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BIOLOGY

Electrical conductivity of the nutrient solution on the vegetative propagation of bell pepper and tomato

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ABSTRACT: *The optimization of resources and time in the production of quality seedlings within a legal framework is of vital importance for greenhouse vegetable crops. This study evaluated the electrical conductivity of the nutrient solution and its effect on the survival and growth of bell pepper and tomato seedlings propagated by cuttings. The electrical conductivities evaluated were 0.92, 1.25, 1.50, and 1.75 dS m^{-1}. The experiment was conducted using a randomized complete block design with four replicates. The number of rooted plants, stem diameter, root length, number of leaves, leaf area, dry weight of leaves, stem, root, and total were determined. In addition, the following indices were determined: stem root index, slenderness index, leaf area ratio, specific leaf area, and pre-transplant horticultural quality index. In both crops, the highest number of rooted cuttings was obtained with the lowest electrical conductivity. Meanwhile, the average electrical conductivity favored leaf number, leaf area, biomass, and seedling quality indices. These results showed that the production of bell pepper and tomato seedlings can be done by cuttings using Stenier nutrient solution at electrical conductivities of 1.25 to 1.50 dS m^{-1} without affecting seedling quality.*
Key words: *cuttings rooting, salinity, seedlings nutrition, seedling quality indices.*

Condutividade elétrica da solução nutritiva na propagação vegetativa de pimentão e tomate

RESUMO: *A otimização de recursos e tempo na produção de mudas de qualidade dentro de um quadro legal é de vital importância para as hortaliças em estufa. O objetivo deste trabalho foi avaliar a condutividade elétrica da solução nutritiva e seu efeito na sobrevivência e no crescimento de mudas de pimentão e tomate propagadas por estaquia. As condutividades elétricas avaliadas foram 0,92, 1,25, 1,50 e 1,75 dS m-1. O experimento foi conduzido em delineamento de blocos ao acaso com quatro repetições. Foram determinados o número de plantas enraizadas, diâmetro do caule, comprimento da raiz, número de folhas, área foliar, massa seca das folhas, caule, raiz e total. Além disso, foram determinados os seguintes índices: índice de raiz do caule, índice de esbeltez, razão de área foliar, área foliar específica e índice de qualidade hortícola pré-transplante. Em ambas as safras, o maior número de estacas enraizadas foi obtido com a menor condutividade elétrica. Já a condutividade elétrica média favoreceu os índices de número de folhas, área foliar, biomassa e qualidade das mudas. Esses resultados mostram que a produção de mudas de pimentão e tomate pode ser feita por meio de estacas com solução nutritiva de Stenier em condutividades elétricas de 1,25 a 1,50 dS m^{-1} sem afetar a qualidade das mudas.*
Palavras-chave: *enraizamento de estacas, salinidade, nutrição de mudas, índices de qualidade de mudas.*

INTRODUCTION

Seedling production is an important part of agricultural production. A seedling of excellent quality guarantees, extent largely, the success of the crop, since there is a close relationship between seedling quality, production, and fruit quality (ARAMÉNDIZ-TATIS et al., 2013). Asexual or vegetative propagation is a useful method for seedling production and is possible because each plant cell possesses the necessary information to generate the whole plant. This type of propagation involves mitotic divisions of cells, which duplicate the genotype of the plant, whereby the specific characteristics of any individual plant are maintained without modification (SANTIAGUILLO-HERNÁNDEZ et al., 2004). The main reasons for commercial vegetative propagation are the conservation of a genotype's valuable characteristics, adaptability, and tolerance or resistance to biotic and/ or abiotic factors (BEYL & TRIGIANO, 2016).

Propagation by cuttings has advantages such as ease procedure, since abundant material

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can be propagated using little space and low operating cost. Numerous cuttings can be obtained from one plant; homogeneity of the crop, since each plant produced by this method is genetically identical to the plant from which it comes (mother plant) (ALVAREZ, 2011; BRAUN et al., 2010; LÓPEZ et al., 2008). Stem propagation is the most common form of this type of propagation. Stem roots are better than other organs, and only the formation of a new root system, that is, adventitious roots, is necessary (ACOSTA et al., 2008). In propagation by cuttings, several factors influence the rooting process. Among these factors are plant characteristics, such as age, phenological stage, and nutritional conditions, in addition to climatic and agronomic management conditions (HASSANEIN, 2013; VILLANOVA et al., 2017; ALAM et al., 2020). Irrigation and fertilization, in addition to affecting the rooting process, also have an impact on the quality of seedlings and their recovery after transplanting (GARCIA-MORALES et al., 2011), and these factors affect some of the vegetative development parameters such as stem root index, slenderness index, and leaf area coefficient (BIRCHLER et al., 1998).

Electrical conductivity (EC) plays a pivotal role in the growth and development of seedlings, as well as the productivity and quality of fruits since salinity is one of the factors that limit the growth, absorption, transport, assimilation, and distribution of nutrients in the plant (WORTMAN, 2015; DE FREITAS et al., 2017). Nutrient solutions with too low EC limit plant growth due to nutrient deficiency, while nutrient solutions with too high EC inhibit growth, because plants increase the activity of antioxidant enzymes to adapt to salt stress conditions (DING et al., 2018). The impact of salinity stress on plants varies with EC level, salt type, species, and phenological stage. Considering the above, this study evaluated the effect of the electrical conductivity of the nutrient solution on the production of bell pepper and tomato seedlings from stem cuttings.

MATERIALS AND METHODS

Location, plant material and management conditions

The experiment was conducted in a greenhouse at the University of Almeria, Spain. The cuttings were obtained from the apex of the main stem of Italian sweet bell pepper seedlings of the Padua F1 variety and tomato plants of the Zynac F1 variety grafted on Maxifort, both of which were in production. The 6 cm long cuttings, with the newest apical leaf, were disinfected with a 3% sodium hypochlorite solution, washed with distilled water, and then planted in plastic trays with alveoli of 100 mL volume filled with B-6 perlite substrate (autoclaved at 121 °C for 30 min), and 20 cuttings were placed in each tray with a three-roll arrangement. The trays were previously saturated with each of the different nutrient solutions and were placed inside transparent boxes with length, width, and height of 50 × 25 × 20 cm; respectively, with holes in the base to facilitate drainage. Temperature and relative humidity conditions were kept constant during the experiment (24.00±3 °C and 91.07±5%, respectively), in an automatic control greenhouse. The nutrient solution used was as described by SONNEVELD & STRAVER (1994) (Table 1). This nutrient solution was diluted with distilled water to obtain three different levels of electrical conductivity 1.25, 1.5, and 1.75 dS m^{-1}, in addition, tap water was used as a control, which had an EC of 0.92 dS m^{-1}. The pH of the treatments and control was adjusted to 5.8 with nitric acid.

Rooting, growth and biomass

At 30 days after staking, the surviving seedlings were counted to determine the number of rooted plants, and the substrate adhering to the roots was removed. They were then separated into leaves, stems, and roots. Stem diameter was measured at the height of the insertion point with the roots, using an electronic caliper model "Stainless Hardened®" of 150 mm and a sensitivity of 0.01 mm. Root length was measured using a millimeter tape measure, while the number of leaves was determined by visual counting. Leaf area was determined using the WinDIAS-3 Leaf Area Meter System® image processing software. Plants were placed in paper bags and dried in a forced air oven at 60 °C for 48 h, after which the dry weights of leaves, stems, roots, and total were determined.

Table 1 - Nutrient solution used for propagation of bell pepper and tomato seedlings by cuttings (SONNEVELD & STRAVER, 1994).

----Macronutriments (mM)----						----Micronutriments (µM)----					
NO_3^-	H_2PO_{42-}	SO_4^{2-}	K^+	Ca^{2+}	Mg^{2+}	Fe	Mn	Cu	Zn	B	Mo
10.25	1.5	1.75	4.75	5.00	1.50	15	10	0.75	5	30	0.5

Seedling quality indexes

Once the dry weight of the seedlings was obtained, the following seedling quality indexes were calculated:

Stem root index (SRI): indicates that the best quality of a plant is obtained when the aerial part is relatively small and the root is large, which can guarantee a better survival since transpiration is prevented from exceeding the absorption capacity (IVERSON, 1984):

$$SRI = \frac{stem\ dry\ weigth\ (g)}{root\ dry\ weigth\ (g)}$$

Slenderness index (SI): relates the height of the plant and its diameter, being an indicator of crop density. It is an important parameter in containerised plants, where plants can be tapered. High values of this index are indicative of a more robust plant that can tolerate physical damage (SCHMIDT-VOGT et al., 1980):

$$SI = \frac{stem\ diameter\ (mm)}{\left(\frac{stem\ height\ (cm)}{10}\right) + 2}$$

Leaf area ratio (LAR): ratio of leaf area (cm^2) to total dry matter (g). Low values of this index imply greater resistance to transplant shock (MASSON et al., 1991):

$$LAC = \frac{\text{leaf area}\ (cm^2)}{\text{aereal dry}\ weigth\ (g)}$$

Specific leaf area (SLA): ratio between leaf area and leaf dry matter. Low values give rise to plants that are more resistant to transplant shock (URRESTARAZU et al., 2016):

$$SLA = \frac{leaf\ area\ (cm^2)}{leaf\ dry\ weigth\ (g)}$$

Pre-transplant horticultural quality index (PHQI): compiles all the information related to the desired or sought-after parameters in pre-transplant seedlings dedicated to intensive horticultural production. The method of evaluating whether a plant is going to resist stress better or worse is related to the dry matter content, so it is considered that high values of this index indicate seedlings with lower transplanting stress (CARRILLO, 2011):

$$PHQI = 10^4 * \frac{shoot\ dry\ weigth\ (g)}{leaf\ area\ (cm^2)} * \frac{root\ dry\ weigth\ (g)}{total\ dry\ weigth\ (g)} * \frac{stem\ diameter\ (cm)}{stem\ height\ (cm)}$$

Statistical analysis

The treatments had four replicates, each experimental unit consisted of 20 stakes and were distributed under a randomized block design. The experimental design was under randomized block. The treatments had four replicates, each experimental unit consisted of 20 stakes. The data obtained in percentages were transformed using arcsine transformation. The final data were analyzed using Levene's test for homogeneity of variances and Shapiro-Wilk test for normality. The data were subjected to analysis of variance and the variables with significant differences; comparison of means was performed with Tukey's test, $P \leq 0.05$. These data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 22.0 (IBM Corp, 2013).

RESULTS AND DISCUSSION

Rooting, growth and biomass

The Levene's test indicated constant variance and Shapiro-Wilk test indicated a normal distribution. The ANOVA showed significant differences ($P \leq 0.05$) among the treatments. In bell pepper, at 1.25 dS m^{-1}, the percentages of rooting and root length were reduced by 46% and by 23%, respectively. Contrary to the above, the number of leaves and leaf area showed maximum values at 1.25 and 1.50 dS m^{-1}, respectively, compared to the control solution (0.92 dS m^{-1}), which increased the number of leaves by 71%, while the total area increased by 36%.

In tomato, unlike bell pepper, the negative effect of EC was observed in solutions with higher EC (1.75 dS m^{-1}), where a reduction of 34% in rooted plants, 29% in root length, and 28% in leaf area was observed. As in bell pepper, when the EC was increased to 1.5 dS m^{-1}, the leaf area increased by 58% compared to the control treatment (Table 2). Different plant species have different effects on the salinity level of the nutrient solution. In some cases, increasing the EC of the nutrient solution can positively affect growth, while in other species it can reduce it. This is related to the degree of tolerance of the species to salinity, as shown by the difference in the optimum EC level among the plants studied in this experiment (AHMADI & SOURI, 2019).

The effect of different ECs on biomass accumulation showed the same trend in the different organs of bell pepper seedlings. The highest dry weight of bell pepper was obtained at a conductivity of 1.25 dS m^{-1}, exceeding the control by 45%. Tomato seedlings showed greater biomass accumulation at ECs of 1.25-1.50 dS m^{-1}, exceeding the control by 12% on average. In contrast to the above, the presence of salts at an EC of 1.75 dS m^{-1} had negative effects on biomass accumulation, particularly bell pepper and tomato biomass, which were reduced by 23% and 18%, respectively, compared to the control treatment (Figure 1). The relationship between

Table 2 - Morphological variables of bell pepper and tomato seedlings propagated by cuttings with nutrient solutions with different EC.

EC ($dS\ m^{-1}$)	Rooted plants (%)	Stem diameter (mm)	Root length (cm)	Leaves number	Leaf area (cm^2)
----------Bell pepper----------					
0.92	98.75 a	3.18 ns	5.60 a	2.44 b	10.95 b
1.25	52.50 b	3.28 ns	4.34 b	4.18 a	13.46 ab
1.50	50.00 b	3.30 ns	3.95 b	3.69 a	14.94 a
1.75	40.00 c	3.40 ns	3.70 b	2.55 b	7.11 c
±SE	2.253	0.060	0.169	0.178	0.774
----------Tomato----------					
0.92	93.75 a	4.43 ns	5.62 a	2.32 a	12.89 b
1.25	86.25 a	4.47 ns	5.40 a	2.18 a	15.18 b
1.50	86.25 a	4.65 ns	5.24 ab	2.49 a	20.36 a
1.75	60.00 b	4.95 ns	3.99 b	1.67 b	14.65 b
±SE	5.217	0.125	0.309	0.118	1.187

The data correspond to the mean of the treatment values. SE: standard error. Different letters in the same column indicate significant differences according to Tukey's at 5%. ns: no significant, in the same column indicate no significant differences according to Tukey's at 5%.

nutrient availability and water uptake is affected by the electrical conductivity of the nutrient solution; therefore, it is necessary to consider optimal EC levels for particular crops (KEMPEN et al., 2017). Low EC limits plant growth owing to nutrient deficiency. High EC inhibits growth due to decreased nutrient assimilation and distribution in the plant; as a consequence, of reduced osmotic potential in the root environment due to salt stress. Particularly in roots, salinity can cause a decrease in elongation and suberization, which can lead to morphological and anatomical alterations and, consequently, reduce plant transpiration and growth (DE FREITAS et al., 2017). Coupled with the above, there is an increase in antioxidant enzyme activities to adapt to stress conditions, which reduces growth (DING et al., 2018).

Seedling quality indexes

The stem root index (SRI) was only affected in the case of bell pepper, where the increase

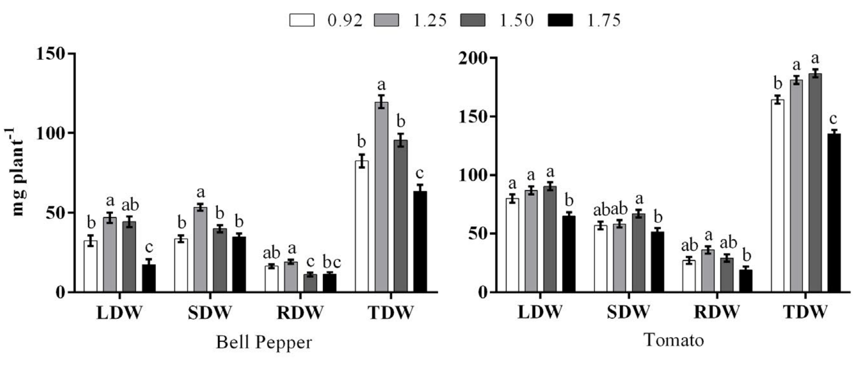

Figure 1 - Biomass accumulation of bell pepper and tomato seedlings propagated by cuttings with nutrient solutions with different EC. LDW: leaf dry weight, SDW: stem dry weight, RDW: root dry weight, TDW: total dry weight. Each bar shows the mean ± standard error. Different letters in the same column indicate significant differences according to Tukey's at 5%.

in EC at 1.50 dS m^{-1} increased this value by 69% with respect to the control. The leaf area ratio (LAR) was affected by EC in both species. The EC of 1.50 dS m^{-1} significantly increased the value of the index by 51% and 41% in bell pepper and tomato, respectively. The pretransplant horticultural quality index (PHQI) was affected in both species, with the maximum values observed at an EC of 1.25 dS m^{-1}. However, in bell pepper, a significant decrease of 31% occurred at an EC of 1.50 dS m^{-1}, while in tomato, a reduction of 45% occurred at the EC of 1.75 dS m^{-1}, compared to the control treatment. Slenderness index (SI) and specific leaf area (SLA) were not modified in the two species evaluated (Table 3).

The differences between the EC of the nutrient solutions had an impact on the quality indices. Low values indicate better seedling quality in the SRI and LAR indices. These low values were related to the avoidance of excessive transpiration. Low values of the SRI index indicated that the root biomass was greater than the aerial part, while low values of the LAR index indicated that the total biomass was greater than the leaf area, thus avoiding more transpiration than water absorption. At higher electrical conductivity, osmotic pressure increases, thus water absorption is reduced and with it, biomass production (BAGALE, 2018). Added to the above, the low concentration of nutrients in the nutrient solution affects the development and growth of organs, as in the case of nitrogen (N) deficiency that forces seedlings to increase the proportion of root biomass to increase the N absorption capacity of roots (WU et al., 2019).

Unlike the aforementioned indices, the PHQI index, which is the index that most variables use, considers that high values indicate seedlings with lower transplanting stress. Seedlings with higher quality were observed in the control treatment and in the solution with 1.25 dS m^{-1}, indicating that low nutrient values in the rooting process favor better seedlings. The need for water and nutrient absorption by the plant increases as the plant growth, so that in the juvenile stages, the need for nutrients in the solution is lower (SIGNORE et al., 2016).

CONCLUSION

The EC of the nutrient solution affects the propagation of bell peppers and tomatoes by cuttings. Higher rooting and growth of cuttings, as well as higher quality seedlings, were favored by nutrient solutions with lower amounts of nutrients in solution (low EC). The limiting EC for bell pepper was 1.25 dS m^{-1}, while that for tomato was 1.50 dS m^{-1}. This suggested greater tolerance of tomato than bell pepper to a higher amount of salt in the solution, in the production of seedlings by cuttings.

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Table 3 - Quality indices of bell pepper and tomato seedlings propagated by cuttings with nutrient solutions with different EC.

EC (dS m^{-1})	SRI	SI	LAR	SLA	PHQI
---Bell pepper---					
0.92	2.13 b	1.04 ns	117.08 b	306.15 ns	1.96 a
1.25	2.88 ab	1.03 ns	135.39 b	302.23 ns	2.08 a
1.50	3.59 a	1.00 ns	176.45 a	335.44 ns	1.44 b
1.75	3.07 ab	1.05 ns	136.96 b	410.46 ns	1.15 b
±SE	0.290	0.029	7.447	34.42	0.124
---Tomato---					
0.92	2.10 ns	1.33 ns	94.39 c	161.52 ns	4.62 ab
1.25	1.64 ns	1.31 ns	104.61 bc	176.13 ns	5.73 a
1.50	2.50 ns	1.28 ns	132.67 a	224.33 ns	4.17 ab
1.75	2.90 ns	1.43 ns	122.22 ab	231.58 ns	3.14 b
±SE	0.324	0.038	6.356	19.292	0.428

SRI: stem root index, SI: slenderness index, LAR: leaf area ratio, SLA: specific leaf area, PHQI: pre-transplant horticultural quality index. The data correspond to the mean of the treatment values. SE: standard error. Different letters in the same column indicate significant differences according to Tukey's at 5%. ns: no significant, in the same column indicate no significant differences according to Tukey's at 5%.

DECLARATION OF CONFLICT OF INTERESTS

No potential conflict of interest was reported by the authors.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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