SEMINA
Ciências Agrárias

DOI: 10.5433/1679-0359.2021v42n2p471

Fruit production and quality of mini-watermelon with different number of stems, in troughs cultivation system and substrate reuse

Produção e qualidade de frutos de minimelancia com diferentes números de hastes, em sistema de cultivo em calhas e reutilização de substrato

Josiéle Garcia Dutra[1]*; Roberta Marins Nogueira Peil[2]; Tatiana da Silva Duarte[3]; Cesar Valmor Rombaldi[4]; Paulo Roberto Grolli[5]; Aline Soares Pereira[6]; Athos Odin Severo Dorneles[7]

Highlights

Troughs system with raw rice husk for mini-watermelon.
Feasibility of reusing the substrate for mini-watermelon in the second cycle.
Stem number effects on the productivity and quality of mini-watermelon.

Abstract

Substrate-filled pots are growing systems commonly used for vegetable farming. However, few are the studies available relating them to mini-watermelon cultivation. Our study presents a growing system using substrate-filled troughs and leachate recirculation as a low-cost and less environmentally harmful soilless cultivation system for mini-watermelons. For a growing system to be viable and provide high fruit yield and quality, several aspects must be studied, including substrate physical properties and reuse potential in successive crops, besides plant management-related aspects. Therefore, our goal was to evaluate the effects of a trough system and substrate reuse on changes in the properties of raw rice husk and on fruit

[1] Technologist in Fruticulture, M.e in Agronomy, Postgraduate Program in Family Agricultural Production Systems, Federal University of Pelotas, UFPel, Capão do Leão, RS, Brazil. E-mail: josigardu19@gmail.com
[2] Profª Drª, Department of Crop Production, UFPel, Capão do Leão, RS, Brazil. Brazilian National Council of Technologic and Scientific Development Researcher, CNPq. E-mail: rmpeil@ufpel.edu.br
[3] Profª Drª, Department of Horticulture and Silviculture, Federal University of Rio Grande do Sul, UFRGS, Porto Alegre, RS, Brazil. E-mail: tatiana.duarte@ufrgs.br
[4] Prof. Dr., Department of Agroindustrial Science and Technology, UFPel, Capão do Leão, RS, Brazil. Brazilian National Council of Technologic and Scientific Development Researcher, CNPq. E-mail: cesarvrf@ufpel.edu.br
[5] Prof. Dr., Department of Crop Production, UFPel, Capão do Leão, RS, Brazil. E-mail: prgrolli@ufpel.tche.br
[6] Biologist, Student of the Doctoral Course at Postgraduate Program in Family Agricultural Production Systems, UFPel, Capão do Leão, RS, Brazil. E-mail: lyne_asp@hotmail.com
[7] Biologist, Dr. in Plant Physiology, UFPel, Department of Biology, Capão do Leão, RS, Brazil. E-mail: athos_odin@hotmail.com
* Author for correspondence

Received: Oct. 04, 2019 - Approved: Dec. 14, 2020

yield and quality for mini-watermelons at different stem training. To this purpose, two trials were conducted using nutrient solution recirculation systems. In the first, we evaluated the effects of pot and trough systems. In the second, first- and second-use substrates were compared in the trough system. In both trials, one and two-stem training systems were analyzed. The results of the first trial show that the trough system had a greater positive impact on substrate water holding capacity (WHC), which increased from 7.9 to 15.6%, while the pots increased substrate WHC only to 11.2%. However, both systems neither affected fruit yield (8 kg/m² on average) nor fruit quality. The two-stem training promoted higher fruit yields (4.2 kg/plant) and contents of total soluble solids - TSS (11.4 ºBrix) but did not affect average fruit weight. Moreover, the one-stem training provided higher fruit number (7.3 fruits/m²) and fruit yield (9.7 kg/m²). In the second trial, the reused substrate showed a higher WHC (12.4%) than the one used for the first time (9.9%). The reused substrate also provided better results in terms of fruit yield and quality (5.9 fruits/m², 5.3 kg/m², and 10.5 ºBrix). In the second trial, two-stem training also increased average fruit weight, and hence yields per plant. Nevertheless, the stem number did not affect fruit number per plant, fruit yield per square meter, and fruit quality.
Key words: *Citrullus lanatus.* Pot cultivation. Fruit yield and quality. Leachate recirculation.

Resumo

O cultivo em vasos com substrato é uma técnica em expansão na produção de hortaliças, porém, para minimelancias, poucos estudos estão disponíveis. Este trabalho introduz o sistema de calhas preenchidas com substrato e com recirculação do lixiviado para esta cultura, como uma alternativa de baixo custo e menor impacto ambiental. Para que o sistema seja viável e possibilite boa produtividade e qualidade dos frutos, vários aspectos devem ser estudados, entre estes, as características físicas do substrato, a possibilidade de reutilizá-lo em cultivos sucessivos e o manejo adequado das plantas. O objetivo do trabalho foi estudar o efeito do sistema de cultivo e da reutilização sobre as alterações das propriedades do substrato de casca de arroz in natura, a produção e a qualidade de frutos de plantas de minimelancia cultivadas com diferentes números de hastes. Dois experimentos, empregando sistemas com recirculação da solução nutritiva, foram realizados. No primeiro, as plantas foram cultivadas em vasos e calhas. No segundo, foram comparados substratos de primeiro e segundo uso no cultivo em calhas. Em ambos os experimentos, foi estudada a condução das plantas em uma e duas hastes. Em relação aos resultados obtidos, no primeiro experimento, o sistema de calhas teve maior impacto positivo sobre as características físicas do substrato, cuja capacidade de retenção de água (CRA) passou do valor inicial de 7,9% para 15,6% ao final, enquanto que nos vasos se elevou a 11,2%. Porém, os sistemas não afetaram a produtividade, com média de 8 kg/m², e a qualidade dos frutos. As plantas de duas hastes apresentaram maior produção de frutos (4,2 kg/planta), com maior conteúdo de sólidos solúveis totais - SST (11,4 ºBrix), ainda que sem efeito sobre o peso médio. Porém, as plantas de uma haste apresentaram maior número (7,3 frutos/m²) e produção de frutos (9,7 kg/m²). No segundo experimento, o substrato de 2º uso apresentou maior CRA (12,4%) que o substrato novo (9,9%) e proporcionou melhores resultados de produtividade e qualidade para a maioria das variáveis estudadas, obtendo-se 5,9 frutos e 5,3 kg/m², com SST de 10,5 ºBrix. As plantas de duas hastes tiveram resultados melhores de peso médio de frutos e, consequentemente, de produção por planta do que as plantas de uma haste, sem efeitos sobre o número de frutos/planta, o rendimento por m^2 e a qualidade.
Palavras-chave: *Citrullus lanatus.* Cultivo em vasos. Rendimento e qualidade de frutos. Recirculação do lixiviado.

Introduction

Due to immoderate use of inputs and soil diversity in Brazil, conventional vegetable cultivation has faced problems such as soil salinization (Goto, Hora, & Demant, 2005) and high degree of contamination by pathogens. In this sense, substrate cultivation facilitates phytosanitary measures and disassociates crop yield from soil quality. However, this practice has not yet been tested for mini-watermelon cultivation in southern Brazil.

Among the substrate cultivation systems, fruit-vegetable growers have mostly used free-drainage pots, which waste nutrient solution. However, in a “closed” system (i.e., with nutrient solution recirculation), pots represent extra costs and impairment. This is because pots must be arranged along collection troughs, which must be sealed to avoid solar radiation incidence on the collected solution. Some farmers and researchers have suggested using troughs as substrate containers since they allow easy leachate collection and renewal. A cultivation trough serves both as a substrate container and as a solution drainage channel. This system has already been successfully used for several vegetables such as strawberries (Peil & Signorini, 2018), tomatoes (Perin et al., 2018), and pickled cucumbers (Neutzling, 2018).

In this study, we proposed a trough system with leachate recirculation that allows using pots economically and with reduced environmental contamination. However, several aspects must be observed for a system to be viable and provide high fruit yield and quality. Among them are substrate physical properties –which can be altered due to different factors, potential reuse of substrate in successive crops, and finally suitable plant management.

Substrates play a fundamental role in cultivation systems. Thus, their physical properties must be well known so that the best materials could be selected (Kämpf, 2005). Raw rice husk is widely available in southern Brazil and requires no prior preparation or environmental license for handling. It has low water retention capacity, which is not a problem in closed systems. Moreover, this problem can be solved by increasing nutrient solution supplies, which could be made without wastes since large leachate volumes can be collected and reused. Rice husk can be used in successive cycles, without damage to yield or quality, as already verified for mini-tomatoes (Rosa et al., 2016) and pickled cucumber (Neutzling, 2018). Nevertheless, studies on its use and reuse as a substrate in mini-watermelon are still unknown.

In a new cultivation system, plant management must be adequate for it to succeed. In this context, vertical systems have been adopted to enhance greenhouse space use. Such a system, associated with the high costs of mini watermelon seeds, must be adapted in terms of the number of stems to be trained per plant, as it has usually been a conditioning factor for fruit yield and final quality.

In this sense, two stems watermelons normally develop larger leaf areas (Gomes, Santos, Braz, Andrade, & Monteiro, 2019), thus wider transpiration surfaces. Moreover, having two apical meristems, whose tissues are the main auxin synthesizers (Taiz & Zeiger, 2006), contributes to a more robust root system when compared to one stem plants. Together, these factors increase plant demand for the nutrient solution. Thus, to show if cultivation with two stems plants training is really viable (reducing seed costs while maintaining yield per unit area), comparative studies between one- and two stems plants should be carried under the same stem density, but with twice the number of one stem plants. Such a condition would imply larger substrate colonization by roots of one stem plants, which would have a greater water absorption capacity within the same substrate volume.

Parallel studies have indicated that both pot and trough cultivation systems (Perin et al., 2018) and substrate reuse (Neutzling, 2018) can alter the physical properties related to water availability in raw rice husks (e.g., total porosity and maximum water retention capacity), thus affecting plant productive responses.

As ours is one of the first studies on the subject, little bibliographic reference was found, reducing the possibility of comparisons. Therefore, our study was guided by the following hypotheses: 1) a trough system and raw rice husk reuse improve substrate physical properties, enhancing productive responses compared to a pot system and first-use substrate; 2) both one- and two stems training systems can affect substrate physical properties at the end of cultivation; 3) each stem of a two stems plant has productive behavior similar to that of one one stem plant, leading to similar yields per unit area; and 4) plant responses to stem numbers is conditioned to the growing system and substrate reuse.

Based on the above, our objective was to evaluate the effect of both growing systems and substrate reuse on changes in the physical properties of raw rice husk and on fruit yield and quality for mini-watermelons at different stem training.

Materials and Methods

Two trials were carried out at the didactic experimental field of the Department of Crop Production, Agronomy College “Eliseu Maciel,” Campus Capão do Leão, Federal University of Pelotas, RS, Brazil (31° 52′ S, 52° 21′ W, and 13-m altitude). The first trial was performed from October 25, 2018, to January 14, 2019, and the second from February 10, 2019, to April 23, 2019. Both were carried out in a greenhouse covered with 150 μm thick polyethylene film, with dimensions of 10 x 21 m (210 m^2). All handling was done daily by opening and closing, always attentive to rainy and windy days.

Polystyrene trays were filled with Carolina Soil® substrate, containing one seed each. After emergence, plants were fertigated by sub-irrigation with a nutrient solution at 50% of its recommended concentration. After reaching 4 to 6 leaves, they were transplanted to growing troughs. The system consisted of six wooden cultivation troughs (0.30 m wide, 0.15 m high, and 7.5 m long) arranged in 1.2 m apart double rows, which comprised two troughs spaced 0.5 m apart. The structure was covered with a black-white plastic film and installed a sloping at 4% to facilitate nutrient solution flow towards 500 L catchment tanks, which were buried at the bottom end of each system (one for every 3 troughs).

In the first trial (October 25, 2018, to January 14, 2019), we evaluated the two growing systems, pots and troughs. The pots were filled with 7 L raw rice husk, which was placed onto a 2 cm medium gravel layer, which was directly on the perforated base of pots. These pots were placed along the above-described troughs. For the trough system, the plastic-coated troughs were directly filled with a 10-cm layer of raw rice husk, totaling 225 L in each trough.

Based on the results of the first trial, we chose the trough system to assess the effects of substrate reuse in the second trial (February 10 to April 23, 2019). To this end, we removed the pots used in the first trial and cleaned the respective troughs, which were then filled with raw raw rice husk material, just as done in the trough system evaluated previously. These comprised the plots destined for evaluations of the first-use substrate. For the second-use substrate, we used the trough system previously assessed, after removing plants by cutting them at the base.

In both trials, after placing the substrate into the troughs, it was irrigated continuously for 1 week to remove its possible impurities. Fertirrigation rates were adjusted according to water demands in each experimental period. For that purpose, a ½ hp circulation pump was coupled to each tank to propel nutrient solution to the upper part of the troughs. Thereafter, irrigation was supplied through polyethylene hoses and drippers, at flow rates of 1.6 L/h, and then drained and collected back to the tanks, thus forming a closed system.

The nutrient solution was composed of the following macronutrients (in mmol l^{-1}): NO_{3-} (12.8), H_2PO_4- (1.4), SO_4^{-2} (2.0), NH^{4+} (0.8), K^+ (6.0), Ca^{+2} (4.0), and Mg^{+2} (1.7) (Requena, 1999). The micronutrients in the solution were the following (in mg L^{-1}): Fe (4.0), Mn (0.56), Zn (0.26), Cu (0.03), Mo (0.22), and B (0.05) (Casas-Castro, 1999). Solution conductivity and pH were monitored daily using digital manual conductivimeter and pH meter, respectively; these parameters were maintained at 1.8 dS/m and between 6.0 and 7.0, respectively.

In both trials, we evaluated the influence of one- and two stems training systems. For this purpose, plants were arranged in single rows spaced 0.40 m apart for one stem plants and 0.80 m apart for two stems plants, which resulted in plant densities of 2.90 and 1.45 plants/m², respectively, but both containing 2.90 stems/m².

The one stem plants were trained by the main stems. In this training, only lateral shoots from the 8th to the 10th leaves were allowed to develop. Also, only three fruits per plant were allowed to grow in lateral shoots, which were above the 11th leaf axil of the main stem.

For the two stems plants, when they had from four to five fully true leaves, their main stems were trimmed. From that point onwards, two secondary stems were selected for training. These stems were trained as were the main stems of the one stem plants. However, in this training, three fruits per stem were allowed to develop, totaling six fruits per plant.

The mini-watermelon vines were trained using a proper trellis, and fruits were suspended with the aid of plastic nets attached to the trellis. Cleaning pruning was performed by eliminating senescent leaves in the lower part of the plants.

Both trials were carried out in a 2x2 factorial split-plot design, with four treatments and six replications. The growing system in the first trial and substrate reuse in the second were allocated to plots with 12 plants. Whereas plant stem training was allocated to subplots with six plants. Two plants per replication were evaluated, excluding the border plants. Fruit yield components [average fruit weight and crop yield (kg/plant and kg/m²)] were determined using data on harvested fruit number, fruit fresh matter, and planting density.

As for fruit quality, contents of total soluble solids and titratable acidity were evaluated at the Post-Harvest Laboratory of the Department of Agroindustrial Science and Technology, Federal University of Pelotas (FAEM/UFPEL).

At the beginning and end of both trials, three substrate samples were taken from each treatment and sent to the Laboratory of Substrate Analysis of the Federal University of Rio Grande do Sul (UFRGS) (81 and 72 days after transplantation, respectively). These samples were used to determine the following physical properties: total porosity (TP), dry density (DD), water holding capacity (WHC), aeration space (AS), remaining water (RW), and easily available water (EAW). Substrate density was also ascertained using the Self-compacting Method (Hoffmann, 1970), while water retention curves at 0, 10, 50, and 100 hPa were determined using tension funnels (Boodt & Verdonck, 1972). The substrate temperature was monitored by a thermohydrometer, which was in a meteorological shelter installed in the middle of the greenhouse area. Global solar radiation data were obtained from a climatological station located 1,000 m from the greenhouse (Table 1).

All results were subjected to analysis of variance and averages compared by the Tukey's test (p≤ 0.05), using the Sisvar® statistical analysis software.

Table 1
Physical characteristics of the raw rice husk substrate before and after the cultivation of mini-watermelon plants in pots or troughs and in substrates for 1st and 2nd use, with one stem and two stems.

	New raw rice husk					
	WHC (%)	DD (kg/m^3)	TP (%)	AS (%)	EAW (%)	RW (%)
	7.92	107.35	66.71	59.79	0.26	7.58
	System × Number of stems					
	WHC (%)	DD (kg/m^3)	TP (%)	AS (%)	EAW (%)	RW (%)
System						
Pots		80.3 ns	72.9 b	61.7 ns	2.1 b	9.1 b
Troughs		82.7	78.8 a	63.2	3.1 a	12.4 a
Nº of stems***						
1		81.8 ns	75.1 ns	61.6 ns	2.8 a	10.7 ns
2		81.1	76.6	63.3	2.4 b	10.8
CV (%)		2.8	2.3	2.8	6.1	2.9
	WHC10 (%)					
	System					
Nº of stems	Pots			Troughs		
1	11.6 b A**			15.5 a A		
2	10.8 b B			15.7 a A		
CV (%)	1,6					

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Substrate × Number of stems						
	WHC (%)	DD (kg/m³)	TP (%)	AS (%)	EAW (%)	RW (%)
Substrate						
1st use	9.9 b*					7.9 b
2nd use	12.4 a					10.4 a
Nº of stems						
1	11.4^{ns}					9.0^{ns}
2	11.0					9.2
CV (%)	1.3					2.2

	DD (kg/m³)		TP (%)	
	Substrate			
Nº of stems	1st use	2nd use	1st use	2nd use
1	77.9 b B**	83.3 a A	73.0 a A	71.6 a B
2	82.9 a A	77.2 b B	64.6 b B	77.8 a A
CV (%)	1,4		2,1	
	AS (%)		EAW (%)	
	Substrate			
Nº of stems	1st use	2nd use	1st use	2nd use
1	62.9 a A	59.0 b B	1.9 b A	2.5 a A
2	54.7 b B	65.7 a A	2.0 a A	1.3 b B
CV (%)	2.6		5.1	

Means followed by "ns" do not show a significant difference (P> 0.05), for each factor evaluated. * Means followed by different letters in the column, differ from each other (P <0.05), for each factor evaluated; ** Means followed by a lower case letter in the line refer to the system/substrate factor, and means followed by a capital letter in the column refer to the number of stems factor. *** Plants of one stem were grown at a density of 2.9 plants/m² and plants of two stems at a density of 1.45 plants/m². WHC10: water holding capacity at 10 cm depth; DD: dry density; TP: total porosity, AS: aeration space; EAW: easily available water, RW: remaining water.

Results and Discussion

The analysis of variance showed no interaction between growing systems and plant stem training for none of the substrate physical properties but WHC. However, significant interactions were observed between substrate use and stem training for most of the physical properties of the substrate (DD, TP, AS, and EAW) but RW and WHC.

After both trials, EAW, WHC, and TP showed significant increases, while DD decreased (Table 1). Regardless of the factor (growing system and plant stem training), treatments did not differ for DD and AS, which showed averages of 81.5 kg/m³ and 62.5%, respectively (Table 1). On average, between both growing systems, substrate DD decreased by 24%, and AS slightly increased by 4.5% (Table 1).

An isolated analysis of the effects of growing systems indicated that substrates from trough cultivation had TP, EAW and RW averages higher than those of pot cultivation

(Table 1). At the beginning of cultivation, substrates in trough system had TP and EAW increases of 18 and 110% (one and two stems, respectively), while increases in pot system were of 9 and 71% (one and two stems, respectively). When compared to before cultivation, WHC increased by 42% (from 7.9% to 11.2%) in the pot system, while it raised by 97% (from 7.9% to 15.6%) in the trough system (Table 1).

For one stem plants, substrate EAW had an average higher than that for two stems plants. However, the other substrate properties (Table 2) were not influenced by stem number in the second trial (cultivation systems x plant stem training).

Table 2
Effect of the cultivation system, the reuse of the substrate of the raw rice husk and the number of stems of the plant on the components of productivity and total soluble solids (SST) of mini-watermelon fruits.

	Number of fruits/ plant	Average mass of fruits	Fruit production (kg/plant)	Number of fruits/m^2	Yield of fruits kg/m^2	TSS (°Brix)
System × Number of stems						
System						
Pots	2.6 ^{ns}	1.4 ^{ns}	3.7 ^{ns}	5.6 ^{ns}	7.9 ^{ns}	10.2 ^{ns}
Troughs	2.8	1.4	3.9	5.8	8.0	11.2
Nº of stems**						
1	2.5 ^{ns}	1.4 ^{ns}	3.4 b	7.3 a	9.7 a	11.4 a
2	2.9	1.5	4.2 a	4.2 b	6.1 b	10.0 b
CV (%)	16.7	14.8	15.6	17.1	15.2	8.2
Substrate × Number of stems						
Substrate						
1st use	1.0 b*	0.72 b	0.8 b	2.2 b	1.7 b	9.7 b
2nd use	2.7 a	1.0 a	2.6 a	5.9 a	5.3 a	10.5 a
Nº of stems						
1	1.8 ^{ns}	0.7 b	1.4 b	5.3 a	4.0 ^{ns}	10.1 ^{ns}
2	1.9	1.0 a	2.1 a	2.8 b	3.0	10.1
CV (%)	32.0	18.9	31.1	37.0	35.8	3.7

Means followed by “ns” do not show a significant difference (p> 0.05), for each factor evaluated. *Means followed by different letters in the column, differ from each other (p <0.05), for each factor evaluated. **Plants of one stem were grown at a density of 2.9 plants/m^2 and plants of two stems at a density of 1.45 plants/m^2. TSS: total soluble solids.

Still, regarding substrate changes, plant stem training affected most of the substrate properties differently when comparing first- and second-use substrates (Table 1). Considering the first-use substrate, one-stem training increased TP to 73%, while two stems reduced it to 64.6%. Yet, for second-use substrate (reused once), average TP was 74.4%, which corresponds to a 12% increase compared to its first use at the beginning of cultivation. However, the average TP of the first-use substrate was 68.8%, which represented an increase of only 3.2%.

In terms of EAW, all treatments showed higher values compared to those of the substrate of the beginning of cultivation. A comparative analysis among treatments at the end of cultivation showed that EAW did not affect stem training on first-use substrate treatments. Otherwise, one-stem training increased EAW of second-use substrates (Table 1).

Second-use substrate promoted significant increases in WHC and RW compared to the first-use substrate, regardless of stem training (Table 1). On average, WHC in second-use substrate increased to 12.4%, which stands for a 56% rise when compared to the beginning of cultivation. On the other side, in the first-use substrate, this rise was of 26% only (from 7.9% to 9.9%). Regarding RW, increases were from 7.6% at the beginning of cultivation to 7.9 and 10.4% in first- and second-use substrates, respectively. These represent increments of 3.7 and 36% compared to the raw rice husk material.

Just as observed for substrates, the analysis of variance showed no significant interaction between cultivation system and stem training for yield parameters (e.g., fruit number and weight per plant and per square meter, average fruit weight, and TSS), allowing individual analysis of effects (Table 2). However, an interaction between TA and TSS/TA ratio was noted (Table 3).

Table 3
Effects of cultivation in pots or troughs, on a substrate of 1st and 2nd use, with one and two stems in the titratable acidity (TA; g 100 mL) and total soluble solids/titratable acidity ratio of (TSS/TA) of mini-watermelon fruits.

System × Number of stems				
	TA (g 100 mL)		TSS/TA ratio	
System	Pots	Troughs	Pots	Troughs
1 stem	0.13 b B*	0.24 a B	88.66 a A	49.32 b A
2 stems	0.49 a A	0.37 b A	18.57 b B	30.48 a B
CV (%)	13.5		12.4	
Substrate × Number of stems				
	TA (g 100 mL)		TSS/TA ratio	
Substrate				
1st use	0.2 ^{ns}		59.4 ^{ns}	
2nd use	0.2		59.5	
Nº of stems**				
1	0.2 ^{ns}		58.3 ^{ns}	
2	0.2		60.6	
CV (%)	25.5		24.4	

Means followed by "ns" do not show a significant difference (p> 0.05), for each factor evaluated. * Means followed by different letters in the column, differ from each other (p <0.05), for each factor evaluated. **Plants of one stem were grown at a density of 2.9 plants/m^2 and plants of two stems at a density of 1.45 plants/m^2.

The trough cultivation system did not differ from pot system in terms of yield and TSS (Table 2), and averages were 2.7 fruits/plant, 1.4 kg average fruit weight, 3.8 kg/plant fruit yield, 5.7 fruits/m^2, 7.9 kg fruits/m^2, and 10.7 ºBrix.

One stem and two stems plants showed similar fruit numbers per plant and average fruit weights (2.7 and 1.4 kg/fruit, respectively), but two stems plants had a higher yield (4.2 kg/plant) than one stem ones (3.4 kg/plant) (Table 4). However, two stems plant fruits showed lower TSS, which averaged 10.0 ºBrix compared to that of one stem plants (11.4 ºBrix). Yet, fruit number and yield per unit area of two stems plants were 37% lower than those of one stem plants (Table 2).

An interaction between titratable acidity (TA) and TSS/TA ratio was also observed (Table 3). However, in both cultivation systems, two stems plant fruits had higher TA and lower TSS/TA when compared to one stem plant fruits (Table 3). Therefore, TSS/TA ratio averages were higher for one stem plants both in pot and trough systems. But, if we compare both cultivation systems, the pots provided higher TSS/TA in one stem plants, whereas in the troughs it was observed in two stems plants (Table 3).

Fruit yield and quality had no significant interaction effect from substrate use and the number of stems trained (Table 2). However, averages of all parameters were higher for second-use than were for the first-use substrate. The averages were 2.7 fruits/plant (corresponding to 5.9 fruits/m^2) for yield, 1.0 kg for fruit weight per plant, and 2.6 and 5.3 kg for yield per plant and per square meter, respectively (Table 2). Respectively, these figures are 170%, 39%, and 215% higher than those obtained for the first-use substrate.

Regarding stem number, two stems plants showed higher averages for fruit weight and yield per plant. However, one stem plants produced a larger number of fruits per square meter (Table 2), with no effect on fruit number per plant nor on fruit yield per square meter (1.9 fruits/plant and 3.5 kg/m^2, respectively) (Table 2).

TA and TSS/TA ratio averages did not differ between first- and second-use substrates. But, second-use substrate promoted fruits with higher TSS (10.5 ºBrix) than did first-use one (9.7 ºBrix). Moreover, stem number did not affect any of these parameters in the second trial (Table 2).

Cultivation system effects

Changes in substrate properties at the end of both trials (Table 1) can be attributed to root filaments in raw rice husk (RRH) substrate. This might have increased TP due to spacing increases and substrate breaking into smaller fractions, increasing micropores. These, in turn, were occupied by water, thereby increasing EAW and WHC at the end of cultivation. Likewise, Neutzling (2018) also found WHC and TP increases and DD reduction after cucumber cultivation in RRH.

The larger WHC, TP, EAW, and RW obtained in the trough system (Table 1) may be due to root entanglement and binding along the troughs. Such root system structure may have retained water for a longer time inside troughs, which may have slowed down the return of excess nutrient solution to the troughs. Such a behavior increased throughout the development of plants, and hence roots.

The lower WHC in pot system corroborates the finding of Perin et al. (2018)

in mini tomatoes. These authors associated it with the larger substrate layers in pots (22 cm) compared to troughs (8 cm). Although WHC analysis at substrate layers deeper than 20 cm is merely representative, this association can be confirmed by the gradual WHC changes we observed. In our study, this parameter ranged from 11.2% at 10-cm depth to 9.1% at 50-cm depth in the pots. As for the troughs, these figures went from 15.6% to 12.5%, respectively.

The best physical properties, which in general were presented by substrate from troughs (Table 1), did not reflect in productivity gains. This was confirmed by the similar yields of both cultivation systems (Table 2). This is because roots of plants grown in pots exceeded the perforated base of pots, developing along the course of nutrient solution and moving by gravity inside troughs, where pots were arranged. Therefore, smaller pots and substrate volumes for each plant did not limit its development.

All treatments had EAW values below the optimum range for growing media (20 – 30%) (Fermino, 2014). Despite differing among treatments, RW averages were within the ideal range from 4 to 10% (Cadahia, 1998). The values ranged from 7.6% before cultivation to 9.1 and 12.7% after cultivation (Table 1) in substrates of pot and trough systems, respectively.

The results of our second trial for fruit number and average weight per plant agree with the findings of Marques (2013), who evaluated the same mini-watermelon hybrid in a hydroponic system. Likewise, our results of fruit yield and number per square meter coincide with those observed by Montezano (2007), who tested melon trained with similar stem densities in a hydroponic system.

Finally, both cultivation systems showed SST averages above 10 ºBrix. This value, according to Hurst (2010), is considered excellent for watermelon marketing.

Substrate reuse effect

The TP of the first-use substrate in a two-stem training system (64.6%) was like that before cultivation (66.7%) (Table 1). This similarity may have been originated from low substrate colonization by roots. That, in turn, was due to wider spacing between plants, associated with less accommodation of substrate particles due to its fast decomposition. The lowest TP of this treatment may be augmented with the lowest WHC averages observed both in this substrate (9.9%) and stem training system (11.0%).

As well as higher WHC in the second-use substrate, a marked increase in RW was observed (Table 1). Plants grown on the first-use substrate grew very slowly, which is associated with water stress. This was caused by the low water reserve due to low WHC of RRH at the beginning of cultivation (Table 1). Such water shortage can be associated with high temperatures, which are common during the establishment of this vegetable crop, with an average of the maximum of 35.7 °C in the first 30 days after transplanting. Plants grown on second-use substrate did not appear to have stress problems after transplanting, which is attributed to increased water reserve (i.e., a larger WHC in the reused substrate). Neutzling (2018) also reported, in summer-autumn cultivation, the poor establishment of cucumber plants grown on first-use RRH substrate and absence of water stress on second-use material.

Regarding fruit yield, our best results (Table 2) were achieved with cultivation on the second-use substrate. In this case, our findings differ from those of Neutzling (2018), who observed similar yields between first- and second-use substrates. Accordingly, the average fruit number and yield per unit area were notably higher for plants grown on the second-use substrate. Furthermore, only these plants reached the minimum average weight for commercialization, which is between 1 and 3 kg (Almeida, 2006). We also found fruit yields per aquare meter similar to those already found by other authors (Campagnol, Mello, & Barbosa, 2012; Campagnol, Matsuzaki, & Mello, 2016).

Although fruits from the first-use substrate had a lower TSS (9.7 ºBrix) (Table 2), it is still above the recommendation by the European Union. The minimum value for watermelon marketing is 9 ºBrix (Dias & Lima, 2010).

Such a substrate reuse effect on TSS did not extend to the TA and TSS/TA ratio. TSS/TA ratio averaged 59.4, which is like that of Campagnol (2009) but below that of Campagnol et al. (2012). Both studies were evaluating mini-watermelon training systems. For Chitarra and Chitarra (2005), TSS/TA ratio is the most representative parameter of balance between sugars and acidity in fruits.

Stem number effect

In both trials, two stems plants had similar numbers of fruits per plant, but a higher yield per plant and fewer fruits per square meter.

Although not statistically different, combining the highest absolute numbers of fruits per plant and average weights, yield per plant was higher for two stems plants in the first trial (Table 2). Likewise, in the second trial, average fruit weight increased by 27% (Table 2), corroborating previous studies on mini-watermelon (Campagnol et al., 2016) and melon (Barni, Barni, & Silveira, 2003). This may have occurred due to the larger leaf area of these plants, hence a greater synthesis of photo-assimilates (Reis, Azevedo, Albuquerque, & Silva, 2013). However, one should consider that the lower density of two stems plants might have influenced such results. Similarly, Rodrigues (2012) found increasing average fruit weights with decreased densities of mini-watermelon, as did Resende and Costa (2003) in watermelon cv. Crimson Sweet.

In terms of fruit number and yield per square meter (Table 2), two stems plants did not reach the same yields as those of one stem mini-watermelon, and their fruits showed lower TSS contents in the first trial (Table 2). Conversely, in the second trial, fruit yields per square meter were not statistically different between both training systems, which is evidenced by the high coefficient of variation. However, all data behaved similarly. For the yield aspects per unit area, two-stem plants did not behave like two one-stem plants, although with two apical meristems and, supposedly, greater auxin synthesis and greater leaf area. Similar behavior per unit area was observed by Montezano (2007) in melon cultivated also from the perspective of half of the plant population, but with an equal density of stems/m^2.

Although it has two apical meristems, and supposedly larger auxin synthesis and leaf area, two stems plants had yield per unit area different from those of two one stem plants. Similar behavior was observed by Montezano (2007) in melon, also about half of the plant population with equal stem densities per square meter.

However, it should be noted that two stems plants had a single root system, originating from a single seed. For Bohm (1979) and Santos, Sá, Ferreira, Resck and Lavres (2007), little is known about watermelon roots, and therefore they are difficult to sample, which hinders understanding its growth dynamics. Despite having a higher yield per plant (Table 2), two stems plants had insufficient water and mineral nutrients to meet demands of both stems and compensate for root absorption by two plants with a single stem, within the same substrate volume. Therefore, this can explain the lower yields per unit area above mentioned.

In the first trial, two stems plants yielded 6.1 kg per square meter. This is equal to what was observed by Campagnol et al. (2016), who also studied two stems plants at densities of 2.40 and 4.80 plants per square meter. These, in turn, are much higher than that used in our study (1.45 plants/m²). However, one stem plants in our study had a density of 2.90 plants/m² and showed a yield of 9.7 kg/m², which is notably higher than that of 4.7 kg/m² observed by Campagnol et al. (2012), in one stem plants at a density of 3.17 plants/m².

We found in the first trial that two stems plants had fruits with a higher average TA and lower TSS, and hence lower TSS/TA ratio (Table 3). These findings can be justified by the increased competition for assimilates in two stems plants, which reduces sugars and increases organic acids in fruits. This balance was suggested by Heine, Moraes, Porto, de Souza and Rebouças (2015) for tomato fruits.

Since TSS/TA ratio is a result of combinations between sugar and acidity levels, we observed in trial 1 that one-stem plant fruits had higher TSS (Table 2) and less acidity, hence a higher TSS/TA (Table 3), which was also found by Heine et al. (2015).

Conclusions

Both pot and trough cultivation systems had positive effects on the physical properties of raw rice husk, but it was superior in the trough system.

The trough system causes no changes in mini-watermelon yield and quality compared to the pot cultivation. Therefore, both can be used for mini-watermelon cultivation with leachate recirculation when using raw rice husk as a substrate.

Both substrate physical properties and mini-watermelon yield and quality improve with substrate reuse.

One-stem cultivation system increases aeration spaces and total porosity in raw rice husk when used for the first time, which does not occur for two-stem cultivation at lower plant densities.

Two stems mini-watermelons grown at half of the plant density and equal substrate volume does not reach the same fruit yield per unit area and fruit quality as does one stem plants.

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