Increased Electrical Conductivity in Nutrient Solution Management Enhances Dietary and Organoleptic Qualities in Soilless Culture Tomato

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Abstract. Greenhouse tomato production is shifting to meet emerging consumer needs. Increasing environmental concerns have pressured growers to supply high-quality vegetables using sustainable production methods. The utilization of adapting fertigation to production conditions and/or nutrient solutions of moderately high conductivity seems promising in providing high yields of superior quality while limiting the emission of nutrients to the environment in greenhouse tomato crops. A tomato crop was grown in soilless culture with various levels of electrical conductivity (EC), 2.2, 3.5, and 4.5 dS·m⁻¹, adjusting the final nutrient concentration and maintaining nutritional balance. The effect of nutrient solutions with moderately high EC on fertigation parameters and the emission of nutrients to the environment, total crop productivity, distribution of fruit sizes, and dietary and organoleptic qualities were measured. Nutrient solutions of moderately high EC decreased total and commercial yield, with an average reduction from 5% to 19% and 3% to 22%, respectively. A considerable decrease in extra large and large fruits, with an average reduction from 69% to 42%, was also observed. Nonetheless, dietary-related metabolites were significantly increased at the highest EC values: lycopene (6.3%), ascorbic acid (8.8%), total phenolics content (8.3%), and total antioxidant activity (11.1%). EC values of 3.5 and 4.5 dS·m⁻¹ are not widely used in commercial production but are frequently measured in drainage solutions in open hydroponic systems and discarded solutions in closed systems, mainly because of the use of poor-quality water and the accumulation of excess nutrients.

The greenhouse industry is focused on the consumer market. Consumers demand a diverse array of high-quality vegetables. Among vegetables, tomato is the most important for its high consumption and dietary quality as it contains mainly health-influencing compounds (Canene-Adams et al., 2005; Etminan et al., 2004; Liu, 2013; Nishino et al., 2004; Willcox et al., 2003). The dietary and organoleptic

quality of fresh tomatoes can be affected by many pre- and post-harvest factors, such as genetic characteristics, growing conditions, ripening stage at harvest, and cultural management (Arah et al., 2015; Dorais et al., 2001a, 2008; Erba et al., 2013; Iglesias et al., 2015; Leonardi et al., 2000; Passam et al., 2007; Urrestarazu et al., 2015). Many commercial greenhouses are forced to use poor-quality water with residual ions such as Cl⁻, Na⁺, SO₄²⁻, and Mg²⁺, but nutrient solutions of moderately high EC are sometimes achieved by adding NaCl or major nutrients. This cultural management provides excellent possibilities for achieving high dietary and organoleptic quality in fresh tomato fruit (Adams, 1991; Auerswald et al., 1999; Borghesi et al., 2011; Cliff et al., 2012; De

Pascale et al., 2001; Dorais et al., 2001b; Krauss et al., 2006; Magán et al., 2008; Morales and Urrestarazu, 2013; Sonneveld, 2000). The physiological responses of tomato plants cultivated using poor-quality water have been characterized in many studies. However, fewer studies have been conducted using nutrient solutions of moderately high EC with the addition of nutrients. The maximum yields for substrate-grown tomato crops are obtained using EC from 2.5 to 2.9 dS·m⁻¹ (Sonneveld and Van der Burg, 1991). To improve the produce quality, nutrient concentrations are sometimes higher than necessary for optimum plant growth and yield, and there is limited information about the effects of increased EC nutrient solution management in soilless culture. Hence, this work aims to assess the effects of moderately high EC nutrient solutions with equal balance of macronutrients on fertigation parameters and nutrient emissions to the environment, total crop productivity, distribution of fruit size, and dietary and organoleptic qualities in an unheated greenhouse under conditions similar to those of a commercial crop.

Materials and Methods

Cultivation conditions. Cultivation was performed at the facilities of the School of Agronomy of the Pontificia Universidad Católica de Valparaíso in a multitunnel greenhouse (polyethylene cover thickness: 200 µm) with a natural ventilation system in the province of Quillota (32°50' S; 71°13' W, 120 masl) in the region of Valparaíso, Chile. Tomato seedlings were planted on 27 July 2015, when the plants had six or seven true leaves. The cultivar Patron (Syngenta, Basel, Switzerland) was grafted onto Empador rootstock (Rijk Zwaan, De Lier, The Netherlands) and used with 2 plants/m². The cultivation was managed following methods commonly used in the Quillota area. All plants were topped above the seventh truss 192 d after transplanting.

Treatment applied and unit crop. Tomatoes were cultivated in a greenhouse equipped for fertigation, which allowed the assessment of the effects of different levels of EC with the same nutritional balance (equal balance of macronutrients) (Table 1) but different nutrient concentrations. The unit crop was a 30 L Projar Golden Grow Hydroponics Balance (Valencia, Spain) coir growth bag (100 × 30 × 10 cm, L × H × W). Three drippers were used per growth bag. Each growth bag contained three plants, each trained with two leading shoots and fertigated by three drippers with a nominal flow rate of 4.0 L·h⁻¹.

The water quality in the area has an EC value of ≈0.7 dS·m⁻¹, and a level of EC = 2.2 dS·m⁻¹ was assumed for the control treatment (T₀). For the next two treatments, the target level was increased to T₁ = 3.5 dS·m⁻¹ and T₂ = 4.5 dS·m⁻¹. Nutrient solutions were sampled daily during the crop cycle and were within 0.2 dS·m⁻¹ of EC target levels.

For each treatment, two control points were used for fertigation control: 1) a control

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drinker (4.0 L·h⁻¹) and 2) a drain pan to monitor the supplied fertigation and its absorption response. At these control points, the volume of nutrient solution, pH, and EC of the fertigation input and drainage were measured daily. EC was determined with an HI99301 conductivity meter (Hanna Instruments, Woonsocket, RI) and expressed in dS·m⁻¹; pH was determined using an HI83141 pH meter (Hanna Instruments). Macronutrients, nitrate, and potassium concentrations were determined spectrophotometrically using the respective Spectroquant test kits (Merck, Darmstadt, Germany). Determinations were performed using a Spectroquant Pharo 300 ultraviolet/VIS spectrophotometer (Merck).

Each irrigation pulse was triggered when 10% of the readily available water in the substrate had been used, and the volume necessary to produce between 15% and 25% of the drainage (Gorbe and Calatayud, 2010; Rodríguez et al., 2015; Urrestarazu, 2015; Urrestarazu et al., 2005, 2008, 2015).

Harvest sampling. The harvest took place during a period spanning the first week of November to the first week of February. Individual fruits were harvested on a weekly basis for tomatoes in a mature state at the light red stage of the color chart (USDA, 2016). Fruits were sized according to their equatorial diameter and the marketing standards for tomatoes (EC, 2000) using the size criteria with six categories: GG (82–102 mm), G (81–67 mm), M (66–57 mm), MM (56–47 mm), MMM (46–40), and S (39–35). Unmarketable fruit yield was classified according to the nature of the blemish: fruits with blossom-end rot, blotchy ripening, cracking, deformed fruits, small fruits, and others. Nine marketable fruits per replicate were randomly selected every two weeks to measure organoleptic and dietary parameters.

Dietary quality of fruit. Fruits were frozen in liquid nitrogen and stored at –20 °C. The frozen samples were homogenized by milling using a basic analytical mill A-11 (IKA, Staufen, Germany). All solvents and reagents were of analytical quality. Determinations were performed using a Spectroquant Pharo 300 ultraviolet/VIS spectrophotometer (Merck).

Lycopene content was determined with the reduced volume method described by

Fish et al. (2002) using 0.5 g of homogenized sample. The absorbance was read at 503 nm, and a hexane blank was used. The calibration curve ranged between 1 and 10 mg·kg⁻¹ using pure lycopene (Sigma-Aldrich, St. Louis, MO). The results were expressed in mg·kg⁻¹ of fresh weight (FW).

Ascorbic acid content was determined according to Al-Ani et al. (2007). The calibration curve was performed with an L-ascorbic acid standard (Sigma-Aldrich) and ranged from 10 to 600 mg·kg⁻¹. The results were expressed in mg·kg⁻¹ FW.

Samples were prepared for total phenolics content and total antioxidant activity by ferric reducing ability plasma (FRAP) analyses using 25 g homogenized with 25 mL of methanol 80% (v/v) in HCl at 1% and incubating for 2 h at 24 °C. The extracts were filtered using a 120 mm paper filter (Whatman, Maidstone, England) and centrifuged at 2500 rpm for 20 min, and the supernatant was sealed and stored at 4.0 °C until analysis. Total phenolics content was measured following Singleton and Rossi (1965) methodology. The calibration curve was for 10–200 mg gallic acid (GA)/kg and was prepared using pure GA (Merck). The results were expressed as mg GA/kg FW.

Total antioxidant activity was measured by the FRAP method of Benzie and Strain (1996) with modifications proposed by Harmanescu et al. (2006). The sample was diluted 10-fold for analysis. The calibration curve ranged from 0.05 to 0.35 (mmol·kg⁻¹) using ferric sulfate as the standard. The results were expressed as mmol Fe²⁺/kg FW.

Organoleptic quality of fruit. Fruits were combined in a blender, and the strained juice was filtered using a 120-mm paper filter (Whatman).

EC was determined with an HI99301 conductivity meter (Hanna Instruments) and expressed in dS·m⁻¹; pH was determined using an HI83141 pH meter (Hanna Instruments). Clear filtered juice was used for both analyses.

To evaluate titratable acidity, 10 mL of filtered tomato juice was titrated with 0.1 N standardized NaOH until equilibrium (pH of 8.1) and expressed as mg of citric acid 100/g FW.

For total soluble solids determination, one drop of clear juice was measured with an

Atago PAL-1, 0.0–53.0 °Brix analog handheld refractometer (Atago, Tokyo, Japan) and expressed as °Brix.

Experimental design and statistical analysis. The experiment was conducted using a completely randomized block experiment design with three replicates per treatment (Little and Hills, 1978; Petersen, 1994). An analysis of variance followed by the post-hoc Tukey test ($P \leq 0.05$) was performed using Minitab 17 Statistical Software® (Minitab Inc., State College, PA). The experimental unit (replicate of a treatment) comprised three growth bags.

Results

Effect on fertigation parameters and nutrient emissions to the environment. The most important parameters to control fertigation were percent of drainage volume, EC, and pH, as displayed in Table 2. Percent drainage volume increased considerably with an average growth of 20.24% and 38.65% in the medium and high EC treatments, respectively, compared with the low EC treatment; these data indicate significant differences between treatments. EC increased significantly, with an average growth of 27.27% and 57.14% in the medium and high EC treatments, respectively, compared with the low EC treatment; these data indicate significant differences between treatments. pH decreased considerably, with an average reduction of 7.58% and 10.61% in the medium and high EC treatments, respectively, compared with the low EC treatment; these data indicate significant differences between the low treatment and the others.

Water uptake decreased dramatically with increased EC, presenting significant differences between treatments. Fertigation parameters in fertigation drainage are frequently used for the practical control of soilless culture (Gorbe and Calatayud, 2010; Rodríguez et al., 2015; Urrestarazu, 2015; Urrestarazu et al., 2005, 2008, 2015). The absolute values were similar to those reported by Urrestarazu et al. (2008, 2015).

In this work, water uptake decreased dramatically with an increase in moderately high EC nutrient solutions with an equal balance of macronutrients. Soria and Cuartero (1998) reported a strong linear relationship ($r = 0.97$) between the EC of the nutrient solution (by adding NaCl) and water absorption. Under high ECs, crop performance may be adversely affected by a water deficit (osmotic effect) regardless of the method of modifying EC. Adams (1991) and Sonneveld (2000) differentiated results between osmotic

Table 1. Nutrient solutions of EC treatments used for tomato cultivation during the crop cycle.

EC (dS·m ⁻¹)	pH	(mmol·L ⁻¹)					
		K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻
2.2	5.8	5.0	5.0	1.8	12.5	2.0	1.75
3.5	5.8	8.3	5.1	2.1	16.2	3.0	2.4
4.5	5.8	11.5	7.4	2.1	21.4	4.0	2.5

Data shown are the average of three replicates.

Table 2. Fertigation parameters and nutrient emissions to environment of nutrient solutions with different electrical conductivity (EC) levels (dS·m⁻¹) used for tomato cultivation during the crop cycle.

Drainage (%)			Drainage EC (dS·m ⁻¹)			Drainage pH			Uptake						Emission		
									Water (L·m ⁻²)		NO ₃ ⁻ (mol·m ⁻²)		K ⁺ (mol·m ⁻²)		NO ₃ ⁻ (g·m ⁻²)		
2.2	3.5	4.5	2.2	3.5	4.5	2.2	3.5	4.5	2.2	3.5	4.5	2.2	3.5	4.5	2.2	3.5	4.5
21.19 c	27.55 b	34.54 a	3.3 c	5.6 b	7.7 a	6.6 a	6.1 b	5.9 b	185 a	148 b	114 c	3.42 c	5.79 b	8.68 a	1.70 c	2.80 b	4.53 a
167 b	178 a	174 a															

Data shown are the average of three replicates.

Different letters indicate significant differences according to Tukey's test ($P \leq 0.05$).

effects (adding NaCl) and the benefits of the increased EC with an equal balance of macronutrients. Their results for decreased water availability, and thus the reduction of root-pressure-driven xylem transport of water and solutes, are similar to the findings reported by Gallegos-Cedillo et al. (2016).

Nitrate and potassium uptake exhibited an opposite trend to that of water uptake, increasing in higher EC treatments. These results are similar to previous results showing that an increase in all nutrients in equal ratios in the root environment can lead to a gradually increased uptake of all cations (Sonneveld and Voogt, 2009) but not enough to achieve equal nutrient emissions to the environment.

Effect on total crop productivity and on distribution of fruit sizes. Total and commercial yield decreased considerably (Table 3), with an average reduction from 15% to 19% and from 19% to 22% in the medium and high EC treatments, respectively, compared with the low EC treatment, thus presenting significant differences. The distributions of fruit size for the extra large (GG) and large (G) sizes were significantly affected, with decreases from 69% to 39.5% and from 42% to 36.5% in the medium and high EC treatments, respectively, compared with the low EC treatment. Medium sizes (M, MM, and MMM) were unaffected, whereas small fruits (S) were significantly affected, with a trend opposite to that of large sizes and an average reduction of 69%.

However, the total and commercial numbers of fruits per area were unaffected between treatments. Distribution of number of fruit size per area corresponding to extra large (GG) and large (G) sizes was significantly affected, with decreases from 68% to 59.5% and from 62% to 35% in the medium and high EC treatments, respectively, compared with the low EC treatment. Medium sizes (M, MM, and MMM) were unaffected, whereas small size (S) was significantly affected, with an opposite trend to that seen in large sizes and an average reduction of 73%.

The results of the present study showed that the fresh fruit yield of tomato was reduced by an increase in moderately high EC nutrient solutions with an equal balance of macronutrients, in accordance with other works in which increased EC was achieved by adding NaCl (Adams, 1991; Borghesi et al., 2011; Sonneveld, 2000) or macronutrients (Adams, 1991; Ehret et al., 2013; Morales and Urrestarazu, 2013; Sonneveld, 2000). Morales and Urrestarazu (2013), using an increase in moderately high EC nutrient solutions with an equal balance of macronutrients, reported a decrease in fruit weight with EC values similar to the present work.

Other authors found that fruit weight was affected when the EC threshold was above 4 dS·m⁻¹, and when the EC value was above 8 dS·m⁻¹, a reduction in the number of fruits per area was observed (Dorais et al., 2001b).

The EC threshold value determines the decline in yield; after this point, a linear

decrease in this parameter was observed (Sonneveld, 2000). Many researchers have tested various EC ranges, obtaining thresholds between 3 and 10 dS·m⁻¹ with no

reduction in commercial yield (De Pascale et al., 2001; Krauss et al., 2006). In addition, Borghesi et al. (2011) stated that the influence of EC threshold value on yield is also

Table 3. Effects of nutrient solutions with different electrical conductivity (dS·m⁻¹) levels on yield, size, and number of fruits per area.

Size	Yield (kg·m ⁻²)			No. of fruits/m ²		
	2.2	3.5	4.5	2.2	3.5	4.5
GG (82–102 mm)	1.04 a	0.81 a	0.32 b	3.93 a	3.11 a	1.26 b
G (81–67 mm)	5.45 a	4.99 a	3.17 b	30.96 a	29.33 a	19.11 b
M (66–57 mm)	2.67 a	3.12 a	2.58 a	23.67 a	27.81 a	23.09 a
MM (56–47 mm)	1.89 a	1.74 a	2.24 a	27.96 a	26.25 a	32.72 a
MMM (46–40 mm)	0.79 a	0.76 a	0.84 a	17.78 a	17.78 a	18.81 a
S (39–35 mm)	0.05 b	0.10 ab	0.16 a	1.48 b	3.19 ab	5.48 a
Marketable yield	11.89 a	11.52 a	9.31 b	105.78 a	107.46 a	100.48 a
Total yield	16.66 a	15.86 a	13.49 b	154.07 a	157.69 a	149.96 a

Data shown are the average of three replicates.

Different letters indicate significant differences according to Tukey's test ($P \leq 0.05$).

Fig. 1. Effect of variations in electrical conductivity values (dS·m⁻¹) of the nutrient solution on dietary quality of tomato fruits. Data shown represent the average of three replicates. Different letters indicate significant differences according to Tukey's test ($P \leq 0.05$).

Fig. 2. Effect of variations in electrical conductivity (EC) values ($\text{dS}\cdot\text{m}^{-1}$) of the nutrient solution on organoleptic quality of tomato fruits. Data shown represent the average of three replicates. Different letters represent significant differences according to Tukey's test ($P \leq 0.05$).

dependent on genetics (e.g., cultivar). Not all tomato cultivars decreased their fruit size to the same extent, and small-sized fruits were least affected by salinity, with a lower reduction in yield (Cuartero and Fernández-Muñoz, 1999). As growers choose tomato varieties depending on the fruit size demanded by consumers, tomatoes chosen to grow under moderately high EC nutrient solutions with an equal balance of macro-nutrients could be adjusted to commercial standards.

Effect on dietary quality of fruit. Functional quality parameters of tomato fruits are presented in Fig. 1. All measured parameters significantly improved as EC treatment increased. The increased dietary value of fruits produced at the higher EC level can be attributed to a lower accumulation of water in fruits caused by an osmotic effect of the higher nutrient solution EC. The percentage of fruit dry matter content showed a significant increase of 8.2% between the low and high EC treatments. This finding is important for addressing the research question in this paper.

Lycopene content was considerably enhanced (with an average growth of 6.3% between low and high EC treatment). These results are similar to those of other studies (Borghesi et al., 2011; De Pascale et al., 2001; Krauss et al., 2006; Kubota et al., 2012). However, EC reduced or had no effect on lycopene content, as previously reported

(Ali and Ismail, 2014; Fernández-García et al., 2002; Van Meulebroek et al., 2012). It has been argued that lycopene content depends on genotype and climatic conditions rather than salinity stress; lycopene content is also negatively correlated with fruit size rather than an increase in biosynthesis (Ehret et al., 2013).

Ascorbic acid content increased, with an average increase of 8.8% between the low and high EC treatment. Previous work has reported similar results (De Pascale et al., 2001; Ehret et al., 2013; Zushi and Matsuzoe, 2015). Ali and Ismail (2014) reported a 7-fold increase in ascorbic acid content in plants subjected to severe salinity stress ($10 \text{ dS}\cdot\text{m}^{-1}$). These authors stated that specific genotype salinity sensitivity plays a key role in tomato plant behavior, and thus, contradictory results were reported (Fernández-García et al., 2002; Kubota et al., 2012).

Total phenolics content and total antioxidants increased, with an average growth of 8.1% and 11.1%, respectively, between the low and high EC treatments. Previous studies found significant differences at extreme EC values ($2\text{--}10 \text{ dS}\cdot\text{m}^{-1}$) (Krauss et al., 2006; Van Meulebroek et al., 2012; Zushi and Matsuzoe, 2015) or no differences at moderate EC values (Ali and Ismail, 2014; Kubota et al., 2012). This enhancement may be a response to increased reactive oxygen species linked to water stress level (Krauss et al., 2006).

Effect on organoleptic quality of fruit.

The EC and pH of the tomato juice showed nonsignificant differences (Fig. 2). Azarmi et al. (2010), similarly, reported no changes in tomato juice EC or pH and argued that the increase in organic acid accumulation counteracted the higher accumulation of K^+/Na^+ compared with that of $\text{SO}_4^{2-}/\text{Cl}^-$, maintaining the pH level.

Total soluble solids showed significant differences in average growth, from 4.0% to 10.8% in the medium and high EC treatments, respectively, compared with the low EC treatment.

Titrate acid showed significant differences in average growth, from 6.7% to 11.2% in the medium and high EC treatments, respectively, compared with the low EC treatment. In general, increasing plant salinity can be explained by the accumulation of plant osmolytes to enable water uptake by the root system (Azarmi et al., 2010; Borghesi et al., 2011; Del Amor et al., 2001; Krauss et al., 2006; Sánchez-González et al., 2015; Zushi and Matsuzoe, 2015). This accumulation is translated into an increase in total soluble solids and/or titrate acidity.

The increase in total soluble solids and titrate acid in fruits produced at the higher EC level could be attributed to lower accumulation of water in fruits because of an osmotic effect of the higher nutrient solution EC. The percentage increase in dry matter content provided evidence for this question.

Conclusions

Moderate salinity decreased total and commercial yield, with an average reduction of 5% to 19% and 3% to 22%, respectively. An important decrease in extra large (GG) and large (G) fruits, with average reductions of 69% to 42%, respectively, was also observed. However, the impact on yield, size, and dietary-related metabolites significantly increased at the highest EC value, including lycopene (6.3%), ascorbic acid (8.8%), total phenolics contents (8.3%), and total antioxidant activity content (11.1%). We emphasize that this increase was achieved at EC values that are frequently measured in drainage solutions in open hydroponic systems.

Literature Cited

- Adams, P. 1991. Effect of increasing salinity of the nutrient solution with major nutrient or sodium chloride on the yield, quality and composition of tomato grown in rockwool. *J. Hort. Sci. Biotechnol.* 66:201–207.
- Al-Ani, M., L.U. Opera, D. Al-Bari, and N. Al-Rabi. 2007. Spectrophotometric quantification of ascorbic acid contents of fruit and vegetables using the 2, 4-dinitrophenylhydrazine method. *J. Food Agr. Environ.* 5(3–4):165–168.
- Ali, H.E.M. and G.S.M. Ismail. 2014. Tomato fruit quality as influenced by salinity and nitric oxide. *Turk. J. Bot.* 38:122–129.
- Arah, I.K., H. Amaglo, E. Kodzo, E.K. Kumah, and O. Hayford. 2015. Preharvest and postharvest factors affecting the quality and shelf life of harvested tomatoes: A Mini Review. *Intl. J. Agron.* 2015:478041.

- Auerswald, H., D. Schwarz, C. Kornelson, A. Krumbein, and B. Brückner. 1999. Sensory analysis, sugar and acid content of tomato at different EC values of the nutrient solution. *Sci. Hort.* 82(3-4):227-242.
- Azarmi, R., R.D. Taleshmikail, and A. Gikloo. 2010. Effects of salinity on morphological and physiological changes and yield of tomato in hydroponics system. *J. Food Agr. Environ.* 8(2):573-576.
- Benzie, I.F.F. and J.J. Strain. 1996. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": The FRAP assay. *Anal. Biochem.* 239(1):70-76.
- Borghesi, E., M.L. González-Miret, M.L. Escudero-Gilete, F. Malorgio, F.J. Heredia, and A.J. Meléndez-Martínez. 2011. Effects of salinity stress on carotenoids, anthocyanins, and color of diverse tomato genotypes. *J. Agr. Food Chem.* 59(21):11676-11682.
- Canene-Adams, K., J.K. Campbell, S. Zaripheh, E.H. Jeffery, and J.W. Erdman. 2005. The Tomato as a functional food. *J. Nutr.* 135(5):1226-1230.
- Cliff, M.A., J.B. Lia, P.M.A. Toivonen, and D.L. Ehret. 2012. Effects of nutrient solution electrical conductivity on the compositional and sensory characteristics of greenhouse tomato fruit. *Postharvest Biol. Technol.* 74:132-140.
- Cuartero, J. and R. Fernández-Muñoz. 1999. Tomato and Salinity. *Sci. Hort.* 78(1-4):83-125.
- De Pascale, S., A. Maggio, V. Fogliano, P. Ambrosino, and A. Ritieni. 2001. Irrigation with saline water improves carotenoids content and antioxidant activity of tomato. *J. Hort. Sci. Biotechnol.* 76(4):447-453.
- Del Amor, F.M., V. Martínez, and A. Cerda. 2001. Salt tolerance of tomato plants as affected by stage of plant development. *HortScience* 36:1260-1263.
- Dorais, M., D.L. Ehret, and A.P. Papadopoulos. 2008. Tomato (*Solanum lycopersicum*) health components: From the seed to the consumer. *Phytochem. Rev.* 7:231-250.
- Dorais, M., A.P. Papadopoulos, and A. Gosselin. 2001a. Greenhouse tomato fruit quality: The influence of environmental and cultural factors. *Hort. Rev.* 26:239-319.
- Dorais, M., A.P. Papadopoulos, and A. Gosselin. 2001b. Influence of EC management on greenhouse tomato yield and fruit quality. *Agronomie* 21:367-383.
- EC. 2000. Commission Regulation (EC) No 790/2000 of 14 Apr. 2000 laying down the marketing standard for tomatoes. *Official J. Eur. Commun.* L95:24-29.
- Ehret, D.L., K. Usher, T. Helmer, G. Block, D. Steinke, B. Frey, and M. Diarra. 2013. Tomato fruit antioxidants in relation to salinity and greenhouse climate. *J. Agr. Food Chem.* 61(5):1138-1145.
- Erba, D., M.C. Casiraghi, R. Ribas-Agustí, R. Cáceres, O. Marfà, and M. Castellari. 2013. Nutritional value of tomatoes (*Solanum lycopersicum* L.) grown in greenhouse by different agronomic techniques. *J. Food Compos. Anal.* 31(2):245-251.
- Etminan, M., B. Takkouche, and F. Caamano-Isorna. 2004. The role of tomato products and lycopene in the prevention of prostate cancer: A meta-analysis of observational studies. *Cancer Epidemiol. Biomarkers Prev.* 13(3):340-345.
- Fernández-García, N., V. Martínez, A. Cerda, and M. Carvajal. 2002. Water and nutrient uptake of grafted tomato plants grown under saline conditions. *J. Plant Physiol.* 159(8):899-905.
- Fish, W.W., P. Perkins-Veazie, and J.K. Collins. 2002. A quantitative assay for lycopene that utilizes reduced volumes of organic solvents. *J. Food Compos. Anal.* 15(3):309-317.
- Gallegos-Cedillo, V., M. Urrestarazu, and J.E. Alvaro. 2016. Influence of salinity on transport of Nitrates and Potassium by means of the xylem sap content between roots and shoots in young tomato plants. *J. Soil Sci. Plant Nutr.* 16(4):1-8.
- Gorbe, E. and A. Calatayud. 2010. Optimization of nutrition in soilless systems: A review. *Adv. Bot. Res.* 53:193-245.
- Harmanescu, M., I. Gergen, and H.D. Isengard. 2006. Polyphenols content, total antioxidant and radical scavenging capacities for different tomatoes and apples juices. *J. Agroaliment. Proc. Technol.* 12(1):83-88.
- Iglesias, M.J., J. García-López, J.F. Collados-Luján, F. López-Ortiz, M. Díaz, F. Toresano, and F. Camacho. 2015. Differential response to environmental and nutritional factors of high-quality tomato varieties. *Food Chem.* 176:278-287.
- Kubota, C., M. Kroggel, M. Torabi, K.A. Dietrich, H.J. Kim, J. Fonseca, and C.A. Thomson. 2012. Changes in selected quality attributes of greenhouse tomato fruit as affected by pre- and post-harvest environmental conditions in year-round production. *HortScience* 47:1698-1704.
- Krauss, S., W.H. Schnitzler, J. Grassmann, and M. Woißke. 2006. The influence of different electrical conductivity values in a simplified recirculating soilless system on inner and outer fruit quality characteristics of tomato. *J. Agr. Food Chem.* 54(2):441-448.
- Leonardi, C., P. Ambrosino, F. Esposito, and V. Fogliano. 2000. Antioxidative activity and carotenoid and tomatine Contents in different typologies of fresh consumption tomatoes. *J. Agr. Food Chem.* 48(10):4723-4727.
- Little, T.M. and F.J. Hills. 1987. Métodos estadísticos para la investigación en la agricultura. Ed. Trillas, México.
- Liu, R.H. 2013. Health-Promoting components of fruits and vegetables in the diet. *Adv. Nutr.* 4:384S-392S.
- Magán, J.J., M. Gallardo, R.B. Thompson, and P. Lorenzo. 2008. Effects of salinity on fruit yield and quality of tomato grown in soilless culture in greenhouses in Mediterranean climatic conditions. *Agr. Water Mgt.* 95(9):1041-1055.
- Morales, I. and M. Urrestarazu. 2013. Thermography study of moderate electrical conductivity and nutrient solution distribution system effects on grafted tomato soilless culture. *HortScience* 48:1508-1512.
- Nishino, H., H. Tokuda, Y. Satomi, M. Masuda, Y. Osaka, S. Yogosawa, S. Wada, X. Mou, J. Takayasu, M. Murakoshi, K. Jinno, and M. Yano. 2004. Cancer prevention by antioxidants. *Biofactors* 22(1-4):57-61.
- Passam, H., I.C. Karapanos, P.J. Bebeli, and D. Savvas. 2007. A review of recent research on tomato nutrition, breeding and post-harvest technology with reference to fruit quality. *Eur. J. Plant Sci. Biotech.* 1(1):1-21.
- Petersen, R.G. 1994. *Agricultural Field experiment*. Marcel Dekker Inc., New York, NY.
- Rodríguez, D., J. Reca, J. Martínez, L. López-Luque, and M. Urrestarazu. 2015. Development of a new control algorithm for automatic irrigation scheduling in soilless culture. *Appl. Math. Inf. Sci.* 9(1):1-10.
- Sánchez-González, M.J., M.C. Sánchez-Guerrero, E. Medrano, M.E. Porras, E.J. Baeza, and P. Lorenzo. 2015. Influence of pre-harvest factors on quality of a winter cycle, high commercial value, tomato cultivar. *Sci. Hort.* 189:104-111.
- Singleton, V. and J. Rossi. 1965. Colorimetry of total phenolics with phosphomolybdic phosphotungstic acid reagents. *Amer. J. Enol. Viticult.* 16:144-158.
- Sonneveld, C. 2000. Effects of salinity on substrate grown vegetables and ornamentals in greenhouse horticulture. Wageningen Agr. Univ. Wageningen, Netherlands, PhD Diss.
- Sonneveld, C. and A.M.M. Van der Burg. 1991. Sodium chloride salinity in fruit vegetable crops in soilless culture. *Neth. J. Agr. Sci.* 39:115-122.
- Sonneveld, C. and W. Voogt. 2009. *Plant nutrition of greenhouse crops*. Springer, Dordrecht, The Netherlands.
- Soria, T. and J. Cuartero. 1998. Tomato fruit yield and water consumption with salty water irrigation. *Acta Hort.* 458:215-220.
- Urrestarazu, M. 2015. *Manual práctico de cultivo sin suelo e hidroponía*. Paraninfo, Madrid.
- Urrestarazu, M., G.A. Martínez, and M.C. Salas. 2005. Almond shell waste: Possible local rockwool substitute in soilless crop culture. *Sci. Hort.* 103(4):453-460.
- Urrestarazu, M., I. Morales, T. La Malfa, R. Checa, A.F. Wamser, and J.E. Alvaro. 2015. Effects of fertigation duration on the pollution, water consumption, and productivity of soilless vegetable cultures. *HortScience* 50:819-825.
- Urrestarazu, M., M.C. Salas, D. Valera, A. Gómez, and P. Mazuela. 2008. Effects of heating nutrient solution on water and mineral uptake and early yield of two cucurbits under soilless culture. *J. Plant Nutr.* 31(3):527-538.
- USDA. 2016. *Index of Official Visual Aids*. Visual Aid TM-L-1 (Feb. 1975).
- Van Meulebroek, L., L. Vanhaecke, T. De Swaef, K. Steppe, and H. De Brabander. 2012. U-HPLC-MS/MS to quantify liposoluble antioxidants in red-ripe tomatoes, grown under different salt stress levels. *J. Agr. Food Chem.* 60(2):566-573.
- Willcox, J.K., G.L. Catignani, and S. Lazarus. 2003. Tomatoes and cardiovascular health. *Crit. Rev. Food Sci. Nutr.* 43(1):1-18.
- Zushi, K. and N. Matsuzoe. 2015. Metabolic profile of organoleptic and health-promoting qualities in two tomato cultivars subjected to salt stress and their interactions using correlation network analysis. *Sci. Hort.* 184:8-17.