PESQUISA AGROPECUÁRIA GAÚCHA

doi: https://doi.org/10.36812/pag.2020261319-331

Quality of tomato seedlings produced in substrates

José Luís Trevizan Chiomento[1]*; Gabriela Oliveira Cavalli[2]; Thomas dos Santos Trentin[2]; Alana Grando Dornelles[2]

Abstract - A difficulty in the production of tomato seedlings in containers is to assure the production of shoot biomass with limited portion of roots, restricted to a small volume of substrate. Therefore, we investigated if substrates associated with tomato cultivars interfere in the seedling quality. In this study, the treatments used were two tomato cultivars and three substrates. The experiment was designed in randomized blocks, with treatments arranged in a two-factorial scheme (2 x 3), with four replications. We carried out the physical and chemical characterization of the substrates and evaluated the attributes of the shoot and the root system of tomato seedlings. The results showed that the substrate with the highest water retention was Horta 2® and the lightest material was TN Gold®. Still, seedlings produced on the substrate with greater water retention capacity had higher performance in relation to the shoot morphology and the root system morphology. We conclude that the seedling quality of tomato cultivars is not associated with the studied substrates and that seedlings produced in substrate with greater water retention have better quality.

Key words: *Solanum lycopersicum* L. Shoot morphology. Root system morphology. Development models.

Qualidade de mudas de tomateiro produzidas em substratos

Resumo - Uma das dificuldades na produção de mudas de tomateiro em recipientes é o de assegurar a produção de biomassa aérea com porção limitada de raízes, restritas a um pequeno volume de substrato. Por isso, investigamos se substratos associados a cultivares de tomateiro interferem na qualidade das mudas. Nesse estudo, os tratamentos usados foram duas cultivares de tomateiro e três substratos. O experimento foi delineado em blocos casualizados, com os tratamentos arranjados no esquema bifatorial (2 x 3), com quatro repetições. Realizamos a caracterização física e química dos substratos e avaliamos atributos da parte aérea e do sistema radicial das mudas de tomateiro. Os resultados mostraram que o substrato com maior retenção de água foi o Horta 2® e o material mais leve foi o TN Gold®. Ainda, mudas produzidas no substrato com maior capacidade de retenção de água tiveram maior desempenho em relação à morfologia da parte aérea e à morfologia do sistema radicial. Concluímos que a qualidade das mudas de cultivares de tomateiro não se associa aos substratos estudado e que mudas produzidas em substrato com maior retenção hídrica têm melhor qualidade.

Palavras-chave: *Solanum lycopersicum* L. Morfologia da parte aérea. Morfologia do sistema radicial. Modelos de desenvolvimento.

[1] College of Agronomy and Veterinary Medicine, University of Passo Fundo, Passo Fundo, RS, Brazil. *corresponding author: jose-trevizan@hotmail.com.

[2] College of Agronomy and Veterinary Medicine, University of Passo Fundo, Passo Fundo, RS, Brazil.

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020 Recebido em 26 jul. 2020.
ISSN: 0104-907. ISSN online: 2595-7686 Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

Introduction

In horticultural crops the supply of quality seedlings to the producers is important to obtain high production after the establishment of the plants in their cultivation environment (CHIOMENTO et al., 2019). Such quality is related to the plants resistance to biotic and abiotic stresses (ZHAO et al., 2016). Thus, the concern with the quality of seedlings produced makes the exploitation of horticultural crops more competitive, as it guarantees greater production and profitability to seedling producer (WATTHIER et al., 2017). Among these vegetables is the tomato (*Solanum lycopersicum* L.), with a Brazilian production of approximately 4.5 million tons (IBGE, 2018). To maintain this production in an upward manner, quality seedlings must be provided to tomato producers. Therefore, seedling production is an important step in tomato cultivation, as this process reflects on the productive performance of plants (COSTA et al., 2012). However, a difficulty in the production of seedlings in containers is to ensure the production of shoot biomass with limited portion of root (LEMAIRE, 1995), restricted to a small volume of substrate, in response to the species/cultivars used.

The substrates vary widely in their physical and chemical properties (FERMINO; KÄMPF, 2012). For this reason, choosing an appropriate material is essential for the development of plants (MONDRAGÓN-VALERO et al., 2017) and this can contribute to reducing the negative effects of ecophysiological stresses during the seedling production and after their transplant. The substrates used must be low cost and easy to handle (NOYA et al., 2017), to have porosity around 85% (KÄMPF; FIOR; LEONHARDT, 2009) and water retention capacity (GRACESON et al., 2013). For tomato, we must choose materials that ensure these physical characteristics, since it is a species with high water demand (MAROUELLI; SILVA, 2006). In addition, the choice of the cultivar is also important, because genotypes can interact with biotic and abiotic factors and this will influence the quality of the seedlings produced (MONTEIRO NETO et al., 2018).

Among the components of mixtures for substrates, the carbonized rice husk (CRH) acquires importance due to the great availability in rice fields. Thus, it is necessary to develop research to support the transition from the use of commercial (high-cost) substrates to alternative (low-cost) substrates. Silva et al. (2012) recommend the use of the alternative substrate PlantHort I and the mixture of 76% PlantHort I and 24% CRH to improve the quality of tomato seedlings.

Considering that the substrate, to be used in the seedling production system, is essential for seed germination and plant establishment (AULER et al., 2015) and that crop productivity is linked to this input (SMIDERLE et al., 2001), we set out to answer the following question: how do substrates associated with tomato cultivars affect the quality of seedlings produced in a protected environment?

Therefore, based on the hypothesis that the seedling quality of tomato cultivar depends of the water retention capacity of the substrate, here we investigate if substrates associated with tomato cultivars interfere in

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

the seedling quality. Our study provides a view of the development of tomato seedlings using different substrates as a growth medium, to improve the quality of seedlings produced in a protected environment.

Material and Methods

The experiment was developed at the Horticulture Sector of the Universidade de Passo Fundo (UPF), in the municipality of Passo Fundo (28º 15’ 46” S, 52º 24’ 24” W), Rio Grande do Sul (RS), Brazil, from September (spring) to November (spring) 2019.

The tomato seeds used in the work were from Coração de Boi (CB) and Gaúcho Melhorado (GM) cultivars, both with an indeterminate growth habit and belonging to the salad group.

The materials used as substrates were carbonized rice husk (CRH), Horta 2® (HOR) and TN Gold® (TNG). The composition of HOR consists of pine bark, vermiculite, acid correction and fertilizers (nitrogen, phosphorus and potassium) in quantities not supplied by the manufacturer. The composition of TNG consists of sphagnum peat, expanded vermiculite, dolomitic limestone, agricultural gypsum and fertilizers (nitrogen, phosphorus and potassium) in quantities not supplied by the manufacturer. No fertilizer was added to the substrates. The rice husk used in the work was carbonized (KÄMPF; TAKANE; SIQUEIRA, 2006).

The treatments, outlined in a two-factorial scheme, consisted of two tomato cultivars (CB and GM) and three substrates (CRH, HOR and TNG). The experiment was designed in randomized blocks, with four replications ($n = 4$). Each plot, in each block, was composed of sixteen plants.

We produce the seedlings in trays of expanded polystyrene, with dimensions of 0.34 m of width and 0.68 m of length. Each tray had 128 cells, with a volume of 35 cm^3. In September, the trays were filled with the substrates CRH, HOR and TNG and then we sowed three seeds of the tomato cultivars in each cell.

The trays were kept on metal benches, 1.2 m above the soil surface, in a greenhouse of 90 m^2, with semicircular roof, installed in the northwest-southeast direction. The galvanized steel frame was covered with low density polyethylene film, with anti-ultraviolet additive and with a thickness of 150 microns, and the sides were covered with anti-aphid screen.

Irrigation used was with sprinklers, in the mechanized system, with a flow rate of 2 L min^{-1} per unit. The irrigation regime consisted of four sprinklers per day, with total wetting of seven minutes. The water blade supplied to the seedlings was 4.35 mm day^{-1}. During the execution of the experiment, the photosynthetically active radiation (PAR) and the mean air temperature inside the greenhouse were monitored, with mean values of 367.13 µmol m^{-2} s^{-1} and 21.6 °C, respectively.

A sample of 1 L of each substrate was collected and analyzed to obtain physical and chemical attributes of the materials. The physical attributes determined in the substrates were: density (D), total porosity (TP), aeration space (AS), readily available water (RAW) and buffer water (BW) (BRASIL, 2007). The chemical

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

attributes determined in the substrates were nitrogen (N), phosphorus pentoxide (P_2O_5), hydrogenionic potential (pH), electrical conductivity (EC) and cation exchange capacity (CEC) (BRASIL, 2014).

After seed germination, thinning was performed, leaving one plant per cell in each tray. Approximately 40 days after sowing, the stem base diameter (SBD, cm) and the shoot height (SH, cm) of the seedlings were measured with a digital caliper. The fresh (SFM, g) and dry (SDM, g) mass of the shoot was also evaluated. In order to obtain the dry mass, the plants were kept in a drying oven with forced air circulation, at 65 °C for 48 hours, until constant mass, and weighed in an electronic balance.

To evaluate the root system morphology, the roots of these seedlings were collected and washed in water to eliminate the substrate fragments. Thus, the roots were scanned and then the images obtained were analyzed by WinRHIZO® software. The attributes evaluated were the total root length (TL, cm), root surface area (SA, cm^2) and root volume (RV, cm^3). The roots were grouped by software in different diameter classes in relation to their total length (BÖHM, 1979): very thin roots (VTR, cm, Ø < 0.5 mm), fine roots (FR, cm, Ø 0.5 to 2 mm) and thick roots (TR, cm, Ø > 2 mm). The fresh (RFM, g) and dry (RDM, g) mass of the root system was also evaluated, following the methodology described previously.

The seedlings quality was obtained by models of plant development. Thus, Dickson quality index (DQI) was determined, as proposed by Dickson; Leaf; Hosner (1960), by the equation:

$$DQI = \frac{(TDM)}{\left(\frac{SH}{SBD} + \frac{SDM}{RDM}\right)} \quad (1)$$

where: TDM = total dry mass (g); SH = shoot height (cm); SBD = stem base diameter (mm); SDM = shoot dry mass (g); RDM = root dry mass (g).

The data obtained were subjected to analysis of variance (Anova) and, when there was significance, the treatment means were compared using the Tukey test, at 5% probability of error, with the aid of the Costat® program.

Results

The results of the physical characterization of the substrates used in our study (Table 1) showed that, considering the density of the materials, the TNG substrate is the lightest. With the values of TP, AS, RAW and BW of Table 1 we elaborated a graph to visualize the relation between air and water in each substrate (Figure 1). We observed that TNG material showed an unbalanced air-water relation (Figure 1).

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

Table 1. Physical properties of the substrates used in the study.

Substrates[1]	D[2]	TP	AS	RAW	BW
	(kg m^{-3})	(m^3 m^{-3})			
CRH	170.0±34.67 b	0.879±0.08 b	0.365±0.002 b	0.395±0.11 a	0.009±0.001 a
HOR	241.0±47.98 a	0.837±0.07 b	0.303±0.006 b	0.149±0.02 c	0.020±0.002 b
TNG	100.0±41.68 c	0.916±0.10 a	0.519±0.004 a	0.202±0.06 b	0.007±0.001 a
Mean	166.33	0.877	0.395	0.248	0.012
CV (%)[3]	20.15	15.89	18.73	17.39	20.56

Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ significantly by the Tukey test ($p\leq0.05$, $n = 4$). [1]CRH: carbonized rice husk; HOR: Horta 2®; TNG: TN Gold®. [2]D: density; TP: total porosity; AS: aeration space; RAW: readily available water; BW: buffer water. [3]Coefficient of variation.

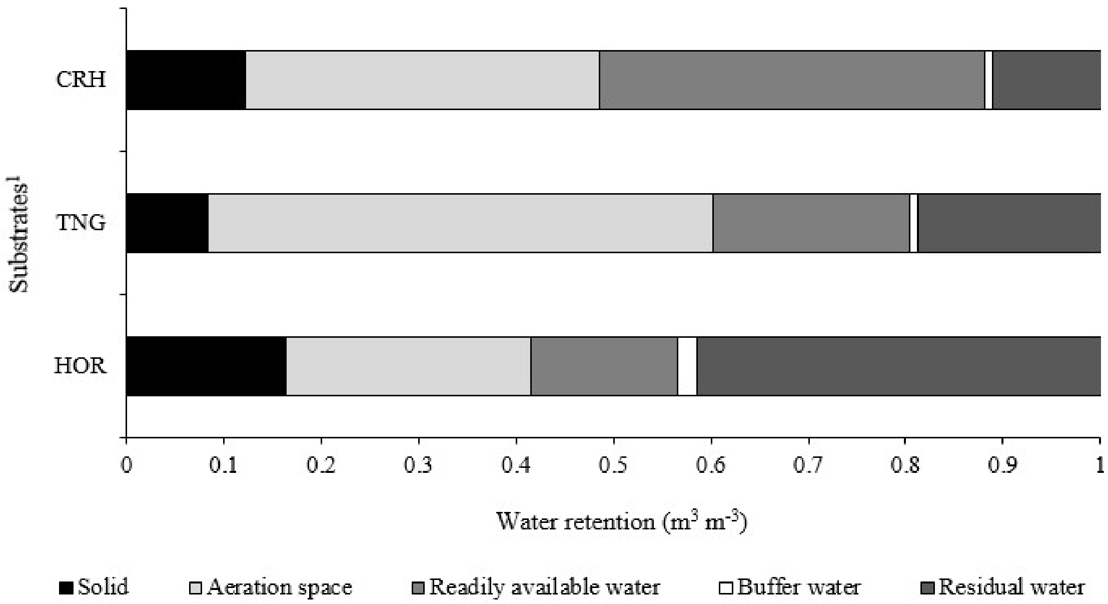

Figure 1. Physical characterization of the substrates used in the study (n = 4). [1]CRH: carbonized rice husk; HOR: Horta 2®; TNG: TN Gold®.

In addition, also with the values of TP, AS, RAW and BW of Table 1 we elaborated a graph to visualize the water retention curve of each substrate (Figure 2), according to De Boodt; Verdonck (1972). The HOR substrate presented higher water retention, requiring volumes of 0.435 m^3 m^{-3} to remain in the range of water

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

easily available to plants (10-50 -cm H_2O) (Figure 2). On the other hand, the CRH substrate had greater drainage of water (Figure 2).

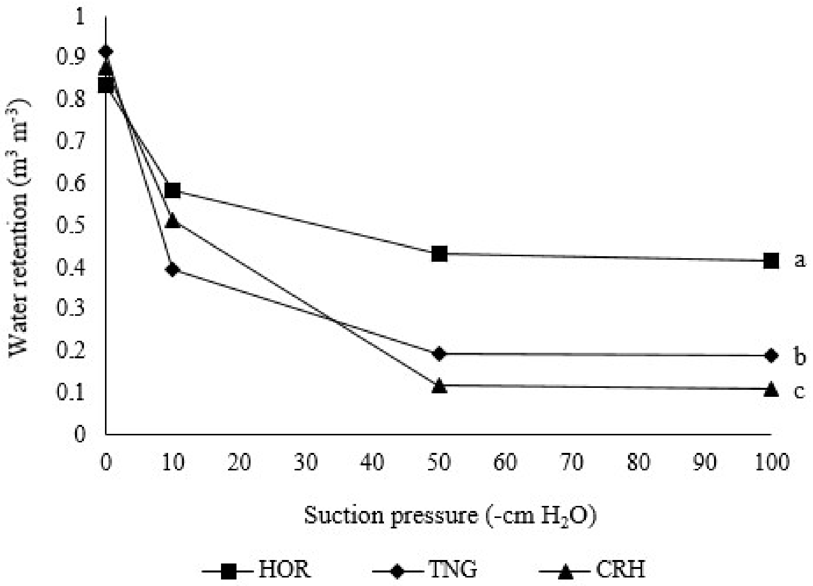

Figure 2. Substrate water retention curve. CRH: carbonized rice husk; HOR: Horta 2®; TNG: TN Gold®. Different letters indicate significant difference by the Tukey test (*p*≤0.05, *n* = 4).

The four materials showed availability of nutrients. Among the substrates, CRH presented 22% more pH than TNG. The opposite was obtained for EC and CEC, with CRH being 58% lower than the HOR for EC and 85% lower than TNG for CEC (Table 2).

Table 2. Chemical properties of three substrates.

Substrates[1]	N[2]	P_2O_5	pH	EC	CEC
	% (m m^{-1})			mS cm^{-1}	$mmol_c$ kg^{-1}
CRH	0.69±0.01 a	1.71±0.09 a	7.2±0.0 a	0.19±0.01 b	134.60±21.21 c
HOR	0.36±0.01 b	0.39±0.01 c	6.1±0.8 b	0.45±0.02 a	278.60±37.84 b
TNG	0.65±0.02 a	1.37±0.06 b	5.6±0.6 c	0.36±0.04 a	892.98±45.98 a
Mean	0.55	1.15	6.30	0.33	435.39
CV (%)[3]	14.12	11.23	10.57	16.51	13.92

Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ significantly by the Tukey test (*p*≤0.05, *n* = 4). [1]CRH: carbonized rice husk; HOR: Horta 2®; TNG: TN Gold®. [2]N: nitrogen; P_2O_5: phosphorus pentoxide; pH: hydrogenionic potential; EC: electrical conductivity; CEC: cation exchange capacity. [3]Coefficient of variation.

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

We did not observe the effect of cultivars or the cultivar-substrate interface on the shoot morphology of the seedlings. However, seedlings produced on the HOR substrate showed SH, SBD, SFM and SDM superior in 44%, 56%, 75% and 78%, respectively, in relation to the seedlings produced in the other substrates (Table 3).

Table 3. Effect of substrates on shoot morphology of tomato seedlings.

Substrates[1]	SH[2] (cm)	SBD (cm)	SFM (g)	SDM (g)
HOR	8.59±0.63 a	0.26±0.03 a	1.20±0.05 a	0.089±0.002 a
TNG	4.76±0.64 b	0.14±0.03 b	0.30±0.09 b	0.020±0.001 b
CRH	4.80±0.41 b	0.14±0.01 b	0.29±0.05 b	0.019±0.001 b
Mean	6.05	0.18	0.60	0.043
CV (%)[3]	18.36	12.16	32.47	33.55

Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ significantly by the Tukey test ($p \leq 0.05$, $n = 4$). [1]HOR: Horta 2®; TNG: TN Gold®; CRH: carbonized rice husk. [2]SH: shoot height; SBD: stem base diameter; SFM: shoot fresh mass; SDM: shoot dry mass. [3]Coefficient of variation.

The effect on the root system morphology of the seedlings was seen only by the substrates. In relation to the radial biomass, we verified that seedlings produced on the HOR substrate presented RFM and RDM superior in 77% and 97%, respectively, in relation to the seedlings produced in the TNG and CRH substrates (Table 4).

Table 4. Effect of substrates on the biomass of the roots of tomato seedlings.

Substrates[1]	RFM[2] (g)	RDM (g)
HOR	0.58±0.29 a	0.021±0.001 a
TNG	0.13±0.11 b	0.006±0.001 b
CRH	0.14±0.07 b	0.006±0.001 b
Mean	0.28	0.011
CV (%)[3]	36.77	28.28

Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ significantly by the Tukey test ($p \leq 0.05$, $n = 4$). [1]HOR: Horta 2®; TNG: TN Gold®; CRH: carbonized rice husk. [2]RFM: root fresh mass; RDM: root dry mass. [3]Coefficient of variation.

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

Regarding to the root system morphology, we observed that seedlings produced on the HOR substrate presented TL, SA, RV and VTR, FR and TR superior in 47%, 69%, 72% 63%, 66% and 78%, respectively, in relation to the seedlings produced on the other two substrates (Table 5).

Table 5. Effect of substrates on the root morphology of tomato seedlings – Passo Fundo, 2019.

Substrate[1]	TL (cm)[2]	SA (cm²)	RV (cm³)	VTR (cm)	FR (cm)	TR (cm)
HOR	134.9±72.28 a	22.8±9.46 a	0.33±0.07 a	98.84±18.27 a	32.03±5.11 a	3.98±0.41 a
TNG	46.44±19.46 b	7.35±3.00 b	0.10±0.06 b	34.37±17.04 b	10.91±3.10 b	1.12±0.29 b
CRH	48.70±24.22 b	6.77±1.92 b	0.08±0.02 b	37.32±22.35 b	10.72±2.85 b	0.62±0.09 b
Mean	76.68	12.30	0.17	56.84	17.89	1.91
CV (%)[3]	29.28	31.32	29.77	31.67	30.07	43.88

Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ significantly by the Tukey test ($p \leq 0.05$, $n = 4$). [1]HOR: Horta 2®; TNG: TN Gold®; CRH: carbonized rice husk. [2]TL: total root length; SA: root surface area; RV: root volume; VTR: very thin roots; FR: fine roots; TR: thick roots. [3]Coefficient of variation.

We did not verify the effect of cultivars or of the cultivar-substrate interface regarding to the seedling quality. However, seedlings produced on the HOR substrate presented higher DQI by 72% when compared to seedlings produced in TNG and CRH (Figure 3).

Discussion

Here, we showed that the seedling quality of tomato cultivars was not associated with the types of substrates studied. However, our study proved that substrates with greater water retention potentiated the seedling development. Thus, the physical characterization of the substrates used in the seedling production allows the selection of materials with greater water availability, with the purpose of increasing the quality of the seedlings produced and establishing an appropriate management to enhance the tomato production chain.

The higher quality of the seedlings produced in the HOR substrate was attribute to the higher availability of water of this material (Figure 2), because the water retention capacity of the substrates influences the growth and development of the seedlings (GRACESON et al., 2013), covering the shoot morphology (PREVEDELLO; ARMINDO, 2015) and the root system morphology (FERRAZ; CENTURION; BEUTLER, 2005). In practice, the data referring to the root system morphology (Table 5) indicated that the tomato seedlings produced on the HOR substrate have a more structured lump, which improves seedling sustainability after transplanting and increases plant survival. As in CRH there is predominance of large particle sizes, this impairs water retention

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

by the material (ZORZETO et al., 2014), which explained the lower quality of the seedlings produced in this substrate.

The higher the seedling quality, the greater the plant robustness and the lower their susceptibility to ecophysiological stresses after transplantation. Through Dickson quality index (DQI), we found that more robust seedlings were produced on the HOR substrate (Figure 3). Higher values for this attribute were found in horticultural and forest species (DORNELLES et al., 2014; MOTA et al., 2016), probably due to the different environmental conditions of seedling production. During the seedling production we observed that PAR mean (367.13 µmol m^{-2} s^{-1}) was below the ideal for the tomato, which corresponds to the range of 477 to 517 µmol m^{-2} s^{-1} (ROCHA, 2007). This may have reduced the photosynthetic rate of the plants, reducing accumulations of biomass and, therefore, DQI values.

As in our study, other works showed greater growth and development of tomato seedlings produced on substrates with greater water retention (COSTA et al., 2007), as we verified in HOR, and lower performance for seedlings produced on substrates with low water availability (MONTEIRO NETO et al., 2018), as noted in CRH. However, our results differ from the other studies with tomato seedlings because we analyzed in detail the roots [CT (cm), AS (cm^2), VR (cm^3), RMF (cm), RF (cm) and RG (cm)] with aid of the WinRHIZO® software (Table 5). Plants/seedlings that have more fine roots, as seen in tomato seedlings produced in HOR (Table 5), generally have better growth/development, as showed in our study (Table 4 and Figure 3), because these roots are the ones that more acquire and use the resources available in the growth medium (MCCORMACK et al., 2015).

Considering the physicochemical characterization of the substrates, the chemical properties are less relevant than the physical properties (BELDA; LIDÓN; FORNES, 2016). This is because plants are provided with nutritional solutions, via fertirrigation, according to the need of the cultivated species. However, the physical quality of the substrates must still be weighed in the choice of materials. The density of the substrates, for example, is linked to plant stability (NOYA et al., 2017). Very light substrates (<100 kg m^{-3}) do not sustain plants and very dense substrates (>300 kg m^{-3}) impair the root growth of seedlings due to mechanical impediment (DE BOODT; VERDONCK, 1972). In addition, a common problem in substrates is insufficient aeration (NEMATI et al., 2002) and, therefore, the seedling producer should choose materials with higher aeration levels to improve root growth and increase the acquisition of water and nutrients by seedlings (JONES; DOLAN, 2012).

In this study, although the genotype did not have a significant influence on plant growth and development, the type of substrate enhanced the seedling quality. The findings of our study can be useful to support the choice of substrates by seedling producer so that these professionals can produce better quality seedlings. Thus, it will be possible to meet the demands of tomato producers increasingly demanding, who are

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

PESQUISA AGROPECUÁRIA GAÚCHA
doi: https://doi.org/10.36812/pag.2020261319-331

looking for more robust seedlings, with higher survival rates and better adaptation of plants after transplantation in the growing environment. Seedlings with a more developed root system and larger stem diameter, as seen in those produced in HOR (Tables 3 and 5), suffer less from abiotic and biotic stresses after transplantation (GROSSNICKLE, 2005). Thus, in order to maximize the quality of the tomato seedlings produced, seedling producer must obtain the physical characterization of the substrates, selecting materials with greater water retention capacity. Still, the use of plant development models contributes to improving the quality standard of the seedlings produced. Finally, these investigations are filling the gap between the quality of tomato seedlings related to substrate water retention.

Conclusions

We conclude that substrates with greater water retention promote greater seedling growth and development. We emphasize that the use of development models can be an alternative to analyze the seedlings quality provided to producers in order to increase tomato production. We suggest to seedling producer that, prior to the seedling production; perform physical analysis of the substrates, selecting materials with greater water availability, regardless of the cultivars used. However, considering that some horticulturists do not have the resources and/or infrastructure to characterize the substrates, we recommend that substrate producers sell materials with a clear label, informing the physical and chemical characteristics of the substrate, so that seedling and tomato producers can establish an adequate management to enhance the tomato production chain.

References

AULER, A.C. et al. Lettuce seedlings development index in different substrates using multivariate analysis. **Científica**, v. 43, n. 1, p. 50-57, 2015.

BELDA, R. M.; LIDÓN, A.; FORNES, F. Biochars and hydrochars as substrate constituents for soilless growthof myrtle and mastic. **Industrial Crops and Products**, v. 94, p. 132-142, 2016.

BÖHM, W. **Methods of studying root systems**. Berlin: Springer-Verlag, 1979. 188 p.

BRASIL. Instrução normativa n. 17, de 21 de maio de 2007: aprova os métodos analíticos oficiais para análise de substratos e condicionadores de solos e revoga a Instrução Normativa n.46, de 12 de setembro de 2006. **Diário Oficial da União**, Brasília, n. 99, Seção 1, p. 8, 2007.

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Manual de métodos analíticos oficiais para fertilizantes minerais, orgânicos, organominerais e corretivos** / Ministério da Agricultura, Pecuária e Abastecimento. Secretaria de Defesa Agropecuária. Coordenação-Geral de Apoio Laboratorial; Murilo Carlos Muniz Veras (Org.) – Brasília: MAPA/SDA/CGAL, 2014. 220 p.

CHIOMENTO, J. L. T. et al. Water retention of substrates potentiates the quality of lettuce seedlings. **Advances in Horticultural Science**, v. 33, n. 2, p. 197-204, 2019.

COSTA, C. A. et al. Fibra de coco e resíduo de algodão para substrato de mudas de tomateiro. **Horticultura Brasileira**, v. 25, p. 387-391, 2007.

COSTA, E. et al. Production of tomato seedlings using different substrates and trays in three protected environments. **Engenharia Agrícola**, v. 32, n. 5, p. 822-830, 2012.

DE BOODT, M.; VERDONCK, O. The physical properties of the substrates in floriculture. **Acta Horticulturae**, v. 26, n. 1, p. 37-44, 1972.

DICKSON, A.; LEAF, A. L.; HOSNER, J. F. Quality appraisal of white spruce and white pine seedling stock in nurseries. **The Forestry Chronicle**, v. 36, n. 1, p. 10-13, 1960.

DORNELLES, P. et al. Production and quality of *Anacardium othonianum* Rizz. seedlings grown in different substrates. **Revista Brasileira de Fruticultura**, v. 36, n. 1, p. 195-202, 2014.

FERMINO, M. H.; KÄMPF, A. N. Densidade de substratos dependendo dos métodos de análise e níveis de umidade. **Horticultura Brasileira**, v. 30, n. 1, p. 75-79, 2012.

FERRAZ, M. V.; CENTURION, J. F.; BEUTLER, A. N. Caracterização física e química de alguns substratos comerciais. **Acta Scientiarum. Agronomy**, v. 27, n. 2, p. 209-214, 2005.

GRACESON, A. et al. The water retention capabilities of growing media for green roofs. **Ecological Engineering**, v. 61, p. 328-334, 2013.

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

GROSSNICKLE, S. C. Importance of root growth in overcoming planting stress. **New Forests**, v. 30, p. 273-294, 2005.

IBGE. Instituto Brasileiro de Geografia e Estatística. **Estatística mensal da produção agrícola:** levantamento sistemático da produção agrícola, fevereiro de 2018. Disponível em: https://agenciadenoticias.ibge.gov.br/media/com_mediaibge/arquivos/62ff13bdd3554efec8535a90712651b9.pdf.

JONES, V. A. S.; DOLAN, L. The evolution of root hairs and rhizoids. **Annals of Botany**, v. 110, n. 2, p. 205-212, 2012.

KÄMPF, A. N.; FIOR, C. S.; LEONHARDT, C. Lowering pH value with elemental sulfur in the substrate for *ex vitro* acclimatization. **Acta Horticulturae**, v. 812, p. 415-420, 2009.

KÄMPF, A. N.; TAKANE, R. J.; SIQUEIRA, P. T. V. **Floricultura:** técnicas de preparo de substratos. Brasília: LK Editora e Comunicação, 2006. 132 p.

LEMAIRE, F. Physical, chemical and biological properties of growing medium. **Acta Horticulturae**, v. 396, p. 273-284, 1995.

MAROUELLI, W. A.; SILVA, W. L. C. Irrigação por gotejamento do tomateiro industrial durante o estádio de frutificação, na região do cerrado. **Horticultura Brasileira**, v. 24, p. 342-346, 2006.

MCCORMACK, M. L. et al. Redefining fine roots improves understanding of below-ground contributions to terrestrial biosphere processes. **New Phytologist**, v. 207, p. 505-518, 2015.

MONDRAGÓN-VALEROA, A. et al. Physical mechanisms produced in the development of nursery almond trees (*Prunus dulcis* Miller) as a response to the plant adaptation to different substrates. **Rhizosphere**, v. 3, p. 44-49, 2017.

MONTEIRO NETO, J. L. L. et al. Seedlings production of two tomato (*Solanum lycopersicum* L.) cultivars under different environments and substrates. **Acta Agronómica**, v. 67, n. 2, p. 270-276, 2018.

PESQ. AGROP. GAÚCHA, v.26, n.1, p. 319 - 331, 2020
ISSN: 0104-907. ISSN online: 2595-7686

Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.

doi: https://doi.org/10.36812/pag.2020261319-331

MOTA, C. S. et al. Growth, nutrition and quality of *Pouteria garderiana* (A. DC.) Radlk. seedlings produced in organic substrates. **Cerne**, v. 22, n. 4, p. 373-380, 2016.

NEMATI, M. R. et al. Determining air entry value in peat substrates. **Soil Science Society of America Journal**, v .66, p. 367-373, 2002.

NOYA, M. G. et al. Substrates for cultivating herbaceous perennial plants in extensive green roofs. **Ecological Engineering**, v. 102, p. 662-669, 2017.

PREVEDELLO, C. L.; ARMINDO, R. A. **Física do solo com problemas resolvidos**. 2. ed. Curitiba: C. L. Prevedello, 2015. 474 p.

ROCHA, R.C. **Uso de diferentes telas de sombreamento no cultivo protegido do tomateiro**. Botucatu: Unesp, 2007. 90 p. Tese (Doutorado em Agronomia) – Programa de Pós-Graduação em Agronomia (Horticultura). Faculdade de Ciências Agronômicas, Universidade Estadual Paulista "Júlio de Mesquita Filho".

SILVA, R. R. et al. Influência de casca de arroz carbonizada em diferentes substratos na qualidade de mudas de tomateiro. **Revista Brasileira de Ciências Agrárias**, v. 7, p. 803-809, 2012.

SMIDERLE, O. J. et al. Produção de mudas de alface, pepino e pimentão em substratos combinando areia, solo e Plantmax®. **Horticultura Brasileira**, v. 19, n. 3, p. 253-257, 2001.

WATTHIER, M. et al. Production of lettuce seedlings in substrates with tung compost, carbonized rice husk and earthworm húmus. **Horticultura Brasileira**, v. 35, n. 2, p. 174-179, 2017.

ZHAO, X. et al. Estimation of the seedling vigor index of sunflowers treated with various heavy metals. **Journal of Bioremediation & Biodegradation**, v. 7, n. 3, 2016.

ZORZETO, T. Q. et al. Caracterização física de substratos para plantas. **Bragantia**, v. 73, n. 3, p. 300-311, 2014.

ISSN: 0104-907. ISSN online: 2595-7686
Recebido em 26 jul. 2020.
Aceito em 30 set. 2020.