Research, Society and Development, v. 11, n. 16, e210111637766, 2022
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i16.37766

Do the training system and spacing affect the productivity and quality of tomato plants?

O sistema de condução e o espaçamento afetam a produtividade e a qualidade do tomateiro?

¿El sistema de conducción y espaciamiento afectan la productividad y calidad de las plantas de tomate?

Received: 11/10/2022 | Revised: 11/26/2022 | Accepted: 11/28/2022 | Published: 12/05/2022

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Abstract
The determined growth tomato plant has advantages such as reduction of labor and inputs, enabling the production of fruits for consumption " in natura" efficiently. The objective of this work was to evaluate the conduction and spacing systems between plants with determined tomatoes and their influence on the production attributes and quality of the fruit. The experiment was carried out in the open field with three conduction systems ("half stake", open V and "mulch") and four spacings between plants (0.2; 0.3; 0.4; and 0.5 m). It was found that the highest yield and commercial production and number of large fruits were obtained in the half stake and mulch system. The spacing at 0.5 m provided the highest fruit production (6.4 kg in 56 fruits), and at 0.2 m, the highest productivity was obtained (145.63 t ha -1). In the 0.2 m and open V 0.5 m stake system, the fruits had a high lycopene content. spacing 0.2 m in half stake, and mulch systems were favorable for the production of quality fruit.
Keywords: *Solanum lycopersicum;* Saladete tomato; Tutoramento; Mulch.

Resumo
O tomateiro de crescimento determinado apresenta vantagens como redução de mão de obra e insumos, possibilitando a produção de frutos para consumo “in natura” de forma eficiente. O objetivo deste trabalho foi avaliar os sistemas de condução e espaçamento entre plantas com determinado tomateiro e sua influência nos atributos de produção e qualidade do fruto. O experimento foi realizado a campo aberto com três sistemas de condução (“meia estaca”, aberto V e “mulching”) e quatro espaçamentos entre plantas (0,2; 0,3; 0,4; e 0,5 m). Verificou-se que a maior produtividade e produção comercial e número de frutos grandes foram obtidos no sistema meia estaca e cobertura morta. O espaçamento de até 0,5 m proporcionou a maior produção de frutos (6,4 kg em 56 frutos), e até 0,2 m, a maior produtividade (145,63 t ha -1). No sistema de estacas de 0,2 me aberto V 0,5 m, os frutos apresentaram alto teor de licopeno. espaçamento de 0,2 m em meia estaca, e os sistemas de cobertura foram favoráveis para a produção de frutos de qualidade.
Palavras-chave: *Solanum lycopersicum*; Tomate saladete; Tutoramento; Mulching.

Resumen
El tomate de crecimiento determinado presenta ventajas como reducción de manos de obra e insumos, lo que posibilita una producción de frutos para consumo “in natura” de forma eficiente. O objetivo de este trabajo para evaluar los sistemas de conducción y espesamiento entre plantas con tomate determinado y su influencia en los atributos de producción y calidad del fruto. O experimento para realizar un campo aberto com três sistemas de condução (“meia estaca”, aberto V e “mulching”) y quatro espaçamentos entre plantas (0,2; 0,3; 0,4; e 0,5 m). Verificou-se que a maior produtividade e produção comercial e número de frutos grandes foram obtidos no system meia estaca e cobertura morta. El espacio de até 0,5 m proporciona una mayor producción de frutos (6,4 kg en 56 frutos), e até 0,2 m, una mayor productividad (145,63 t ha -1). No sistema de estacas de 0,2 me aberto V 0,5 m, os frutos apresentaram alto teor de licopeno. espaçamento de 0,2 m em meia estaca, e os sistemas de cobertura foram favoraveis para a produção de frutos de qualidade.
Palabras clave: *Solanum lycopersicum*; Saladete de tomate; Tutoría; Mantilla.

1. Introduction

Tomato (*Solanum lycopersicum* Mill.) is one of the most consumed fruit vegetables in the world (Mattos, Shirahide and Melo, 2012) due to its organoleptic characteristics and nutritional composition, with high contents of minerals, vitamins, carotenoids, lycopene and antioxidants (Nick and Silva, 2018). Worldwide, 48 million hectares are planted, with a production of 179 million tons (FAOSTAT, 2019). In Brazil, tomato cultivation is present in almost all states of the country, with a total area of 64.6 thousand hectares, producing 4.5 million tons.

Plants with an indeterminate growth habit are the most used in the production of fruits for "in natura" consumption, while determinate plants are used for the production of fruits for industry (Paula, 2013). However, cultivars with a determined habit can be used for the "in natura" market as long as they present desirable fruit characteristics for the market (Yuri et al., 2016), such as size, attractive color and sweet taste.

Management directly influences the growth and production of tomato plants (Schwarz et al., 2013), as well as the quality of the fruit. This means that different production systems can be used to adapt the method of cultivation to the place and the purpose of consumption.

Cultivation practices such as trellising reduce the contact of the plants with the soil, increasing the incidence of sunlight and ventilation and helping the development of the tomato plant (Wanser et al., 2008), thus increasing the productivity, quality and appearance of the fruit. Another promising technique is the use of soil cover with mulch (polypropylene plastic film), since it reduces weeding operations, controls erosion, and retains soil moisture, facilitating crop management and significantly affecting production and growth. fruit size (Ogundare, 2015).

In addition to these factors, adequate spacing increases the incidence of radiation on the tomato plant, improving nutrient accumulation and fruit quality (Wamser et al., 2012). The reduction of the spacing with the increase in the population of plants increases the productivity and the profitability per surface. An example is the Viçosa system, which is a combination of technologies, such as trellising the plant with a 75° inclination with respect to the ground in the form of a "V" and various cultural treatments (Almeida et al., 2015). Thus, cultural treatments are essential for the efficient cultivation of table tomato without losing the quality of the fruit (Cardoso et al., 2018). Therefore, this work aimed to evaluate the training systems and spacing of tomato plants and their influence on production attributes and fruit quality.

2. Materials and Methods

The experiment was carried out from March to September 2018 at the State University of Mato Grosso – UNEMAT, municipality of Nova Mutum, Mato Grosso (geographical coordinates of 13° 05' 04” S and 56° 05' 16” W), medium altitude of 486 m. The climate is tropical equatorial hot and humid Aw (Kopen), with two well-defined seasons: dry (May to September) and rainy (October to April). During the period of the experiment, an average temperature of 24°C was obtained, with a maximum average temperature of 34°C.

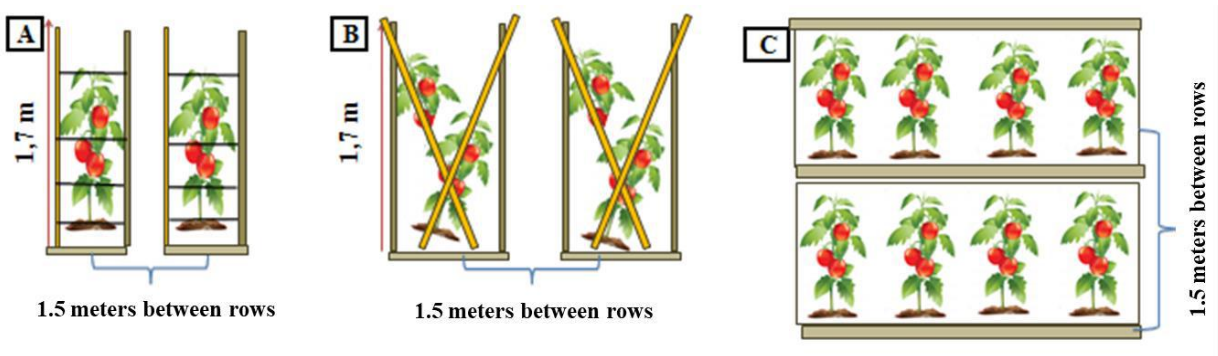
The fertilization was carried out according to the soil analysis: pH of 6.3; P 69 mg.dm³ and K 30, Ca 2.4, Mg 0.7, H + Al 1.3 cmol.dm -3. Fertilization at the time of planting was carried out in juice with 10% urea, 100% simple superphosphate and 10% potassium chloride. Fertigation was carried out weekly by means of fertigation (ammonium sulfate and potassium nitrate).

The Fascinio cultivar (determined habit, salad-like fruit) was used; the seedlings were produced in rigid polypropylene plastic trays (162 cells) filled with commercial Vivato® substrate, one plant per cell. The transplant to the open field was carried out 25 days after sowing (DAS), when the plants had 3 to 4 definitive leaves (Alvarenga, 2004).

To determine the need for irrigation, tensiometers were used to better adapt to the needs of the crop, the phenological state, the climatic conditions and the suction pressure of the soil. Irrigation was drip. The phytosanitary control of pests and diseases was according to the level of damage and the recommendations for the crop (Alvarenga, 2013), and the management of invasive plants was through weeding. Because the habit of the plant was determined, there was no pruning or thinning, and the other cultural treatments were carried out equally for all treatments.

The experimental design was in randomized blocks with a 3 x 4 factorial scheme and four repetitions. The treatments consisted of three cultivation systems (Figure 1), two of which were staked: "half stake" (plants nailed vertically with the use of horizontal plastic tapes, with a separation of 20 cm, bamboo every 3 m and beams of wood at the ends), "open V" (plants nailed at random, with an angle of 75°, supported by siding-type canvases on the sides, in a "V" shape, bamboo every 3 m and wooden beams at the ends), and “ mulch ” (plants without trellising, creeping on the bed 1.20 m wide, covered with 25 μm white (external) and black (internal) plastic film, conducted from the edge to the inner part of the bed), both with four plant spacings (0.2, 0.3, 0.4, 0.5 m) in single rows with 1.5 m between rows.

Figure 1 – Arrangement of the two tomato plants in the half stake (A), open V (B) and plastic mulch (C) conduction systems.



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The harvest was carried out weekly during the period between June 02 and September 06, 2018, in which the fruits were harvested in stage VI of maturity (completely ripe) from eight central plants of each plot.

2.1 Evaluation parameters

Production characteristics: The fruits were harvested when they were red and ripe, counted and weighed on semianalytical scales, and the diameter in millimeters and length in millimeters were measured with a digital pachymeter to classify the size of the fruits. Total productivity and commercial productivity (the commercial standard corresponds to the total number of fruits minus the damaged fruits, all the extras) were estimated in t ha -1, the classification of the fruits according to their size in small, medium and large/t ha -1, the production of fruits per commercial plant and the production of small, medium and large plants in kg plant -1, the number of fruits per commercial plant, the average weight of commercial fruits in grams (Ministry of Agriculture, Livestock and Supply - MAP, 2002); the earliness index in % (Almeida, 2012) and the length of plants in m at the end of the cycle (measuring tape) were also measured.

Quality attributes (physical-chemical and biochemical, ten fruits from each evaluation plant were evaluated in triplicate from the third harvest): lycopene and β-carotene in µg/100 g of fresh fruit (Nagata, Yamashita, 1992), total titratable acidity in % of citric acid (IAL, 2008), total soluble solids in °Brix (portable digital refractometer, PAL-1) (IAL, 2008), total titratable acidity ratio x total soluble solids (Ratio) and vitamin C or ascorbic acid in mg per 100 g (IAL, 2008).

2.2 Statistical analysis

The results were subjected to variance analysis, and the significant differences were compared by the Scott–Knott test at the 5% probability level for the qualitative characteristics (driving systems) and for the qualitative ones (spacing between plants) polynomial regression using the SISVAR 4.0 program (Ferreira, 2010).

3. Results and Discussion

Production characteristics

Hobo interactions between the factors studied, training systems versus plant spacing, productivity parameters, small fruit production and plant length. Most of the factors analyzed in isolation showed significant differences; however, no differences were found for the driving system factor in the characteristic number of commercial fruits, productivity and production of average fruits (Table 1).

The highest total productivity was obtained in the crop under mulch; however, commercial productivity was lower in the "open V" culture. Productivity may vary depending on the hybrid, production system, place of production, and cultural treatments (Almeida et al., 2015; Wanser et al. 2017, Alam, 2016; Wanser et al. (2017). However, for the conditions in which the experiment was carried out, the plastic mulch and the "half-stake" system were more advantageous for total yield, commercial yield, average commercial fruit mass, and large fruit production (Table 1). In the cultivation of tomatoes under mulch, the plants were later and longer.

Table 1 - Total productivity (TP), commercial productivity (CP), large fruit productivity (G), fruit production per commercial plant (PFC), average commercial fruit mass (PMF), large fruit production (PPG), earliness index (IP) and plant length (LOG) for the training systems between tomato plants.

Training system	Average two treatments							
	PT	Zip	G	PFC	FAQ	PPG	IP	LOG
		t ha $^{-1}$			kg plant $^{-1}$		%	m
Half stake	128.9b	117.8a	39.2a	5.7a	115.1a	1.9a	26.5a	1.7b
V open	117.7b	103.1b	30.5b	5.0b	109.6b	1.4b	23.8a	1.7b
Mulch	140.6a	116.3a	35.6a	5.8a	120.0a	1.8a	16.3b	1.8a

Means followed by the same lowercase letter in the column do not differ by the Scott–Knott test at 5% probability. Source: Authors.

The 'open V' system has proven to be advantageous for the production of large fruits and productivity in indeterminate tomato cultivation due to the association of various techniques, such as turning, pruning, thinning and cleaning, justifying this better yield (Almeida et al., 2015; Wanser et al., 2012). For the cultivation of table tomato with a determinate habit, it was observed that creeping cultivation on mulch and half stakes favored productivity and the production of larger fruits.

The 'half-stake' training system acts in a similar way to the vertical trellis system in tomato; in the cultivation of indeterminate tomato, it provides an increase in the efficiency of the production of photosimilates, which is reflected in the productivity of larger-sized fruits. (Wamser et al., 2007), being the most suitable for the production of fruits in natura (Marin et al., 2005). Justifying the results obtained in this study and the use of this type of driving even when hybrids of determined habit are used.

The 'mulch' can be an interesting training system due to its commercial productivity, similar to that of half stakes, especially when the grower intends to obtain large fruits. Creeping plants are manipulated only in the initial phase of development and do not need trellising or other cultural treatments. The fewer cultural treatments carried out, the less labor will be used, which will mean a reduction in costs. The cost of plastic mulch is much less when compared to the use of string, stakes and posts required in the 'half-stake' system'meia stake' system.

Although the commercial productivity was lower than that of the other conduction systems, the “open V” produced 103.16 t ha -1, 30% above the national average. Although pruning was not done, the plants in the 'open V' system had to be driven over the tarpaulin, the weight of the fruit and the wind moved the plants and they had to be put back in place. This created stress, which resulted in fewer large fruits, lower large fruit production and lower fruit production compared to the others. Fruit production per plant in the 'V open' system was lower, approximately 800 grams, compared to the half stake and mulch. (5.7 and 5.8 kg plant -1). The arrangement of the plants may have affected the exploratory capacity of radiation and atmospheric CO2, reducing the production of photoassimilates of the hybrid (Wamser et al., 2015).

With an average of 46 fruits per plant, the training systems will not affect this characteristic. The number of fruits is related to the genetic potential of the hybrid and cultural treatments such as the number of clusters and spacing. The average weight of the fruits was 120.0 and 115.1 grams for the plants and for the cultural treatments (Matos; Shirahade and Melo, 2012), which influence the flow/drain ratio of photosimilates and may increase the accumulation of mass in the fruits as a function of density and conduction.

Plants with a determined habit are not pruned, keeping the plants more upright in the case of the 'half-stake' system and the distribution of the plant's leaves on the bed when mulching allows greater access to light and, consequently, a higher production of photoassimilates, which is reflected in the production of fruits.

In this study, 39.6% of the fruits were classified as medium, and the medium stake and mulch conduction systems provided 35 and 32% of the large fruits, respectively. In the 'open V' system, the proportion of large fruits was 30%, and the largest caliber fruits are preferred by the consumer market (Wamser et al., 2015).

As trellised plants showed greater earliness in fruit production, the mulch system showed a lower rate of earliness. Almeida (2012) verified a higher earliness in plants grown in training systems where the plants were erect. In a study conducted by Lédo et al. (2015), the determinate tomato plant was previously found in creeping cultivation.

The formation of tomato plants in trellis systems favors the precocity of the plant and flowering (Maciel et al., 2016), which reduces the time the plants remain in the field and sanitary problems. In addition, vertically stationed plants have higher photosynthetic efficiency, which increases the production of large fruits (Wamser et al., 2007). However, the use of the plant in a creeping way in the mulch system provides a more humid microclimate in the soil, reducing volatilization and leaching (Hirata and Hirata, 2015), which significantly reflects on plant growth and fruit production (Wanser et al., 2007). Justifying the positive results of the mulch system in this study.

Influence of spacing on productive performance:

The greater densification of the plants at a spacing of 0.2 m provided higher total and commercial yields, reaching 168.44 and 145.63 t ha -1 (Figure 2 A), while the minimum points (PM) were estimated at spacings of 0.46 and 0.50 m, with values of 106.62 and 91.39 t ha -1, respectively.

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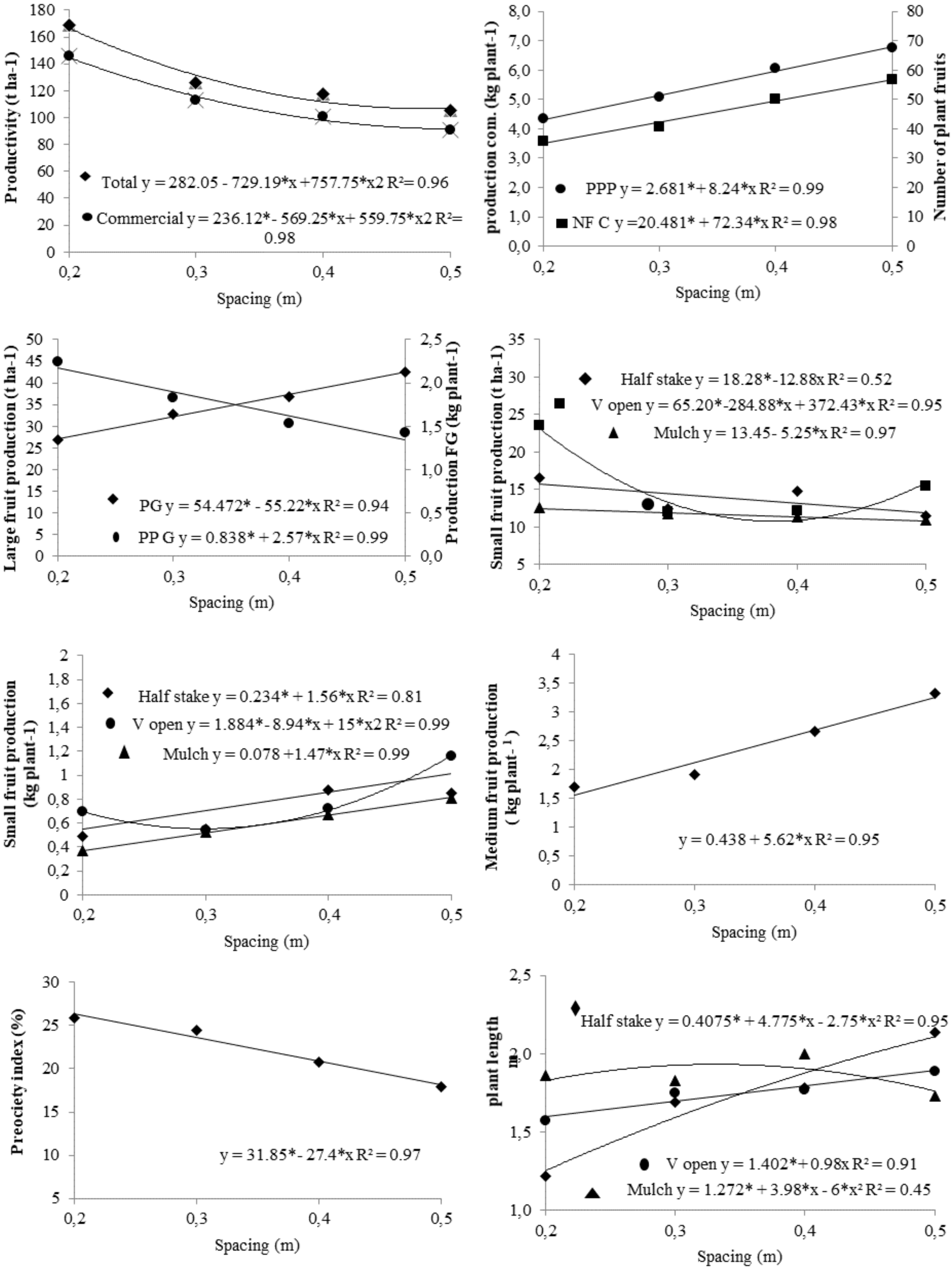
Figure 1– Regression for the characteristics of total and commercial productivity (A), production and number of fruits per commercial plant (B), productivity and production of large fruits (C), productivity (D) and production of small fruits (E), average fruit production (F), earliness index (G) and plant compression (H) for the spacing of the determined tomato plants. * significant at 5% probability.



Source: Authors.

The productivity was inverse to the production per plant due to the increase in the development space of the plant, making it productive; however, it reduced the productivity per area. In this context, the smaller spacing reduces the yield per plant but increases productivity by presenting a larger population of plants. Likewise, in tomato with a determined habit, the same trend is observed (Almeida et al., 2015; Yuri et al., 2016).

With the increase in the population of plants and the reduction in spacing, it directly affects the incident radiation and the foliar development of the plant, so the available photoassimilants are reduced, causing a reduction in production per plant (Wanser et al., 2017) due to competition for light, water and nutrients. However, when an adequate spacing is used for the development of the plant, there is no loss of yield (Seleguini; Seno; Faria Júnior, 2006).

The plants also showed a linear trend of increased commercial yield with greater spacing, reaching the maximum tomato yield (6.4 kg plant -1) with a spacing of 0.5 m (Figure 2 B). This provides an increase of 1.4 kg plant -1 compared to plants grown 0.2 m apart. Despite increasing the production of the fruits per plant by increasing the spacing, the average weight of the fruits was not influenced by the density, and the results were also obtained in the cultivation of the indeterminate tomato plant (Cardoso et al., 2018).

There was a variation from 35 to 56 fruits per plant due to the increase in the spacing between plants, showing the same trend of linear increase (Figure 2 B); the MP was 0.14 m common to 30.60 fruits plant -1. This is due to the decrease in the population at greater distances, which reduces the competition between plants (soil, air, water and radiation) and improves the yield of the tomato plant.

The spacing of 0.5 m provided the production of fruits with large caliber production (Figure 2 C) and medium (Figure 2 F); however, the yield in this spacing was lower, with an inverse trend between production and yield. The maximum yield of large fruits was produced with a separation of 0.2 m, with a fruit yield of 45 t ha -1, and the minimum, 27.4 t ha -1, with a separation of 0.5 m. The increase in planting density did not reduce the yield of large fruits of the tomato plant. This result was also obtained in the indeterminate growth tomato plant carried out in the Viçosa 20" system (Almeida et al., 2015),

Interaction of trellising with yield and small fruit production (Figure 2 D, E), the highest amount of small fruit was obtained in the 'Open V' system, and the maximum points for small fruit productivity at 0.38 m was 10.7 t ha -1 for production at 0.29 m spacing, which was 0.55 kg plant -1. The lowest yield of small fruits was observed in the mulch system, with a minimum point at a distance of 0.26 m with 0.46 kg of plants. These results corroborate those of Bogiani et al. (2008), where the plastic mulch on the ground provided fewer small fruits.

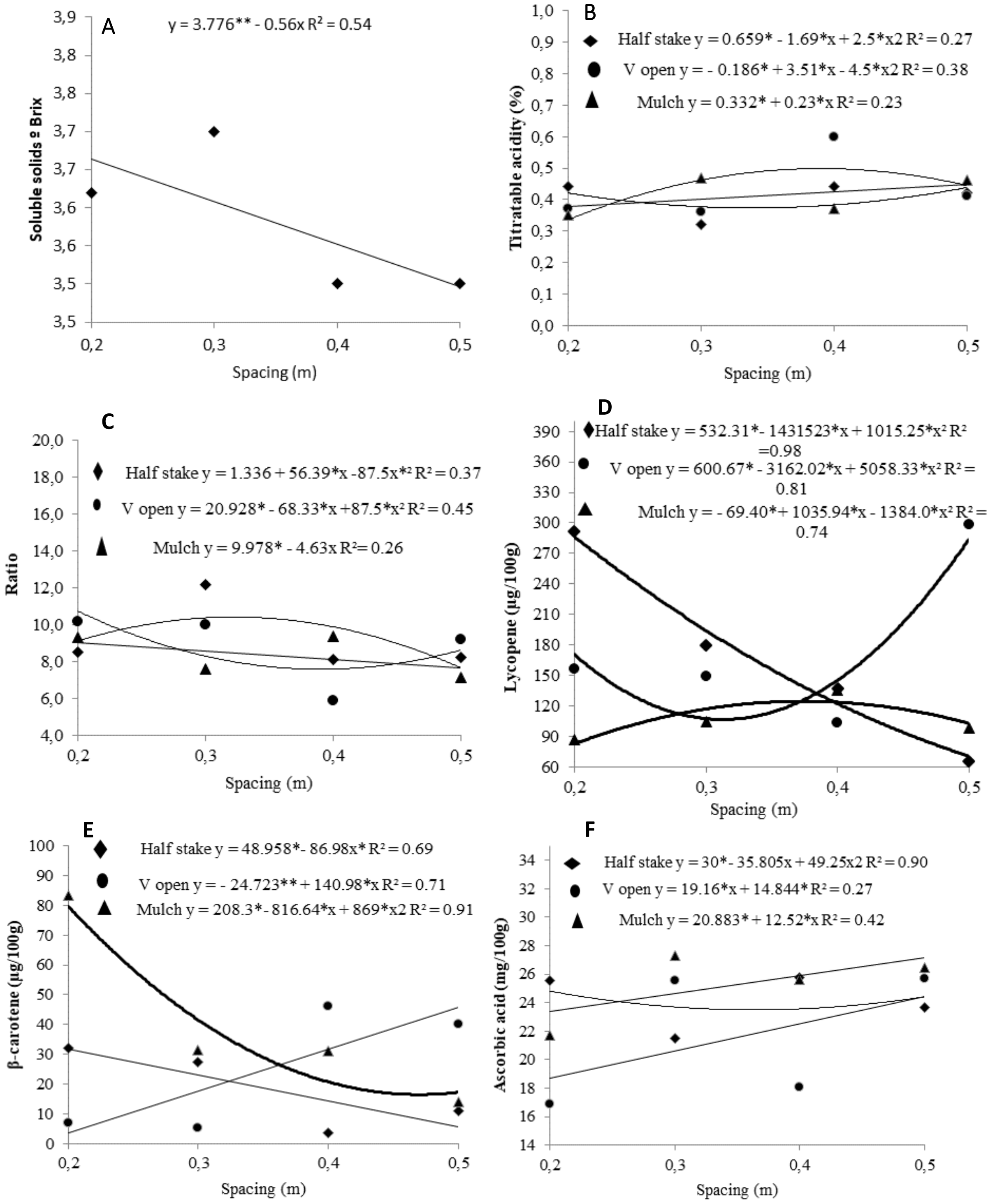
Plants grown in reduced spaces showed less earliness (Figure 2 I), while increasing the spacing between plants to 0.5 m reduced the percentage of earliness of tomato to below 20%. Thus, a greater spacing between plants generated less competition and reduced the concentration of production in the first three harvests, and its minimum point at 0.50 m was 16%.

The characteristic length of tomato plants depends on the interaction between the trellising system and the spacing used (Figure 2H). The greatest length of the plants was found in the 'half stake' system, with the maximum a being 0.8 m with a length of 2.46 m of compression. The 'Open V' system with 0.7 m spacing provided 2.0 m plants on top of mulch with a spacing of 0.3 m and length of 1.9 m. Thus, the production system and the spacing between plants can act on the vegetative development of the tomato plant due to the difference in the intersection of sunlight (Seleguini; Seno; Faria Júnior, 2006). However, the work of Cardoso et al. (2018) in hydroponics did not find any influence of the planting density on the length of the plants because they had easy access to water and nutrients.

Quality features

The total titratable acidity of the fruits varied from 0.3 to 0.6% citric acid, with an interaction between the factors driving systems versus spacing (Figure 3 A), where plants grown in compost estimated the highest acidity of fruits 0.5% at a spacing of 0.7 m, but plants grown in a half-stake and open V system had a polynomial trend descending, where they presented minimum points of 0.3 and 0.5% for plants grown at a spacing of 0.3 and 0.4 m, respectively. Fruits of high quality and flavor must have values of total titratable acidity greater than 0.32% (Ferreira et al., 2004), which indirectly indicates the amount of organic acids and the astringency of the fruits. Genetic factors are the main determinants of acid content in tomato fruits, with great variation between genotypes.

Figure 3 - Regression for the averages of the physicochemical and biochemical characteristics of the soluble solids (A), total titratable acidity (B), ratio (C), lycopene (D), β-carotene (E) and ascorbic acid (F) for the conduction systems and the spacing between determined tomato plants. * significant at 5% probability.



Source: Authors.

Soluble solids levels ranged from 3.5 to 3.7° Brix, but spacing was not influenced by the piping system. However, the values found are within the quality standard for tomato fruits that must be above °Brix 3.0 (Schwarz et al., 2013).

The highest ratio value (10.0) was obtained in the fruits of the plants formed in a half-stake system with a spacing of 0.3 m between plants (Figure 3 B), giving rise to more palatable fruits due to the balance between acids and sugars. In the open V and mulch systems, the results were polynomial, which allowed us to estimate minimum points of 7.5 and 5.0 at spacings of 0.4 and 1.0 m between plants, respectively, for the conduction systems.

High values indicate a mild flavor due to the excellent combination of sugar and acid, while low values correlate with acid flavor (Ferreira et al., 2004). In addition, this index has been related to the maturation state of the fruits. tomato fruits. The results of soluble solids, titratable acidity and ratio found were consistent with the characterization of table quality fruits according to Ferreira (2010), with titratable acidity greater than 0.30%, soluble solids of 3% and SS/AT ratio greater than ten.

The highest lycopene content (Figure 3C) was found in the open conduction system V at the 0.5 m spacing, with 298.2 µg 100 g -1. There was also an interaction of half stake system 0.2 m obtained 291.4 µ g 100 g -1, and the mulch system had the maximum ema 0.3 m with 124.4 µ g 100 g -1, showing the lowest levels.

The interactions for β-carotene (Figure 3D) were different from those of lycopene, and the highest content was found in the 0.2 m mulch system with 83.1 µg 100 g -1. The teve half-stake conduction system had a linear reduction with a minimum of 0.3 with 24.6 µg/100 g and open V with a maximum of 0.9 m with 124.5 µg 100 g -1.

The fruits produced in the mulch system, being in contact with the plastic and the low distribution of radiation on the fruit, compromised the content of lycopene and increased that of β-carotene. There is an inverse relationship between the concentration of β-carotene and lycopene due to the ripening process of tomato fruits (Fattore et al., 2016); with maturation, there is a decrease in the concentration of β-carotene, and the concentrations of these pigments vary, mainly due to the difference in the distribution of radiation and temperature in tomato fruits. Lycopene and β-carotene are pigments responsible for the coloration and external appearance of tomato fruits, with expected values of 35 µg/g for lycopene and 3.2 µg/g for β-carotene (Choi et al., 2008). Their concentrations are related to environmental factors (temperature and radiation) and the ripening of the fruits (Chitarra, Chitarra, 2005). Among the natural pigments of tomato fruits, lycopene represents on average 80% of the total carotenoids (Renju; Kurup; Saritha Kumari, 2013); its concentration is important, and it has antioxidant action, preventing carcinogenic and cardiovascular diseases (De Carvalho et al., 2006).

For the content of ascorbic acid (vitamin C), a linear trend of increase in the content was obtained in the plants grown in wider spacing in V open and mulch, reaching 16.85 and 27.32 mg 100 g -1 of ascorbic acid, respectively (Figure 3E). In the tomato plants grown in the half-stake system, there was a polynomial trend, and the minimum point of 23.5 mg 100 g -1 could be estimated at the 0.3 m spacing. The results found are within the standards for ripe tomato fruits, which range from 18 to 40 mg/100 g of pulp (Alvarenga, 2004). In addition, vitamin C is influenced by the time of year, the cultivar, fertilization, light and solar radiation that affects the plant and the fruit (De Carvalho et al., 2006).

4. Conclusion

The plants grown in the half-stake and mulch systems were more productive. The 0.5 m spacing allowed a better yield in fruit production per plant and the production of large- and medium-sized fruits, which is an important characteristic for the most demanding markets. However, the spacing of 0.2 m, as the population of plants increases, is the most indicated to increase productivity.

All the training and spacing systems produced fruits with the physical-chemical and biochemical standards established for the “in natura” tomato. complying with the demands of the consumer market. Although the plants grown in litter produced fruits with lower lycopene content and higher β-carotene content, mainly with reduced spacing (0.2 m), the fruits had a less accentuated red coloration and were less attractive.

Acknowledgments

To the Research Support Foundation of the State of Mato Grosso- FAPEMAT for financing the project, process Nº.0588013/2016, Edital Nº 038 /2016 Induzido - FAPEMAT - Agricultura Familiar and to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior- CAPES for the scholarship granted.

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