18). The P variety at 100% had the heaviest fruits and the C variety at 100% the lightest; with 25% treatment, weight of the fruits decreased by 109 and 9 g in C and P, respectively, when compared to 100% irrigation.

The Cid variety at 100% produced more yield compared to the E variety at 100% (Table 3). A decrease in irrigation (25%) caused less production in the four varieties, Cid, C, E and P, in different magnitudes (2.8, 1.8, 1.0 and 2.3 kg/plant) when compared to the 100% treatment, such that the E variety was the least affected in yield by water stress. In total biomass the control accumulated 407 g (Cid 75%) when compared to the E variety with 242 g at 100% treatment, which indicates that it had 37% more than the E variety. The regime affected in greater proportion the P and control varieties with stops, and E and C were less affected in biomass accumulation.

The C variety had fewer locules (6.5) because of its round shape when compared to Cid with 2 locules; related to this characteristic, drought had no effect (Table 4). With complete irrigation (100%) the content of total soluble solids in the fruits varied from 5 to 6 between the varieties. The reduction in water to 25% caused an increase in total soluble solids in 52, 45, 38, and 34% for Cid, P, E and C, respectively.

It should be noted that the quantity of fruits with apical rotting highlights the C variety which did not have any fruit with this physiological disorder; in contrast to P, E and control varieties, which presented fruits with this physiological plant pathology in both 100% irrigation and in all water reduction levels.

The results found in this study indicate that the characteristics of the variables evaluated presented significant differences (Table 1 and 2). The reduction in water

Table 2. Sum of squares of total biomass and fruit quality of tomato plants cultivated in greenhouses with four irrigation regimes in Guasave, Sinaloa, Mexico.

Variation source	Degrees of freedom	Biomass (g/planta)	Number of locules	Total soluble solids (%)	Blossom end rot
		Sum of squares			
Tratamiento	15	413759**	172**	129**	2842**
V	3	115177**(27)	172**(100)	37**(29)	2167(76)**
R	3	263955**(64)	0(0)ns	70**(54)	392(14)**
V × R	9	34627**(8)	0(0)ns	22**(17)	283(10)**
Error	48	2664	18	4	58
Total	63	416423	1163	133	2900

***: Statistically significant with P≤0.05 and 0.01; ns not significant, R: irrigation, V: variety, V × R: variety × irrigation. (Initials based on Spanish terms).

affected physiological functions and therefore the whole plant. The variables: number of fruits, number of locules, and number of fruits with apical rotting showed characteristics specific to each variety. On the other hand, water stress had a greater effect on fruit weight, yield, total biomass and total soluble solids, which agrees with Cui *et al*. (2020) who mentioned that irrigation is the most important source of water for tomatoes and affects both yield and fruit quality. The plants exposed to water deficit presented alterations in physiological and metabolic processes, such as a reduction in photosynthesis rates, a decrease in total protein synthesis and in growth rates (Chaves *et al*., 2009).

Table 3. Means comparison in plant quality in tomatoes cultivated in greenhouses with four levels of irrigation (25, 50, 75 and 100 %).

Treatment	Plant height (m)	Leaf area (m^2 / plant)	Number of fruits	Weight per fruit (g)	Yield (kg/ plant)
Cid 25	1.3 h	2.1 h	25.3 efg	22.4 j	0.6 g
Cid 50	1.8 cd	3.9 e	34.7 b	45.5 hg	1.6 g
Cid 75	2.3 a	2.8 g	33.0 bc	95.8 bc	3.1 a
Cid 100	2.3 a	8.4 a	32.0 bcd	106.1 b	3.4 a
C 25	1.2 i	0.9 j	29.3 cde	34.5 hij	1.0 h
C 50	1.4 g	2.0 h	46.0 a	44.4 ghi	2.0 ef
C 75	1.6 e	3.7 e	46.5 a	47.9 fg	2.2 de
C 100	1.7 d	4.5 d	47.5 a	52.4 fg	2.4 cd
E 25	1.1 i	0.7 j	27.2 edf	53.4 fg	1.0 f
E 50	1.3 h	1.6 i	29.5 cde	58.3 ef	2.0 ef
E 75	1.5 f	2.7 g	30.5 bcd	70.3 de	1.9 f
E 100	1.6 e	3.3 f	31.0 cbd	87.1 c	1.9 f
P 25	1.3 h	1.4 i	13.3 h	32.8 ji	0.4 i
P 50	1.8 d	3.6 e	16.3 h	72.7 d	1.2 h
P 75	2.0 c	5.8 c	21.5 g	124.3 a	2.6 bc
P 100	2.2 b	8.1 a	22.3 fg	122.2 a	2.7 b

E (1001), C (1003), P (10001). Means with different letters indicate significant differences ($p<0.05$).

The commercial Cid variety had a height of 2.3 m, reached 150 days after transplantation (Table 4). This coincides with Núñez *et al*. (2012), where the maximum height of 2.8 m was reached at 180 days with a Bola Beatrice variety. In this context, Osakabe *et al*. (2013) mentioned that prolonged water stress decreases the hydric potential of leaves and stomatal opening, reduces leaf size, and limits growth and plant productivity.

Table 4. Means comparison of variables of fruit quality in tomato plants cultivated in greenhouses with four irrigation regimens (25, 50, 75 and 100 %).

Treatment	Biomass (g/planta)	Number of locules	Total soluble solids (%)	Blossom end rot
Cid 25	205 gh	2.2 cb	10.2 a	14.0 bc
Cid 50	275 d	2.0 b	7.3 d	13.0 cd
Cid 75	407 a	2.3 cb	5.9 ef	5.0 f
Cid 100	390 ab	2.0 c	5.3 fg	2.8 fg
C 25	200 h	6.5 a	8.4 c	0 g
C 50	272 d	6.3 a	5.8 ef	0 g
C 75	314 c	6.5 a	5.5 fg	0 g
C 100	316 c	6.5 a	5.2 fg	0 g
E 25	126 j	3.3 b	8.6 bc	2.2 fg
E 50	221 fg	3.3 b	5.7 ef	1.3 g
E 75	231 ef	3.3 b	5.6 fg	1.5 g
E 100	242 e	3.2 b	4.8 g	1.2 g
P 25	175 i	3.0 bc	9.3 b	20.3 a
P 50	250 e	3.0 bc	7.2 d	16.5 b
P 75	374 b	3.0 cb	6.5 de	11.0 d
P 100	379 b	2.7 cb	6.0 ef	8.0 e

E (1001), C (1003), P (10001). Means with different letters indicate significant differences ($p<0.05$).

Leaf area ranged between 8.4 and 3.3 m^2, in Cid and E with 100% irrigation, while in those submitted to stress (25%) this decreased from 1.2 to 0.7 m^2 (Table 3). Such loss of leaf area is important since leaves are a fundamental organ for photosynthesis, where energy from sunlight is captured by chlorophyll and utilized for the synthesis of water and carbon components (Fischer *et al*., 2012; Wang *et al*., 2014).

The number of fruits varied between 22 and 47 with 100% treatment in P and C varieties (Table 3), compared to 25% treatment which decreased markedly the amount of fruits in P (13) and C (29), respectively. This demonstrated that drought affects each variety of tomato. Pervez *et al*. (2009) determined that drought significantly reduces the number of fruits, plant height and number of leaves.

The fruit weight ranged from 52 to 122 g in the C and P varieties with irrigation (100%) and with water stress (25%), the weight of the same varieties decreased to 34 and 32 g (Table 3). This indicated that C variety is tolerant to drought in terms of fruit size. According to Kinet and Peet (1997), the final fruit size is closely related to dominant environmental conditions during the fruit's growth phase.

The highest yield was obtained from the Cid variety with complete irrigation (100%) with 3.4 kg/plant, compared to C plants that only produced 2.4 kg/plant, which represents a 1 kg decrease (Table 3). However, the 25% treatment with C variety produced 1000 g, which is more than the 600 g produced by the control per plant. According to Nuruddin (2001), water deficit affects negatively the fruit and is reflected in the yield due to water and nutrient deficiencies.

In terms of total biomass, the control accumulated the most (390 g) in the 100% treatment 37 % than the E variety (242 g), and the 25% water treatment decreased 185 and 116 g, where the least affected was the E variety. Heuvelink (1995) and Link (2000) mentioned that 70% of total biomass is destined to fruits. The production of biomass in any crop is strongly determined by the amount of water available (Medrano *et al*. 2007).

The number of locules (Table 4) obtained were similar to that reported by Raana (2019), who mentioned that tomatoes varied in number from 2 to 10 locules. In this study the highest number of locules (6) was seen in the C variety. The amount of total soluble solids in terms of fruit quality shows that it can vary with water stress and during fruit development (Table 4), because the flow of water to the fruit decreases and causes stress from salts (osmosis), which induces the accumulation of active solutes. According to Sakamoto *et al*. (1999), tomato fruits under stress accumulate mainly ions and organic molecules (fructose and glucose). The results of total soluble solids in 100% irrigation agree with Bui *et al*. (2010), who indicated that tomatoes should have between 4.5 and 6.25 % soluble solids.

The calcium deficiency was present in Cid, P and E in all treatments, although the 25% treatment had the most number of fruits with this physiological disorder (Table 4). Its emergence is attributed to alterations in the absorption and transport of calcium from the roots to the fruits, especially in its distal part and the factors which accelerate this are high temperature, high radiation and low relative humidity (Cardona *et al*., 2005). The disorder starts in the immature fruit since only 3% of calcium makes it to the fruit, despite the fact that fruits represent 90% of the crop's growth and the least susceptible varieties are those that have a stronger xylema network (Ho *et al*., 1993). The C variety does not present this physiological plant pathology which is clear evidence of its tolerance and immunity.

CONCLUSIONS

The C variety was shown to tolerate water stress and also did not present apical rotting (calcium deficiency) in the fruit. With water stress at 25%, the E variety significantly exceeded the hybrid, with a 400 g difference per plant.

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