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Agronomic performance of watermelon under direct sowing system and seedling transplanting

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ABSTRACT

Watermelon is traditionally grown under direct sowing system. However, due to high costs of good quality seeds of improved cultivars, seedling transplanting is a promising alternative for watermelon production. This study aimed at evaluating, during two production cycles, the performance of watermelon under direct sowing cultivation system and seedling transplanting. The field trials were carried out from May to September, 2015 and 2016, at Setor de Horticultura da Escola de Agronomia of Universidade Federal de Goiás. In 2015, the experimental design was randomized blocks (DBC) with four replicates in a 2x4 factorial scheme (two hybrids: Manchester and Talisman, and two planting methods: direct sowing and transplanting 15-, 20- and 25-day old seedlings). In 2016, the experimental design was DBC with six replicates. The treatments consisted of three direct sowing dates (0, 5 and 10 days) and three different seedling ages (15, 20 and 25 days). Number of leaves, plant height and dry mass of seedlings of different ages, vine length and virus incidence along the crop cycle were evaluated. Upon significant F-test (5%) for seedling age, regression analysis was performed, and when cultivar effect was significant, Tukey test (5%) was used. Planting methods (direct sowing X seedlings) were compared by orthogonal contrasts. In 2016, the beginning of flowering was evaluated, and in both trials, the average crop cycle for each treatment was determined. Fruit length and width, fruit mass, thickness of the white part of the rind, and soluble solids content were evaluated at harvesting. The 25-day old seedlings had higher number of leaves, as well as, higher dry mass, comparing with seedlings on the transplanting day. Yield and fruit quality were not influenced by treatments. No significant differences for virus disease incidence were detected, in both production cycles. Direct sowing reduced the crop cycle in both field trials, with no differences in production and quality of fruits. Considering the costs of establishing watermelon fields as relevant, the results suggest the importance of direct sowing as the most viable method for watermelon cultivation, due to the ease of the process, as well as, reduction in costs related to seedling production and transplanting operations.

Keywords: *Citrullus lanatus*, sowing, hybrids, cultivation, productivity.

RESUMO

Resposta agronômica de melancia em semeadura direta e transplantio de mudas

A melancia é tradicionalmente cultivada por semeadura direta, porém, em função do alto valor das sementes de materiais melhorados, o transplantio de mudas é alternativa promissora. Este trabalho teve como objetivo avaliar, em dois ciclos de produção, o desempenho agronômico da melancia por semeadura direta e transplantio de mudas. Os experimentos foram conduzidos em campo, entre maio e setembro de 2015 e de 2016 no Setor de Horticultura da Escola de Agronomia da Universidade Federal de Goiás. O ciclo de produção de 2015 foi em delineamento de blocos ao acaso (DBC) com quatro repetições em esquema fatorial 2x4 (dois híbridos: Manchester e Talisman e dois tipos de cultivos: semeadura direta e mudas com 15, 20 e 25 dias). Na safra de 2016 foi em DBC com seis repetições. Os tratamentos foram constituídos por três datas de semeadura direta (0, 5 e 10 dias) e três idades de mudas (15, 20 e 25 dias). Avaliou-se número de folhas, altura e massa seca por muda de diferentes idades e comprimento de ramas e a incidência de viroses ao longo do ciclo da cultura. Quando o teste F (5%) foi significativo para idade da muda, realizou-se análise de regressão, e quando houve efeito da cultivar foi aplicado o teste de Tukey (5%). Métodos de plantio (semeadura direta versus mudas) foram comparados por contrastes ortogonais. Em 2016, avaliou-se o início do florescimento, e em ambos os experimentos foi determinado o ciclo médio da cultura em cada tratamento. Na fase de colheita avaliaram-se: comprimento e largura do fruto, massa do fruto, espessura da parte branca do fruto e teor de sólidos solúveis. Mudas com maior idade (25 dias) apresentaram superioridade em relação ao número de folhas e massa seca da muda no dia do transplantio. Variáveis associadas à produtividade e qualidade dos frutos não foram influenciadas pelos tratamentos. Não houve diferença significativa com relação à incidência de viroses nos dois ciclos de produção. A semeadura direta reduziu o ciclo da melancia nos dois experimentos, entretanto, sem alteração da produção e qualidade dos frutos. Considerando que o custo de implantação de lavouras de melancia é fator relevante, os resultados obtidos reafirmam a importância da semeadura direta como o método mais viável ao plantio de melancia, considerando a facilidade do método e também a redução dos custos com a produção de mudas e operações de transplantio.

Palavras-chave: *Citrullus lanatus*, semeio, híbridos, cultivo, produtividade.

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Watermelon (*Citrullus lanatus*) is originated from the dry regions of Tropical Africa, with a secondary diversification center in South Asia (Nascimento *et al.*, 2011). The crop is of great economic expression, both nationally and worldwide, and it stands out among other Cucurbit species (Santos *et al.*, 2011).

In 2016, China was the largest watermelon producer of the world (68.77%), followed by Turkey (3.4%), Iran (3.3%) and Brazil (1.81%), reaching, approximately, 77.30% of the total produced in the world (FAO, 2018). In Brazil, watermelon was grown in an area of 99,212 ha in 2020, with a production of 2,184,907 tons (IBGE, 2021). Still in 2020, the Northeast region led the ranking in terms of cultivated area and production, with 42,377 ha and 825,970 tons, respectively, according to surveys carried out, by IBGE. The Midwest region had the highest national average yield, 33.4 t ha^{-1}, and the state of Goiás stood out with the highest yield, 41.3 t ha^{-1}, followed by the state of Pernambuco, which showed yield of 27.7 t ha^{-1} (IBGE, 2021).

Watermelon fields can be established by direct sowing, using three or four seeds per hole, followed by thinning or through transplanting seedlings. The production of seedlings for transplanting aims at reducing or eliminating the need for seedling-thinning after planting the seeds in the field (Boyhan *et al.*, 2017). However, the direct sowing cultivation is still the most used technique in Brazil, since it is a relatively easy method to grow low-cost seeds, especially in those open-pollinated cultivars (Nascimento & Silva, 2014). When planting higher-cost seeds, generally, of hybrid materials, fewer seeds are sowed per hole or furrow (Shrefler *et al.*, 2015). Nevertheless, seedlings are still produced in pots, aiming at providing plants for replacing field failures. New technologies have been introduced in watermelon cultivation (planting seeds of higher-cost hybrid materials, mulching, fertigation, grafting) improving the production system in order to obtain higher yields (Ban *et al.*, 2009; Rao *et al.*, 2016; Narine *et al.*, 2019; Rolbiecki *et al.*, 2020).

Seedling transplanting aims to reduce seed costs, which can be advantageous when high-cost seeds are planted, providing reduction in crop cycle, more uniform stand, possibility of cultivation under unfavorable weather conditions, ease initial cultural practices, high phytosanitary control and, probably, increased crop productivity (Dalastra *et al.*, 2016). The use of seedlings for planting watermelon in the field is done, traditionally, when working with seedless material, due to high cost of seeds and the difficulty in establishing a stand for this type of watermelon (Shrefler *et al.*, 2015; Levi *et al.*, 2017). Planting high-quality seedlings, associated with other cultivation techniques, makes vegetable exploration more competitive and, consequently, more sustainable and profitable (Ban *et al.*, 2009). Nevertheless, malformed seedlings can compromise the development of the crop, increasing the cycle length and leading to production losses (Echer *et al.*, 2007).

Thus, in order to produce high-quality seedlings, it is also essential to provide suitable conditions for root development, such as nutrition and, environment and physical support (Oliveira *et al.*, 2015). Another important point is to determine the optimum age for seedling transplantation, to avoid planting old seedlings which maybe not favorable to the development of both root system and plant shoot (Salata *et al.*, 2011).

There is still a lack of information on the impact of direct seeding regarding to variables such as productivity and quality of fruits, as well as, incidence of viruses. Thus, the aim of this study was to determine production (fruit weight) and fruit quality (fruit length; fruit width; thickness of the white part of the rind; total soluble solids content), besides the incidence of five virus species, in relation to two methods for planting watermelon (transplanting 15, 20 and 25-day old seedlings and direct sowing). The hypothesis to be tested is that planting watermelon by transplants will provide differential traits, such as higher plant growth and higher productivity, as well as reduction on incidence of viruses, when compared to direct sowing cultivation, which result in an improvement of total marketable fruit productivity. The obtained results will contribute to the knowledge of selecting the most suitable method for planting seeded-watermelon, to ensure higher production as well as, high quality-fruits with lower cost/benefit ratio.

MATERIAL AND METHODS

Assay location

The experiments were carried out, in 2015 (May 15th to September 17th) and 2016 (May 17th to September 20th), at the Setor de Horticultura da Escola de Agronomia, Universidade Federal de Goiás (EA-UFG), Goiânia-GO (16°35’49”S, 49°16’54”W, 720 m altitude).The region climate is classified as Aw, according to Köppen’s Classification System (rainy tropical climate). The rainfall regime is well defined, with rainy period from October to March and dry period from April to September. By the time experiments were carried out, the average relative humidity and the total precipitation were 60.07% and 34.4 mm, respectively in 2015 and 56.19% and 32.6 mm in 2016. Minimum and maximum temperatures during both assays ranged, respectively, from 8.8°C to 37.9°C in 2015 and, from 8.2°C to 37.2°C in 2016.

In both areas soils were classified as dystrophic Red Latosol. In 2015, the experimental area presented the following chemical characteristics: pH (H_2O) = 6.4; organic matter = 23.86 g/kg; Ca= 3.7 $cmol_c/dm^3$; Mg= 1.4 $cmol_c/dm^3$; Al= 0 $cmol_c/dm^3$; H+Al= 2.5 $cmol_c/dm^3$; K= 100 mg/dm^3; P= 32.6 mg/dm^3; Base saturation = 68.1. In 2016, the soil in the experimental area had the following chemical characteristics: pH (H_2O) = 5.3; organic matter = 18 g/kg; Ca= 2.2 $cmol_c/dm^3$; Mg= 0.94 $cmol_c/dm^3$; Al= 0 $cmol_c/dm^3$; H+Al= 2.5 $cmol_c/dm^3$; K= 62 mg/dm^3; P= 8.7 mg/dm^3; Base saturation = 56.9.

Experimental design and treatments

The experimental design was of randomized blocks, with four (2015 trial) and six (2016 trial) replicates and 10 plants per plot, displayed in a single row. Planting density was 4,166 plants ha^{-1}, spacing 0.8 m between plants and 3 m between lines. The plot size was 24 m^2, considering the eight central plants as the useful area of the plot measuring 6.4 x 3 m and, two plants as a border, one at each end of the plot.

During the 2015 growing season, treatments consisted of a combination of two watermelon hybrids (Manchester and Talisman) and four types of cultivation (direct sowing and transplanting of 15, 20 and 25-day old seedlings) in a factorial scheme 2x4. The trial covered a total area of 768 m^2. The hybrid Manchester (Syngenta) is a Crimson Sweet type, with round fruits, firm flesh, intense red color, crunchy flesh, weighing 11 to 12 kg and an average cycle between 88 and 90 days (Ascom Syngenta, 2017). The first commercial season of this hybrid was in 2009. The hybrid Talisman (Bayer) is considered vigorous, showing round-oval-shaped fruits, dark green skin with light green streaks, and intense red pulp with high soluble solids content, high crunchiness and early cycle. This hybrid is also resistant to *Fusarium oxysporum* f.sp. *niveum*, races 1 and 2 (Nunhems, 2017).

In the 2016-production cycle, treatments consisted of three direct sowing dates of the hybrid Talisman, at a five-day interval between two plantings to produce plants 15- 20- and 25-day old, and transplanting seedlings of three different ages (15, 20 and 25 days). For each direct sowing done in the field, seeds were also planted on the same date, in nursery to produce seedlings at respective age to be transplanted; then, seedlings produced on both sowing methods had the same age. Fifteen days after the last sowing in the nursery, seedlings at 15, 20 and 25 days after planting (as old as plants obtained under direct sowing system), were transplanted to field. This experiment covered an 864 m^2 area.

Soil preparation

After soil preparation by plowing and a harrowing, furrows were opened in planting rows, followed by limestone application, according to soil analysis results, to achieve 70% base saturation. As mineral fertilizer N-P-K, in 2015 assay, 714 kg ha^{-1} of the formula 4-14-8 was applied at time of seedbed preparation, while, in the year 2016, 1.000 kg ha^{-1} of the formula 4-30-10 was used. In both trials, 2 kg ha^{-1} of boron was used as FTE BR 12. Top dressing fertilization was performed by fertigation with 40 kg ha^{-1} nitrogen (urea source) and 40 kg ha^{-1} K (potassium chloride) applied weekly, through a Venturi-type fertilizer injector, which split the fertilization in doses according to crop phenological stages.

Irrigation

Fertigation started 26 days after the first sowing (DAS), when all plants were established in the field, as follow: 26-35 DAS = application of 13% of total nitrogen (N) and 8% of total potassium (K); 35-50 DAS =15% N and 10% K; 51-65 DAS = 27% N and 16% K; 66-80 DAS = 30% N and 18% K; 81-91 DAS = 10% N and 30% K and, 91-110 DAS = 5% N and 18% K, according to Andrade Junior *et al*. (2007), with some modifications. Plants were grown by drip-irrigation using drippers spaced 0.3 m from each other, with capacity to deliver 4 L/m/hour (flow rate), three times a week.

Seedling preparation and cultural practices

In 2015, seedlings were grown in trays with 162 cells (31 cm^3/cell) filled with a mixture of coconut fiber substrate (Golden Mix type PM) and vermiculite (1:1; v:v) and seeds covered with vermiculite. In the second production cycle (2016), seedlings were grown in a commercial nursery (Vivati-Abadia), in the county of Abadia de Goiás, Goiás state, using also coconut fiber substrate and seeds covered with vermiculite. Seedlings were transplanted to the field on June 9, 2015 (first production cycle) and on June 11, 2016 (second production cycle).

For direct seeded treatments, plants were thinned to a single plant per pit, after emergence, in the field, when they presented two to three definitive leaves. Combing of vines was done twice a week, when vines measured more than 50 cm in length. Fruits were thinned, leaving just one fruit per plant, being, afterwards, covered with newspaper to avoid occurrence of sunburn.

Invasive plants were controlled, whenever necessary, through manual weeding. Insecticides and fungicides, recommended for the crop (2015; http://extranet.agricultura.gov.br/agrofit_cons/principal_agrofit_cons), were applied following instruction on the product label.

Evaluated variables

In both field trials, 2015 and 2016, the following characteristics were evaluated: fruit production per plant (kg); fruit length (cm); fruit width (cm); fruit weight (g); thickness of the white part of the rind (mm); total soluble solids content (°Brix) and, incidence of virus-diseased plants. Only in the 2015 assay, the following traits were considered: number of leaves; plant height (cm), and dry mass (g) of seedlings (aerial part + roots), In addition, length of the main vine (cm) at 34, 55 and 75 days after transplanting (DAT) was also measured, considering the plant collar region as the base for emission of the main vine.

Seedling dry mass and fruit mass were determined on a precision scale (0.001 g). Data were recorded by measuring fruit length and width trough a measuring tape and a digital caliper (Zaas Precision -150 mm) was used to take the thickness of the white part of the rind. Total soluble solids content was measured on three pulp samples taken from a fruit slice using a digital refractometer (Tecnal®, Rudolph Research, J47), according to the methodology of the Association of Official Analytical Chemistry (1997).

Harvest

In the 2015 growing season, six harvests were carried out, according to indications of watermelon fruit ripening (dry tendrils at the fruit peduncle node; a change in the color of the rind in contact with the soil, from white to light yellow; rind color change from bright green to a more opaque tone; fruit rind resistance to pressure with the nail; resonance produced by hitting the fruit) and crop cycle. In 2016, fruits were collected in nine harvests. For both field trials, by the time of fruit harvesting, plants were identified to determine the average cycle of each treatment. Harvesting took place, when plants were in between 103 and 115 days of planting. All fruit analyses were carried out in the Laboratório do Setor de Horticultura of EA-UFG.

Viruses

The incidence of virus-diseased plants was evaluated at 27, 41, 63 and 80 DAT, in the 2015 assay, and at 45 and 85 days after the first sowing, in the 2016 assay. In 2015, the number of symptomatic plants was counted in the useful area of the plot, while in 2016, three plants from the useful area of the plot were collected for virus detection by serology. NCM-ELISA (*Nitrocellulose membrane – Enzyme-linked immunosorbent assay*; Clark & Adams, 1977) was the test of choice for virus detection in leaf samples. Apical leaves randomly collected from three plants, regardless of the presence or not of virus symptoms, were employed in extract preparation to be used as antigen. This first stage of leaf sample processing was carried out at Laboratório de Fitopatologia da EA/UFG. Aliquots of leaf extract (≃5 μL) prepared by macerating each individual sample in 0.5X PBS buffer (0.02 M KH_2PO_4; 0.02 M KCL; 1.4 M NaCl; 0.08 M Na_2HPO_4), pH 7.4, (1g/10 mL) were deposited onto a nitrocellulose membrane (Merck Millipore, Finland) previously wetted with PBS.

Samples were tested for detection of six virus species: *Zucchini yellow mosaic virus* (ZYMV), *Papaya ringspot virus*, type watermelon (PRSV-W), *Watermelon mosaic virus* (WMV), *Zucchini lethal chlorosis virus* (ZLCV), *Cucumber mosaic virus* (CMV) and *Groundnut ringspot orthotospovirus* (GRSV). Sample analyses were carried out at the Laboratório de Virologia e Biologia Molecular da Embrapa Hortaliças, Brasília-DF using specific antisera against nucleocapsid protein (N) produced at Embrapa Hortaliças. Leaf extracts obtained from zucchini plants (*Cucurbita pepo*), cv. Caserta (PRSV-W; ZYMV; WMV; ZLCV; CMV) and *Datura stramonium* (GRSV), individually inoculated with each viral species and leaf extracts obtained from non-inoculated plants was applied onto the membrane as a positive and negative control, respectively. Membranes remained in a blocking solution (0.5X PBS-T, pH 7.4, containing 2% low-fat milk powder) for 1-2 h to inactivate the sites not occupied by the antigen, followed by antiserum (specific IgG) at 1:1000 (v:v; μL/mL) dilution in 0.5X PBS-T, overnight. Membranes were washed three times in 0.5X PBS-T buffer and kept for 2-3 hours in general conjugate (goat-anti-rabbit-SIGMA/A3887) at 1:30,000 dilution (v:v; μL/mL) in 0.5X PBS. Membrane washing was repeated in 0.5X PBS-T, followed by the development process by detection of antigen-antibody complex in revelation buffer (1 M Tris-base; 0.1 M NaCl; 5 mM $MgCl_2$, pH 9.5) containing 5-bromo-4-chloro-3-indolyl phosphate (BCIP) and nitroblue tetrazolium (NBT), in a 1:2 BCIP-NBT ratio.

Statistical analysis

For both experiments, data adequacy was performed according to presuppositions of a parametric analysis, using Kolmogorov-Smirnov and Bartlett tests to verify normality and homogeneity of variance of model residues, respectively. For data collected in the 2015 trial, when the mean square of treatments was significant by the F test (5% probability), a regression analysis was conducted as function of seedling age at transplanting, thus, to define the best adjustment, according to a combination of significance and higher coefficient of determination. The F test was used to compare averages, when hybrid effect was detected.

Only for the 2016 trial, averages of the results of three direct sowings were considered for F test and regression analysis. Orthogonal contrasts were employed in the comparison of the planting methods (direct sowing *versus* seedling age). Virus incidence data was analyzed using the non-parametric chi-square method ($\chi 2$).

RESULTS AND DISCUSSION

In 2015 growing season, age of seedlings was significant ($p<0.05$), considering the variables evaluated on the transplanting day: number of leaves, seedling height and seedling dry mass. The average number of leaves (2.05 leaves/seedling), as well as, the average dry mass per seedling (0.69 g/seedling) was higher for 25-day old seedlings as compared to 15 and 20-day old seedlings (Table 1).

For number of leaves, statistical difference was found among seedlings of different ages, considering, individually, the hybrid cultivars. Seedlings with 25 days had higher number of leaves/seedling for Manchester (2.0 leaves/seedling) and Talisman (2.1 leaves/seedling), as compared to 15- and 20-day old seedlings. However, considering specifically each seedling age, the number of leaves did not differ between Manchester and Talisman, according to Table 1.

There were significant differences for average in seedling height for both hybrids at different ages of seedlings (Table 1). Height values for seedlings with 15 days were statistically different between Manchester and Talisman, 6.86 cm and 5.32 cm, respectively. Similar results were also found for seedlings with 20 days with significant differences between hybrids: 5.23 cm (Manchester) and 4.74 cm (Talisman). However, at 25-day age, no significant differences were found, for height, for both hybrids (Table 1). Considering individually, each hybrid, for Manchester, seedling height at 15 days age (6.86 cm) differed from that of 20 days (5.23 cm) and also of 25 days (5.44 cm); nevertheless, the last two values were not statistically different. On the other hand, for Talisman, no differences for seedling height were verified, considering 15-, 20- or 25-day old seedlings.

Significant difference was found for dry mass (MS) of seedlings with 15, 20 and 25 days, for Manchester and Talisman. Seedlings of 25 days had higher MS values (Manchester = 0.65 g/plant; Talisman = 0.73 g/plant) as compared to seedlings with 20 days (Manchester = 0.51 g/plant; Talisman = 0.58 g/plant) and 15 days (Manchester = 0.31 g/plant; Talisman = 0.38 g/plant). For Talisman, greater values for dry mass of seedlings were obtained, as compared to Manchester, regardless of seedling age, 15, 20 or 25 days (Table 1).

Plants of the hybrid Talisman

showed superiority, compared to those of Manchester, what can be related to its earliness genetic characteristic, resulting in a greater plant development and, consequently, higher dry mass production. Talisman (85-90 days) is slightly earlier than Manchester and has a longer cycle (Ascom Syngenta, 2017; Nunhems, 2017).

Similar results were obtained by Salata *et al*. (2011) for zucchini seedlings at 32 DAS. They obtained values for dry mass and number of leaves that were superior to those for seedlings at 27 DAS. These authors also verified a quadratic model for those variables in relation to seedling age. In addition, despite the better seedling development at 32 DAS, it apparently, did not influence obtaining higher yields as compared to 27-DAS seedlings, which produced more productive plants. These results indicate that seedling age (or development stage) at transplanting, among other factors, can have a significant effect on plant development in the field.

Several aspects related to watermelon production system should be considered when it comes to seedling production to be used in the establishment of new plantings, aiming to provide good crop performance in the field, considering that malformed seedlings can result in less developed, as well as, less productive plants. Thus, seedlings are among the main factors that influence crop development in the field.

Seedling development after transplantation to the field depend on a variety of factors, such as cell volume in the tray used for sowing seeds and seedling production, type of substrate and irrigation system, spacing adopted for transplanting seedlings and

Table 1. Average number of leaves (NF), height (Al) and dry mass (MS) of watermelon seedlings of hybrid cultivars Manchester and Talisman, in relation to transplanting age. Goiânia, UFG, 2015.

Age (days)	NF/plant		Average	Al (cm)/plant		Average	MS (g)/plant		Average
	Manchester	Talisman		Manchester	Talisman		Manchester	Talisman	
15	1.0 bA[1]	1.3 bA	1.15 b	6.86 aA	5.32 abB	6.09 a	0.31 cB	0.38 cA	0.34 c
20	1.2 bA	1.5 bA	1.35 b	5.23 bA	4.74 aB	4.98 c	0.51 bB	0.58 bA	0.54 b
25	2.0 aA	2.1 aA	2.05 a	5.44 bA	5.53 aA	5.48 b	0.65 aB	0.73 aA	0.69 a
CV (%)		23.9			11.57			3.19	

[1]Lowercase letters in column (related to seedling age), and uppercase in line (related to hybrids), did not differ statistically from each other, by Tukey test, at 5% probability.

Table 2. Fruit mass, total soluble solid content (SST), fruit length, fruit width, fruit thickness of the white part of the rind and average percentage of virus-diseased plants (SV), in relation to seedling age and hybrids used. Goiânia, UFG, 2015.

Treatment	Mass (kg)		Average	SST (ºBrix)		Average	Length (cm)		Average
	Manchester	Talisman		Manchester	Talisman		Manchester	Talisman	
Direct sowing	8.24	7.64	7.94	12.61	12.62	12.34	79.12	78.32	78.72
15-day old seedlings	8.06	7.71	7.89	12.12	12.09	12.11	75.18	77.21	76.19
20-day old seedlings	8.23	7.35	7.79	12.83	12.28	12.56	80.05	73.09	76.57
25-day old seedlings	8.59	7.56	8.08	12.56	12.68	12.63	81.16	75.09	78.12
Average	8.28 A	7.56 A		12.40 A	12.42 A		78.88 A	75.93 A	
CV (%)[1]	15.70			7.98			5.89		

Treatment	Width (cm)		Average	Thickness of the white part of the rind (cm)		Average	SV (%)		Average
	Manchester	Talisman		Manchester	Talisman		Manchester	Talisman	
Direct sowing	72.79	74.45	73.65	14.34	14.43	14.38	60.0	65.5	61.25
15-day old seedlings	71.56	73.52	72.54	13.79	14.43	14.11	55.0	50.0	52.50
20-day old seedlings	75.66	70.00	72.83	14.83	14.08	14.46	62.5	70.0	63.75
25-day old seedlings	75.45	71.98	73.71	14.38	14.53	14.46	65.0	62.5	66.25
Average	73.87 A	72.48 A		14.34 A	14.37A		60 A	61 A	
CV (%)	6.06			8.36			28.18		

[1]CV (%): Coefficient of variation.

Table 3. Average fruit mass, soluble solid content (SST), fruit length and fruit width in relation to cultivation under direct sowing and seedlings at different ages, hybrid Talisman. Goiânia, UFG, 2015.

Treatment	Mass (kg)	SST (°Brix)	Length (cm)	Width (cm)
Direct sowing	5.99	8.34	69.8	67.41
15-day old seedlings	5.15	8.01	65.45	64.27
20-day old seedlings	5.77	7.94	69.29	66.39
25-day old seedlings	5.64	7.81	65.9	65.32
CV[/1] (%)	16.92	5.6	6.28	6.43

[/1]CV (%): Coefficient of variation.

Table 4. Averages of watermelon crop cycle and beginning of flowering (IF) and significance of regression for these variables. Goiânia, UFG, 2015.

Treatment	Days after sowing	
	IF	Cycle
Direct sowing	49.10	101.92
15-day old seedlings	51.38	105.59
20-day old seedlings	58.31	109.05
25-day old seedlings	63.30	114.67
RL[1]	**	**
RQ[2]	*	*

[1]RL: Linear regression; [2]RQ: Quadratic regression; *and** significant values at 5% and 1%, respectively, using F test.

Table 5. Values of orthogonal contrasts between averages of direct sowing (SD) and watermelon seedlings at different ages, for variables associated with the beginning of flowering (IF) and crop cycle. Goiânia, UFG, 2016.

Contrast	Days after sowing	
	IF	Cycle
Y1: (1° SD, 2° SD, 3° SD) *vs* (15, 20, 25-day old seedlings)	44.82***	52.01***
Y2: (1° SD) *vs.* (25-day old seedlings)	75.94***	66.56***
Y3: (2° SD) *vs.* (20-day old seedlings)	4.05*	3.02 *
Y4: (3° SD) *vs.* (15-day old seedlings)	0.75ns[1]	6.73**
Y5: (15-day old seedlings) *vs.* (25-day old seedlings)	25.791***	23.20***

[1], *, ** and ***: non significant values, significant at 10%, 5% and 1%, respectively, using Scheffé test.

environment conditions (Ban *et al.*, 2009; Silva & Ferreira, 2015). In the present study, seedlings were produced in trays including 162 cells, with a cell volume of 31 cm^3 available for root system formation, which may have influenced seedling root development on the tray and, consequently, seedling development.

At 34 DAS, there were significant differences for vine length (CR), considering seedling age and watermelon cultivar, and also for the interaction between CR and cultivar. For Talisman ($p<0.05$), higher average value for CR (0.87 m) was obtained as compared to Manchester (0.74 m) (Figure 1A). In that evaluation, quadratic behavior of CR was observed, in relation to seedling age, for plants of both cultivars, Talisman and Manchester. According to regression analyses results, the best estimated age of seedlings with the best result for vine length was 14.41 and 16.38 days, respectively, for the hybrids Manchester and Talisman. At 55 DAT, there were no significant differences for CR averages and neither for the interaction between seedling age and cultivar. However, significant differences were observed for the interaction between CR and seedling age showing a quadratic trend ($y=1.783+0.1053x-0.0036x^2$; $R^2=0.9497$), with estimate of 14.63 days as optimum seedling age for transplanting (Figure 1B). However, throughout crop cycle, the advantages associated to plant development by direct sowing as compared to seedling transplantation at different ages was overcome. At 75 DAT, treatments did not show any differences from each other.

In 2015, fruits were collected in six harvests (September 2, 8, 10, 11, 14 and 17). For variables related to fruits (mass; total soluble solids content; length; width; thickness of the white part of the rind) no significant differences were detected in relation to seedling age (15, 20 or 25 days) of the watermelon hybrids (Manchester or Talisman), neither to the effect of direct sowing. These results indicate that these traits were not affected by the evaluated treatments (Table 2). The average fruit mass ranged from 8.28 kg to 7.56 kg, respectively, for Manchester and Talisman, which is equivalent to yield estimates, 34.49 t ha^{-1} and 33.49 t ha^{-1}. The average value of SST was 12.40°Brix (Manchester) and 12.42°Brix (Talisman), whereas the average values for fruit length and width were 75.93 x 72.48 cm (Talisman) and 78.88 x 73.87 cm (Manchester).

Transplanting of seedlings at different ages influenced the crop cycle length. There were significant differences for crop cycle as compared to seedlings age at transplanting to the field, and also for the interaction between seedling age *vs.* cultivar. According to regression analyses results, both hybrids [Manchester: $y=93.356+1.0121x$; $R^2=0.9959$; Talisman: $y(T)=96.486+0.838x$; $R^2=0.9692$] showed linear response to seedling age (Figure 2). Plants from direct sowing (age 0) had shorter average cycle (95.56 days), as compared to transplanted seedlings (107.39 days for 15-day old seedlings; 113.02 days for

20-day old seedlings and 119.21 days for 25-day old seedlings).

For number of plants with symptoms of virus infection, there were no significant differences between the treatments, direct sowing and transplanting of seedlings at 15, 20 and 25 days and neither between the two hybrid cultivars (Manchester and Talisman; Table 2). However, a trend towards a gradual increasing in the incidence of symptomatic plants throughout the growing season was observed for Manchester and Talisman (data not shown).

At 41 DAT, the value of symptomatic plants for Manchester ranged from 27.5% (seedlings with 20 and 25 days) to 35% (direct sowing), whereas for Talisman these values were 20% (direct sowing) and 35% (seedlings with 20 and 25 days) (data not shown). At 80 days, when the last evaluation was concluded for plants obtained from direct sowing, the percentage of symptomatic plants ranged from 60.0% (Manchester) to 65.5% (Talisman) for plants obtained from direct seeding. However, when considering seedling transplanting, these percentages varied from 55 to 65% (Manchester: 15- and 25-day old seedlings, respectively) and from 50 to 70% (Talisman: 15- and 25-day old seedlings, respectively) (Table 2).

Serological tests (NCM-Elisa) confirmed data obtained with the evaluation of visual symptoms (exhibiting mottle, mosaic, roughness, blistering, and reduction of the leaf blade) on plants in the field. Simple and mixed viral infections (presence of more than one virus species infecting the same plant) were detected in 64% of total number of plants evaluated. The most frequent viral species was ZLCV, detected in 50% of the leaf samples tested, followed by ZYMV (7.14%); the other virus species (PRSV-W; WMV; GRSV; CMV) did not occur in the evaluated samples.

In 2016 field trial, nine harvests were conducted (August 15, 19, 23, 26, September 2, 6, 9, 14, 20). In that production cycle, no significant differences were observed ($p<0.05$) for yield, total soluble solids content, fruit length and fruit width as compared to seedling age (15, 20 and 25 days), neither as compared to direct sowing (Table 3). In addition, no significant differences were also verified between the treatments regarding to virus incidence (data not shown).

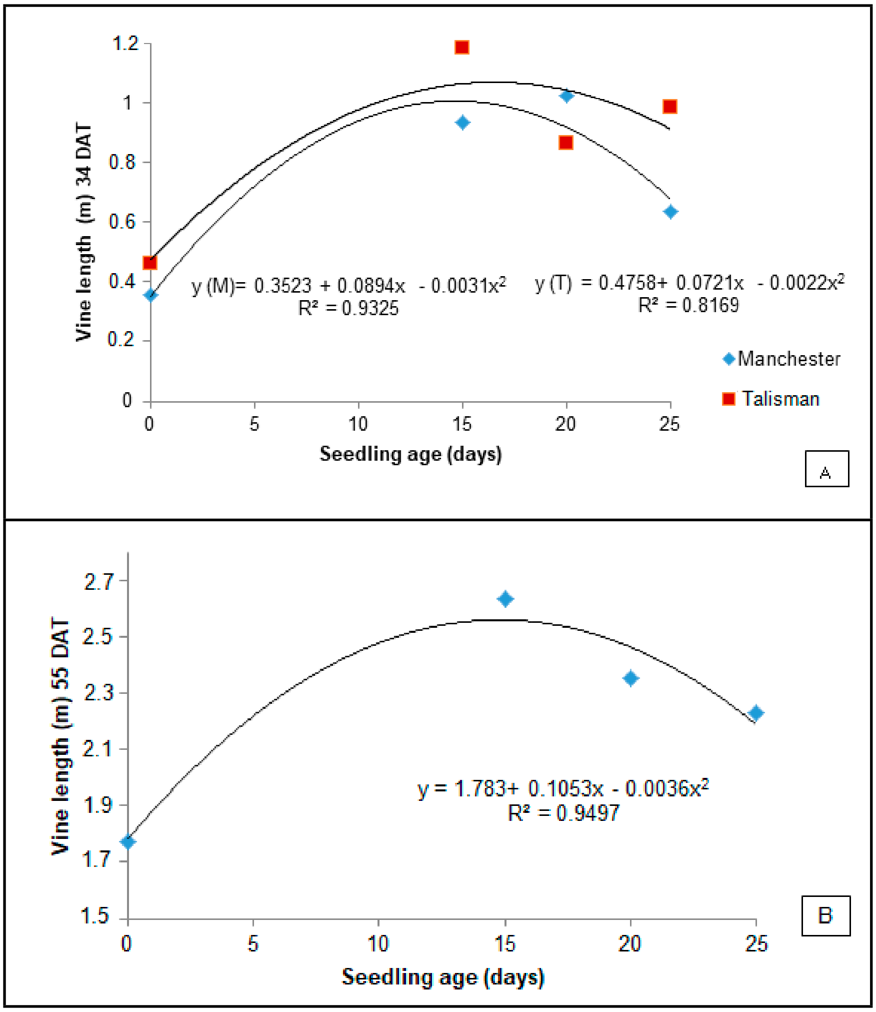

Figure 1. Vine length at 34 days after transplanting (DAT) in relation to seedling age for cultivars Manchester and Talisman (A) and at 55 days after transplanting (DAT) (B) in relation to seedling age. Goiânia, UFG, 2015.

The beginning of flowering and crop cycle duration were influenced by seedling age ($p<0.05$) and showed linear response to age of seedlings transplanted to the field (Table 4).

According to analysis results using orthogonal contrasts, regardless of seedling age, 15, 20 or 25 days, planting seeds directly in the field provided plant development with earlier flowering and cycle. This flowering anticipation was 2.28; 9.21 and 14.2 days, respectively, as compared to plants developed from seedlings with 15, 20 and 25 days. Regarding crop cycle, plants resulting from the direct sowing anticipated the cycle by 3.67; 7.13 and 12.75 days, respectively, when compared to plants that resulted from planting seedlings 15, 20 and 25 days old.

Still for flowering variable, a significant difference was observed at 1 and 10% levels, respectively, comparing the first direct sowing *versus* seedlings with 25 days and the second direct sowing *versus* seedlings with 20 days. For both contrasts, direct seeding in the field provided the development of earlier plants. However, plants obtained from the third direct sowing showed no significant differences as compared to plants of 15 days, suggesting proximity of physiological conditions between plants of those two treatments (Table 5).

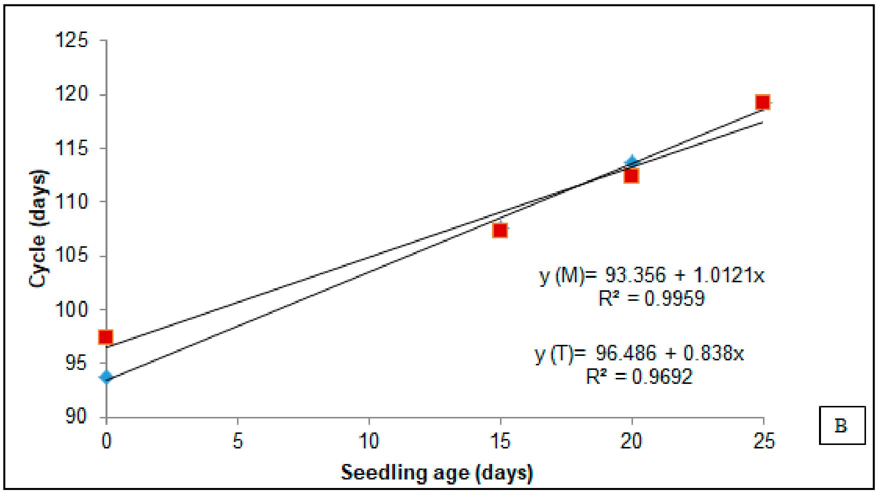

Figure 2. Crop cycle in relation to seedling age for watermelon hybrids Manchester (M) and Talisman (T). Goiânia, UFG, 2015.

Comparing just seedling planting systems, seedlings with 15 days were superior for flowering precocity and plant cycle duration over those of 25 days. Whereas seedlings with 15 days bloomed 51.38 days after sowing, seedlings with 25 days transplanted to the field showed later flowering, at 63.3 days.

Contrasting the crop cycle as compared to different treatments, significant differences were detected at the levels of 1, 10 and 5%, respectively, considering the comparisons between the first sowing *versus* seedlings with 25 days, second seeding *versus* those of 20 days and third seeding vs. seedlings with 15 days (Table 5).

Comparing (based on orthogonal contrasts) plants obtained through direct sowing and plants grown under transplanting of seedlings at different ages, indicated superiority of direct sowing system as compared to seedling transplanting system. Gribogi & Salles (2007) highlighted that direct sowing provides appropriate conditions for establishing plant root system (deeper) with no limitations on well-prepared soils, resulting in plants more resistant to bad weather conditions and adverse actions, which may occur during the crop cycle.

Regarding to seedling production in trays, the limited available cell space in the tray can restrict the seedling root growth, impairing plant development after being transplanted to the field, depending on time taken to their restoration. Echer *et al.* (2007) highlighted that transplanting seedlings with undesirable formation can impair the entire crop development, including extending plant cycle. In the present study, seedlings were produced in trays with 162 cells and cell volume available for root growth was only 31 cm^3, which could have influenced seedling root development and, consequently, plant development. The results obtained by comparing treatments with transplanting of seedlings at different ages showed that, in order to establish new areas, seedling age should be considered as a factor that may influence the precocity of the crop.

According to results of serological analyses of samples, no significant differences were detected considering virus incidence and the different treatments: direct sowing and transplanting of seedlings at the ages of 15, 20 and 25 days. As in 2015, an increase in the incidence of virus-infected plants throughout the crop cycle was observed in 2016 (data not shown). Over all, the percentage of symptomatic plants was similar to that verified in the previous experiment, 2015 (data not shown). However, in the 2016 assay, the presence of different viral species infecting the sampled plants was detected: PRSV-W (20.8%), WMV (25.4%), ZYMV (20.8%), ZLCV (25.1%), CMV (19.4%), and GRSV (22.2%).

Thus, in both field trials any influence of the sowing method used in crop establishment was not verified, either by direct seeding or by seedling transplanting in the field, the cultivar planted in the present assay, Talisman or Manchester, on fruit quality and yield traits. Nevertheless, for both assays, the direct sowing provided the development of plants with shorter cycle, followed by planting seedlings 15-, 20- and 25-days old.

For both 2015 and 2016 assays, no difference was verified, regarding to incidence of virus-infected plants, showing that regardless of the planting system adopted (direct sowing or seedling transplantation), no reduction in the percentage of virus-infected plants was observed.

The permanence of seedlings for prolonged periods on trays, as mentioned by Seabra Júnior *et al.* (2004), may result in symptoms of nutrient deficiency, oxygen deficiency, as well as twisted roots, affecting seedling development after transplanting to the field. Gribogi & Salles (2007) concluded that post-transplant stress, climatic fluctuations and physical impact on the roots during plant establishment in the field influenced the cycle of sugar beet plants, increasing cycle in up to 21 days after transplanting 28-day old seedlings to the field. According to these authors, a longer plant cycle had an impact on yield and reduced the benefits of seedling producing on trays.

In the present study, watermelon seedlings with 25 days, although they were more developed compared to younger seedlings (with 15 and 20 days), did not provide better performance for precocity of crop cycle, resulting in a longer cycle, compared to other treatments. Direct seeded treatments resulted in plants with a shorter cycle, followed by 15- and 20-day old seedlings. According to Echer *et al.* (2007), transplanting seedlings with undesirable formation can compromise the entire crop development, including extending the crop cycle. All those factors should be considered when choosing a production system in the establishment of new areas, either direct sowing or seedling transplanting.

Evaluation of virus incidence in both field trials, 2015 and 2016, revealed the presence of different viral species (PRSV-W; WMV; ZYMV; CMV; ZLCV; GRSV) infecting sampled plants, especially in the 2016 assay. In 2015, only ZLCV and ZYMV were detected, being ZLCV identified in a greater number of samples compared to ZYMV. Those viruses have been frequently found infecting watermelon in different Brazilian regions (Yuki *et al*., 2000; Lima & Inoue-Nagata, 2008; Lima & Alves, 2011; Spadotti *et al.*, 2014; Aguiar *et al*., 2015; Lima *et al.,* 2015, 2017). Four of these viral species (PRSV-W; WMV; ZYMV; CMV) are transmitted by aphids in a non-persistent manner, in which the virus is acquired in an infected plant and transmitted to a healthy plant by the insect vector during very brief probes (Adams *et al*., 2012).

On the other hand, ZLCV and GRSV are transmitted by thrips, in a persistent-propagative manner, in which the virus is acquired by the insect vector when it is still in the larval stage and the virus multiplies in the insect body (Rotenberg *et al*., 2015). ZLCV infects mainly pumpkin (*Cucurbita* spp.) and watermelon (*Citrullus* spp.) and it is reported only in Brazil, so far (Lima, 2014). The virus has already been identified infecting watermelon in the Southeast (Rezende *et al*., 1995; Yuki *et al*., 2000), Northeast (Lima & Inoue-Nagata, 2008), Midwest (Lima & Alves, 2011; Lima, 2014) and, North regions (Aguiar *et al*., 2013). GRSV is an emerging pathogen in watermelon crop and it already has been detected in the states of São Paulo (Spadotti *et al.*, 2014) and Goiás (Lima *et al*., 2015).

For these two groups of viruses (transmitted by aphids and thrips), transmission occurs in a very efficient way, being also favored by the presence of virus sources represented by alternative host plants of these pathogens and their respective vectors (aphids and thrips) occurring in high populations in the field. In the present study, the results obtained in both field trials carried out along two years did not indicate any effect of treatments at reducing virus incidence in watermelon plants, neither under direct-sowing system nor transplantings grown in a protected environment with chemical pesticide control, including insecticide applications aiming at controlling insects, mainly virus vectors in the crop (e.g. aphids and thrips). Nevertheless, considering aphids as virus vectors, chemical control is highly questionable when it comes to aiming at reducing damages due to aphid-borne viruses mainly due to the non-persistent type of transmission. Therefore, genetic resistance is still considered the most efficient and effective way to control viruses, by planting resistant varieties. Sources of resistance and tolerance to PRSV-W have been identified by Munger *et al*. (1984), in *Citrullus lanatus* PI accessions from India (PI 179662 and PI 179878) and South Africa (PI 295848).

Considering the characteristic symptomatology observed in the field-grown plants sampled for serology tests in this work, the difference between the number of symptomatic plants, and the percentage of plants actually positive for viral infection through the use of antisera, may have occurred due to: (a) sampling, considering that the virus is not evenly distributed in the plant; (b) plant age at the time of sampling (80 days) suggesting a possible reduction in the viral titer in symptomatic plants; (c) infection of the plant by viruses other than those against which the antisera were tested; (d) symptoms caused by abiotic factors.

When selecting the method for implementing watermelon crop, growers should evaluate advantages and disadvantages of direct sowing or alternatively, seedling transplanting, aiming at selecting the planting method with the lowest cost/benefit ratio for establishing the crop in the field. In the present research, the results of production cycles, in 2015 and 2016, with the comparative study on direct sowing and seedling transplanting, indicated that sowing seeds directly into the soil provides an earlier plant development when compared to the seedling transplanting method. Thus, 25 day-old seedlings gave rise to longer-cycled plants, as compared to seedlings with15 and 20 days and also, to plants obtained by direct sowing. However, despite the earlier cycle in plants resulting from direct sowing, no influence on traits, such as yield and fruit quality, was verified. Considering the costs of implementing watermelon crops as an important factor for growers, the results obtained in this research reaffirm the importance of direct sowing seeds, which has traditionally been the most used method. Direct sowing is an easy process, considering the low relative cost of seeds (diploid watermelons), in which enables producers to use more seeds for planting, and later thinning, to obtain an appropriate stand. In addition, direct sowing provides reduction in costs for seedling production and transplanting operations.

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