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Physicochemical characteristics of tomato fruits for industrial processing according to the irrigation management[1]

Características físico-químicas de frutos de tomateiro para processamento industrial em função de manejos da irrigação

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HIGHLIGHTS:
Growing processing tomato under water deficit promotes greater water productivity for the fruit pulp yield.
Irrigation deficit before harvesting reduces tomato yield and does not increase pulp yield.
High irrigation levels can reduce the yield of processing tomatoes in Brazilian Cerrado.

ABSTRACT: This study was carried out to evaluate the postharvest quality of processing tomato fruits, submitted to irrigation depths and periods of suspension of irrigation before harvest, irrigated by subsurface drip in Cerrado areas in the southern region of Goiás State, Brazil, in 2015 and 2016. The experiments were established under a randomized block design, with four replicates arranged in a split plots scheme. In the plots, five irrigation depths were evaluated (50, 75, 100, 125 and 150% of the crop evapotranspiration) and, in the subplots, five periods of suspension of irrigation (0, 7, 14, 21 and 28 days before harvest) were assessed. After harvesting, which occurred at 125 days after transplanting the seedlings, the average fruit mass, fruit shape (longitudinal and transversal diameter), total soluble solids content, titratable acidity, pH, firmness, pulp yield, and water productivity for pulp yield were evaluated. Irrigation deficit, with the replacement of less than 100% of crop evapotranspiration, allowed to save water but significantly reduced the size of the fruits and the production of concentrated pulp. The suspension of irrigation before harvest decreased pulp yield and fruit size. The highest water productivity for pulp yield of tomato fruits occurred under water deficit with 50% of crop evapotranspiration. Irrigation depths from 50 to 150% of crop evapotranspiration and suspension before harvest does not influence total soluble solids content, pH, and fruit firmness.

Key words: *Solanum lycopersicom* L., subsurface drip irrigation, irrigation depths, suspension of irrigation, crop evapotranspiration

RESUMO: A pesquisa objetivou avaliar a qualidade pós-colheita de frutos de tomateiro para processamento industrial, submetido a lâminas de irrigação e períodos de corte de irrigação antes da colheita, irrigado por gotejamento subterrâneo em áreas de Cerrado na região Sul de Goiás, Brasil, nos anos de 2015 e 2016. Os experimentos foram instalados no delineamento em blocos ao acaso, com quatro repetições, em parcelas subdivididas. Nas parcelas avaliaram-se cinco lâminas de irrigação (50, 75, 100, 125 e 150% da evapotranspiração da cultura) e nas subparcelas cinco períodos de suspensão da irrigação (0, 7, 14, 21 e 28 dias antes da colheita). Após a colheita, que ocorreu aos 125 dias após o transplantio das mudas, foram avaliados a massa média de frutos, o formato dos frutos (diâmetro longitudinal e transversal), teor de sólidos solúveis totais, acidez titulável, pH, firmeza, rendimento de polpa e produtividade da água para rendimento de polpa. A irrigação deficitária, com reposição menor que 100% da evapotranspiração da cultura, permitiu economizar água, mas reduziu significativamente o tamanho dos frutos e o rendimento de polpa. A suspensão da irrigação em antecedência à colheita diminuiu o rendimento de polpa e o tamanho dos frutos. As maiores produtividades da água para rendimento de polpa dos frutos de tomateiro ocorreram sob déficit hídrico com 50% da evapotranspiração da cultura. Lâminas de irrigação de 50 a 150% da evapotranspiração da cultura e a suspensão da irrigação antes da colheita não influenciaram os teores de sólidos solúveis totais, pH e firmeza dos frutos.

Palavras-chave: *Solanum lycopersicom* L., gotejamento enterrado, lâminas de irrigação, suspensão da irrigação, evapotranspiração da cultura

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Introduction

Water is one of the factors that most affect the development, yield, and industrial quality of processing tomato crops. Generally, deficit irrigations favor fruit quality (total soluble solids and titratable acidity) and water productivity and can harm the crop yield (Patanè et al., 2011; Moreira et al., 2012; Wang et al., 2015; Nangare et al., 2016; Rebouças Neto et al., 2017; Wang & Xing, 2017; Samui et al., 2020).

According to Patanè et al. (2011), deficit irrigations during the vegetative phase or from flowering, associated with longer periods of suspension of irrigation before fruit maturation, increased the content of total soluble solids of the fruits, with lower yield losses. Similar results were observed in Brazil (Moreira et al., 2012; Silva et al., 2018; Silva et al., 2019) and other countries (Wang et al., 2015; Wang & Xing, 2017; Samui et al., 2020), when was possible to conclude that the water deficit elevates the total soluble solids content and the acidity of tomato fruit. However, this procedure tends to reduce the yield and fruits size of the crop due to water stress (Soares et al., 2013; Morales et al., 2015; Rebouças Neto et al., 2017; Viol et al., 2018).

According to Moreira et al. (2012), to obtain higher soluble solids contents, it is convenient to reduce the amount of water, increase the irrigation interval in the ripening phase of tomato fruits and completely suspend the irrigations several days before harvest. However, tomato water requirements are related to the hybrid, development stage, and edaphoclimatic conditions of cultivation (Bacallao & Fundora, 2014; Silva et al., 2019).

In Brazil, the Cerrado biome is the main tomato-producing region, where irrigation management is still one of the main challenges for tomato growers, who mostly use empirical irrigation management methods. The cultivation areas are irrigated by center pivot sprinkler systems, resulting in economic, environmental, and social losses (Delazari et al., 2016). Thus, this study evaluated the postharvest quality of processing tomato fruits, submitted to irrigation depths and suspension periods of irrigation before harvest, irrigated by subsurface drip in Cerrado areas in the southern region of the Goiás state, Brazil.

Material and Methods

The experiment was conducted in 2015 (from June to October) and 2016 (from May to September) at the Instituto Federal Goiano, Campus Morrinhos, Goiás state, Brazil, at 17° 49’ 19.5” S, 49° 12’ 11.3” W, and altitude of 885 m. The local climate is AW-type, semi-humid tropical, with rainy summer and dry winter, according to the Köppen classification.

The experiment was carried out in a Cerrado area of Oxisol, bulk density of 1.16 g cm^{-3}, moisture contents of 0.36 m^3 m^{-3} (-10 kPa), and permanent wilting point of 0.23 m^3 m^{-3} (-1500 kPa), in the 0-30 cm layer. The soil tillage was carried out in a conventional way in 2015 and under the no-tillage system in 2016. According to the soil analysis (Table 1), the soil fertilization was carried out, aiming at an expected yield of 130 t ha^{-1} (CFSGO, 1988).

In 2015, liming was carried out 51 days before transplanting. In 2016, liming was not necessary. In both years of research, fertilization was done in the planting furrow, three days before transplanting the seedlings, and topdressing fertilization was applied through fertigation, 50% at 22 days after transplanting (DAT) (urea - 45% N and potassium chloride - 58% K_2O) and the other 50% at 35 DAT (calcium nitrate - 19% N and 19% Ca and potassium chloride - 58% K_2O).

Tomato seedlings, BRS Sena hybrid, were transplanted 26 days after sowing, with soil at field capacity. The fertilizer was incorporated in the soil used to cover the transplanting furrow. Below each transplanting furrow, there was a dripping tube. Until 8 DAT, the plants were irrigated daily; from 8 to 25 DAT, they were irrigated on alternate days, replacing 100% of the crop evapotranspiration (ETc) to ensure the seedlings survived. From that point on, they were submitted to the treatments.

The experiments were established under a randomized block design, with four replicates arranged in a split-plot scheme. Five irrigation depths equal to 50, 75, 100, 125 and 150% of crop evapotranspiration (ETc) were applied in the plots. In the subplots, five periods of irrigation suspension: 0, 7, 14, 21 and 28 days before harvest (Marouelli et al., 2007) were evaluated. Each experimental plot consisted of five subplots. Each subplot was composed of three rows of plants of 5.5 m in length, spaced 1.10 m between them. The plants were spaced at 0.30 m in the planting row, totaling 18 plants per row, 54 plants per subplot, 270 plants per plot, and 5,400 plants in the experiment, which results in a stand of around 30,303 plants ha^{-1}. The blocks and plots were spaced in 6.0 and 4.0 m, respectively.

The drip irrigation system was installed at 0.20 m depth, using a self-compensating emitter per plant, a flow of 2.2 L h^{-1}, and an antisiphon system operating at a pressure of 150 kPa. The ETc (100%) was determined by the mass variation of five weighing lysimeters, with a capacity of 52 L, diameter of 32.5 cm, and precision of 10 g, which were filled with soil

Table 1. Chemical and particle-size characteristics of soil in the experimental area, in Morrinhos, GO, Brazil

Soil layer (cm)	Chemical characteristics								Organic matter	Particle-size characteristics		
	pH	P	K	Na	Ca	Mg	Al	H + Al		Sand	Silt	Clay
	(water)	(mg dm^{-3})			(cmol$_c$ dm^{-3})				(g dm^{-3})	(g kg^{-1})		
2015												
0-20	5.7	2.6	44.0	9.0	2.9	1.2	0.0	2.6	31.1	486	100	414
20-40	5.5	1.5	35.0	8.0	1.8	0.8	0.1	2.9	26.0	494	121	385
2016												
0-20	6.4	13.3	94.4	87.0	3.2	1.2	0.0	1.7	37.8	-	-	-
20-40	5.7	13.3	6.5	88.0	0.8	0.8	0.0	2.3	32.6	-	-	-

Methodology used: pH - Electrode in soil suspension: water (1: 2.5); P, K, and Na - Mehlich 1; Ca, Mg, and Al - Potassium chloride; H + AL - Calcium acetate at pH 7.0; Organic matter - Wet oxidation (organic carbon concentration x 1.724) naturally dried by the air of the experimental area (layer 0-15 cm) and cultivated with a tomato plant. The accumulated ETc values obtained in the lysimeters during the conduction of the experiments (125 days) were 490.2 and 426.9 mm, and the reference evapotranspiration (ETo) values, calculated by Penman-Monteith, according to Allen et al. (1998), were 474.1 and 492.2 mm, in the years 2015 and 2016, respectively. The irrigation times of each treatment were calculated according to ETc, wetted strip width, spacing, dripper flow rate, and irrigation depth (treatments). The meteorological data were monitored at an automatic meteorological station located about 400 m from the experiment.

During the experiments, the meteorological station recorded maximum temperatures of 35.4 and 34.1 °C, minimum temperatures of 11 and 8.2 °C, precipitation of 86 and 27.6 mm in 2015 and 2016, respectively. In the first year of study, 30.6 mm of rainfall occurred up to 40 DAT and 55.4 mm in the final phase of the experiment. In the second year, 13 mm of rain occurred up to 25 DAT and 14.6 mm in the final 30 days of the experiment.

From 97 days after transplantation, irrigation was gradually suspended. Initially, the suspension was applied to the subplots 28 days before harvest. Seven days later, the subplots of 21 days and so on until reaching the harvest date, when the plots with zero-day irrigation suspension were irrigated 12 hours before harvest.

The harvest was carried out manually on the central row of the subplot at 125 DAT. After harvest, 30 ripe fruits of each subplot were randomly chosen for postharvest evaluations in the laboratory. With these 30 ripe fruits, the average fruit mass (AFM, g per fruit) using a precision scale of 1 g, the shape of the fruit through the transverse diameter (TD, mm) and longitudinal diameter (LD, mm) was measured with a digital caliper, as proposed by Silva et al. (2018).

To determine the contents of total soluble solids (SS, °Brix), titratable acidity (% citric acid), and pH, the juice from 20 fully ripe fruits of the sample was processed in a fruit centrifuge to obtain the juice. Two drops of juice were placed on the prism of a portable refractometer of scale 0 to 32 °Brix, and then the refractive index was read (IAL, 2008). Before reading the sample, the refractometer was calibrated with distilled water. A direct pH reading was carried out with a digital pH meter using a portion of the juice. Titratable acidity (TA) was determined by the official methodology described by IAL (2008), by neutralization titration with 0.1 N sodium hydroxide (NaOH) until pH 8.2.

Firmness (FZ, kgf cm^{-2}) was determined by the planer method in 10 ripe fruits of each treatment sample. For greater confidence in the results, two readings were performed on each fruit; that is, in each treatment, 20 firmness readings were made, and the average per treatment was calculated. The FZ of the fruits was calculated considering the deformed area and the weight of the glass plate (Calbo & Nery, 1995).

The industrial pulp yield (PY) was calculated after harvest, according to the methodology proposed by Giordano et al. (2000) (Eq. 1).

$$PY = \frac{TFY \cdot 0.95 \cdot {}^{\circ}BRIX}{28} \quad (1)$$

where:

PY - concentrated pulp yield (t ha^{-1}) at 28 °Brix;
TFY - total fruit yield per treatment (t ha^{-1}); and,
°Brix - total soluble solids content of fruits per treatment.

Water productivity (WP) for pulp yield (PY) was calculated by the relation between PY (kg ha^{-1}) by the total volume of proportional water of each treatment (m^3 ha^{-1}), summing up all irrigations performed throughout the experiment (Eq. 2), as also proposed by Silva et al. (2018) and Mattar et al. (2020)

$$WP = \frac{PY}{V} \quad (2)$$

where:

WP - water productivity (kg m^{-3});
PY - average pulp yield of each treatment (kg ha^{-1}); and,
V - volume of water applied per hectare in each treatment (m^3).

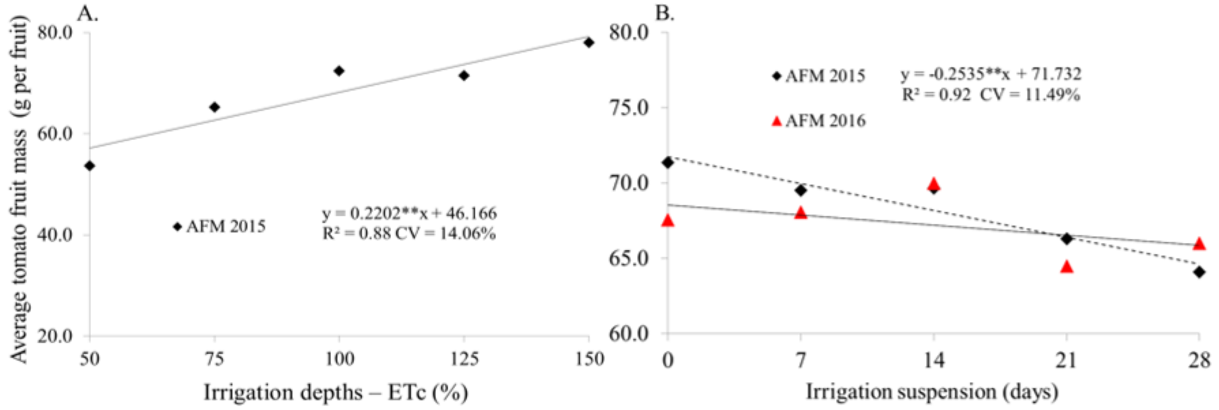
The evaluated data were submitted to the analysis of variance (F test) at $p \leq 0.05$, using the Software SISVAR (Ferreira, 2011). When there was a significant effect of the treatments on the evaluated variables, the polynomial regression analysis was applied in the primary treatments (irrigation depths) and the secondary treatments (periods of irrigation suspension). The regression model chosen was according to the significance level of up to 0.05 probability by the F test and the highest coefficient of determination (R^2).

Results and Discussion

There was no influence of the interaction between the irrigation depths (%ETc) and irrigation suspension periods on any of the variables evaluated in postharvest in both years. In the first year, the irrigation depths significantly influenced ($p \leq 0.01$) the average fruit mass (AFM), transversal (TD) and longitudinal (LD) diameter of the fruit, pulp yield (PY), titratable acidity (TA), and water productivity for pulp yield (PY). The periods of suspension of irrigation before harvesting had a significant effect on the PY ($p \leq 0.01$) and AFM ($p \leq 0.05$). In the second year, the irrigation depths influenced the PY, water productivity for pulp yield (PY) ($p \leq 0.01$), and TA ($p \leq 0.05$), and the suspension periods of irrigation before harvest influenced the water productivity for pulp yield (PY) ($p \leq 0.01$), AFM, PY and fruit shape LD ($p \leq 0.05$).

In both years, the content of SS, pH, and FZ were not significantly influenced by the irrigation depths and suspension periods of irrigation. Also, TA was not influenced by the suspension periods of irrigation. Possibly, these variables may have been influenced by the rains of 55.4 and 14.6 mm at the end of the crop cycle, in 2015 and 2016, respectively, which may have equalized the humidity on the soil surface, canceling the possible effects of treatments on these variables.

The average fruit mass (AFM) increased linearly as the irrigation depths increased (Figure 1A) in the first year. In the second year, there was no effect of the treatments on this variable. However, the suspension periods of irrigation



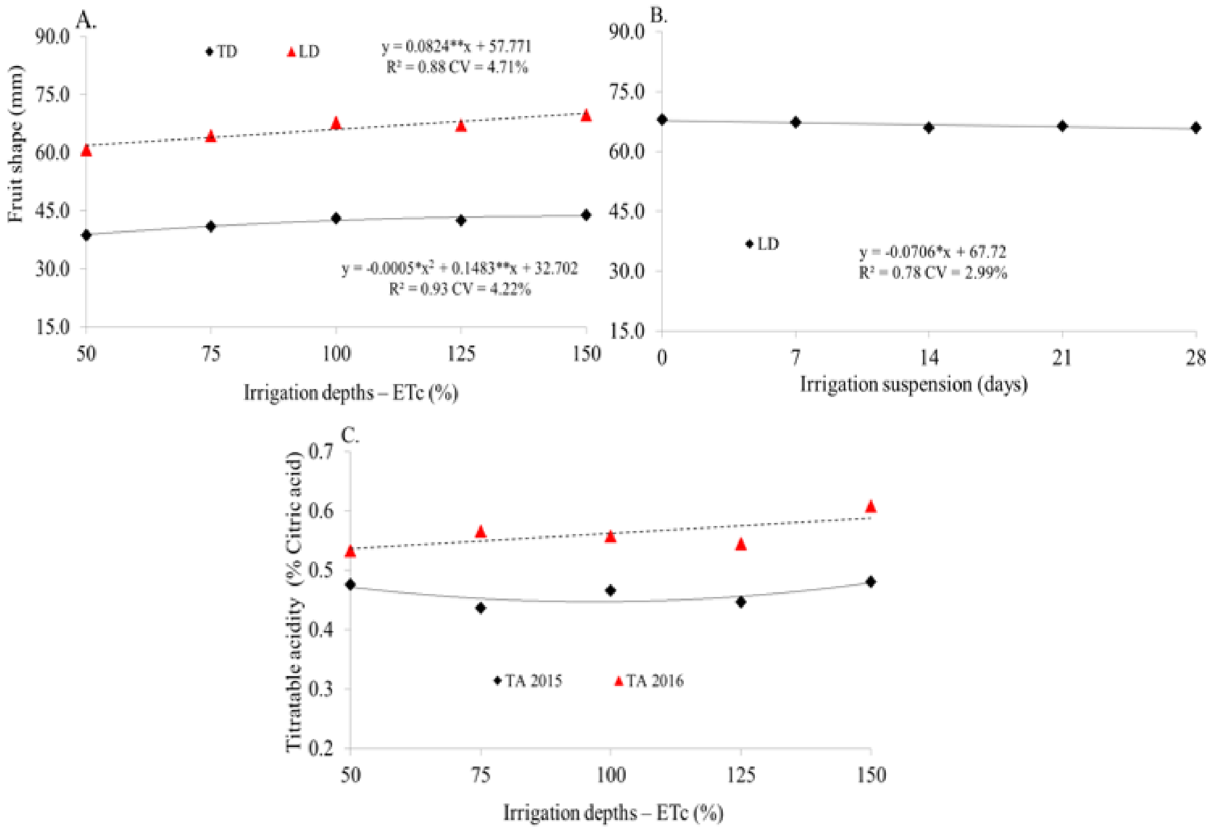
** - Significant at p ≤ 0.01 by F test

Figure 1. Average tomato fruit mass (AFM) as function of irrigation depths in 2015 (A) and AFM as function of suspension periods of irrigation in 2015 and 2016 (B), of tomato fruits harvested at 125 DAT

significantly influenced the AFM in both years. There was a linear decreasing effect for AFM as the period without irrigation increased before harvest (Figure 1B). The reduction in AFM was probably due to the lower level of soil moisture content, as the period without irrigation before harvest increased. Lower soil moisture certainly reduced the water content of the fruits and consequently caused lower AFM. The average fruit mass data for 2016 did not adequately adjust to the linear equation ($y = -0.0955^{*}x + 68.557$; $R^2 = 0.46$; CV = 8.18%). The average mass was equal to 67.22 g per fruit.

Regarding fruit shape, the transverse diameter (TD) had a quadratic behavior, and the longitudinal diameter (LD) showed a linear increasing effect according to the increase in irrigation depths (%ETc) in the first year (Figure 2A). However, irrigation depths did not significantly influence these variables in the second year. When the suspension periods of irrigation before harvest on the TD and LD of the fruits were analyzed, there were no significant effects of the treatments in the first year. However, in the second year, the LD had a linear decreasing behavior as the suspension periods of irrigation before harvest increased (Figure 2B).

The titratable acidity (TA) data for 2015 and 2016 did not fit perfectly to the quadratic equation model ($y = 1E\text{-}05^{**}x^2 - 0.0022^{**}x + 0.553$; $R^2 = 0.50$; CV = 7.67%), and linear equation model ($y = 0.0005^{*}x + 0.5104$; $R^2 = 0.51$; CV = 7.67%), being the mean values found 0.46 and 0.56%, respectively (Figure



*, ** - Significant at p ≤ 0.05 and p ≤ 0.01 by F test, respectively

Figure 2. Transverse (TD) and longitudinal (LD) diameter as function of irrigation depths in 2015 (A), LD as function of suspension periods of irrigation in 2016 (B), and titratable acidity (TA) of tomato fruits at 125 DAT, as function of irrigation depths (%ETc) in 2015 and 2016 (C)

2C). However, the suspension of irrigation before harvest did not significantly influence TA in any of the years.

Water deficit conditions reduced fruit size. This response was verified in both years (Figures 2A and B). The results found are similar to those of Rebouças Neto et al. (2017) in Fortaleza, CE, Brazil, using the Heinz 9498 tomato hybrid for industrial processing and the dominator F1 hybrid, when they concluded that irrigations below 120% of the reference evapotranspiration (ETo) reduced the diameter and average fruit mass.

The results also confirmed those found by Nangare et al. (2016) in India and Viol et al. (2018) in Lavras, MG, Brazil, who observed larger fruit size with irrigation depth equal to 100% of the crop evapotranspiration and 140% of the ETo measured in a class "A" mini pan with cultivation in a greenhouse, respectively. The results of this research also corroborate those of Soares et al. (2013) in Pombal, PB, Brazil, who verified a linear increasing effect of the average fruit mass as irrigation depths increased from 60 to 120% of ETc.

The titratable acidity (TA) results found in this research differ from those of Patanè et al. (2011) and Nangare et al. (2016), who found that irrigation regimes did not influence the titratable acidity. However, they found trends towards higher amounts of citric acid in fruits subjected to water deficit. Also, the results corroborate those found by Mattar et al. (2020) in Saudi Arabia, where they observed that irrigations below 100% of the ETc decrease the titratable acidity. Irrigations with 50% replacement of ETc provided mean values of TA equal to 0.55%, which are consistent with the results found in this study, where irrigations with 50% of ETc provided TA of 0.48 and 0.54% in 2015 and 2016, respectively.

The concentrated pulp yield is directly related to the total soluble solids content and crop yield (Giordano et al., 2000). The deficit and excess of water harmed the PY of BRS Sena tomato cultivar fruits. The highest pulp yield was estimated at 17.35 and 10.81 t ha^{-1}, with a water replacement depth of 117.21 and 136.36% of ETc in 2015 and 2016, respectively (Figure 3A). The longer the suspension period of irrigation before harvest, the lower the PY of tomato fruits in both years (Figure 3B).

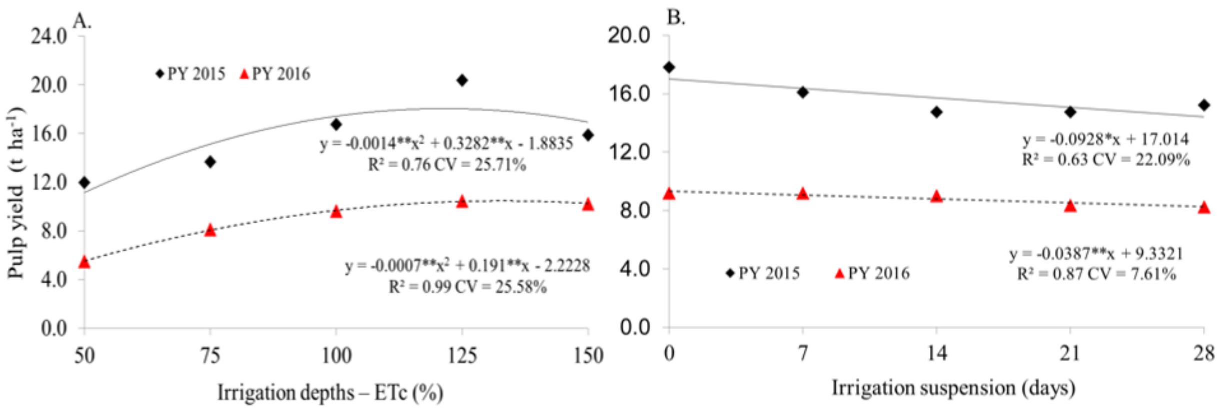
Pulp yield (PY) results observed with irrigation deficits of 50% of ETc are lower by about 70 and 80%, compared to the maximum PY estimated with 117.21 and 136% replacement of ETc in 2015 and 2016, respectively. The results of this study corroborate those observed by Patanè et al. (2011) in Italy, who observed a reduction of about 20% in PY when they irrigated tomato with 50% ETc, compared to treatments irrigated with 100% ETc. The results are also consistent with those observed by Silva et al. (2019) in Morrinhos, GO, Brazil, who concluded that deficit irrigation with 50% of ETc reduced tomato yield by up to 70 t ha^{-1}, when compared to the irrigation depth of 125.47% of ETc, that provided the highest tomato yield in 2015. These results corroborated those of Morales et al. (2015), Rebouças Neto et al. (2017) in Brazil, Wang et al. (2015) in China when they verified lower tomato crop yields as the water deficit in tomato plants increased.

Regardless of the years of evaluation (2015 and 2016), the highest water productivity (WP) for PY were 4.70 and 2.56 kg m^{-3}, which occurred in the lowest irrigation replacement depth (50% of ETc) (Figures 4A). In the first year, there were no effects of suspension periods of irrigation on water productivity. In the second year, the more days without irrigation before harvest (28 days), the higher the water yield for PY (Figure 4B).

Results obtained corroborate those found by Patanè et al. (2011) in the region of Sicily (Italy), where they found that the water productivity for commercial tomato fruit yield is higher under water deficit. With the irrigation depth of 50% of ETc, they obtained WP of 19.65 and 28.07 kg of fruit m^{-3} in two consecutive years, respectively. The results also corroborate those found by Nangare et al. (2016) in India, which obtained the highest water productivity for total fruit production (17.9 kg m^{-3} average of two years of cultivation), with irrigation deficits of 60% of ETc.

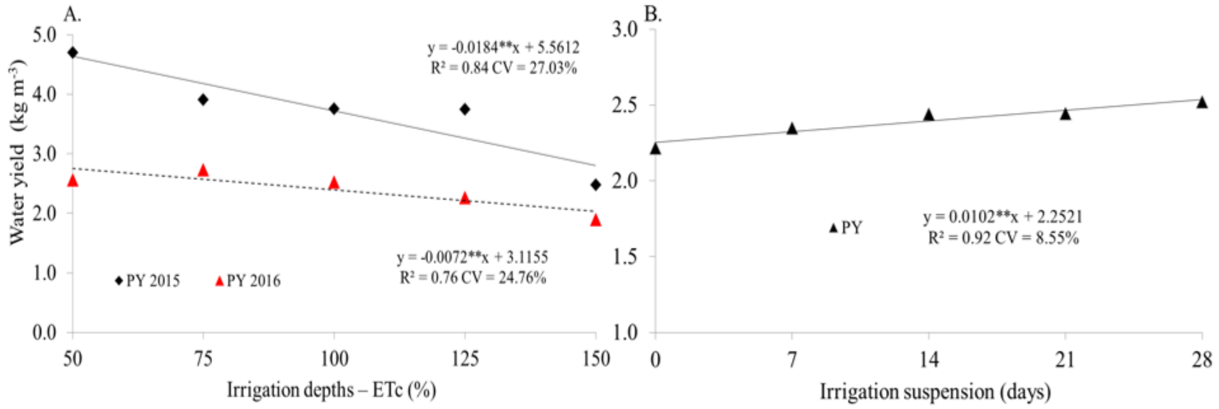
A fact also evidenced by Silva et al. (2019) in Morrinhos, GO, Brazil, Mattar et al. (2020) in Saudi Arabia, where the highest water productivity for total fruit production was 15.55 and 12.65 kg m^{-3} and 12.44 and 12.15 kg m^{-3} in two consecutive years, respectively, with irrigation depth of 50% ETc. Results are also consistent with Wang & Xing (2017) in China, Silva et al. (2018) in Morrinhos, GO, Brazil, and Samui et al. (2020) in India, who concluded that under water deficit, the tomato has higher water productivity.

In the two years of research, rainfall occurred at the end of the crop cycle, which somehow influenced the treatments with suspension periods of irrigation already being applied, which certainly may have influenced some of the postharvest results in the two years of research. In the first year, no typical



*, ** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by F test, respectively

Figure 3. Pulp yield (PY) of tomato fruits at 125 DAT as function of irrigation depths (%ETc) (A) and suspension periods of irrigation before harvest (B) in 2015 and 2016



** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by F test

Figure 4. Water productivity (WP) for pulp yield (PY) of tomato fruits at 125 DAT as function of irrigation depths (%ETc) in 2015 and 2016 (A) and suspension periods of irrigation before harvest in 2016 (B)

symptoms of begomoviral were observed in the crop. Although in the second year, despite the intensification of whitefly control, there was an intense pressure of the pest in the tomato fruit, which ended up in a high incidence of virus symptoms caused by a complex of viruses of the begomoviral genus, with typical symptoms of roughness, deformation, leaf rolling, decrease in leaf area and consequently less development, water, and nutrient absorption and lower crop yield (Inoue-Nagata, 2005). This fact explains the lower water consumption and worse yield of the hybrid tomato, BRS Sena, in 2016 compared to 2015.

Conclusions

1. Deficient irrigation, with replacement of less than 100% of crop evapotranspiration, allowed to save water but significantly reduced the size of the fruits and the production of the concentrated pulp of the fruits of the BRS Sena tomato cultivar.

2. The suspension of irrigation before the harvest decreased pulp yield and fruit size of the BRS Sena tomato cultivar.

3. The highest water productivity for pulp yield of tomato fruits occurred under irrigation depth equal 50% of crop evapotranspiration.

4. Irrigation depths (from 50 to 150% of crop evapotranspiration) and irrigation suspension before harvest do not influence total soluble solids content, pH, and fruit firmness.

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