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Qualitative Characteristics of Processing Tomato Cultivated Under Water Deficit Induced in the Vegetative Growth Stage

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Water management for irrigation can be defined as a strategy of planning and support systems to save and optimize water resources for human and environmental purposes. Regulated deficit irrigation (RDI) or soil water deficit is a strategy where the amount of water used is kept below the maximum level, and the minor stress that develops has minimal effects on yield. In this irrigation model, the entire root zone is irrigated at less than the maximum crop evapotranspiration, in different phenological phases, without interfering significantly in the physiological behavior of crops. This allows a quantitative and qualitative increase in different crops, and water use efficiency in the agriculture. The present study aimed to identify the effect of regulated deficit irrigation on the qualitative standards of tomato cultivar N-901 for industrialization purposes. Deficit irrigation was carried out during the vegetative growth stage, considering different seedling transplanting periods. The experiment was conducted in a greenhouse at the School of Agronomy of the Federal University of Goias (UFG). The experimental design was a randomized complete block with five replicates, in a 2 x 4 factorial arrangement. The plots were made by combining two periods of irrigation deficit (10 and 20 days after transplanting - DAT) and four soil water tension thresholds (30; 40; 60; and 70 kPa). The results showed that the studied cultivar responded significantly to the soil (substrate) water tension, providing different agronomic development profiles. Water deficit was shown to reduce the total volume of water applied during the cycle, increasing the concentration of soluble solids in the fruits and maintaining titratable acidity in the standards of processing industries, in addition to increasing pulp yield when compared to processing industries. The tensions of 60 and 70 kPa applied at 10 DAT were the ones that most intensified the soluble solids content without significantly affecting the agronomic development of the crop.
Keywords: water productivity, deficit irrigation, pulp yield, soluble solids.

1. Introduction

Brazil stands out as the ninth world producer of industrial tomato, with 28% of the national production taking place in Goias state. In 2017, production was approximately 1 million tons, in 13 thousand hectares of cultivation (IBGE, 2017). Silva et al. (2013) emphasize that to obtain better industrial yields and, consequently, maximize economic returns, appropriate nutritional management, water supply, selection of improved cultivars, and crop sanitation are necessary.
Kögler and Söffker (2017) accentuate that water deficits during cultivation can result in morphological and/or metabolic anomalies and affect crop development (water stress), minimizing productive and qualitative efficiency. The authors also suggest how the crop responds to water stress through variations in cell growth and protein synthesis, as well as low accumulations of sugars. However, Cantore et al. (2016) suggest that controlled irrigation deficit (ID) in the different phenological phases has become an important strategy in the current water scarcity scenario. This is because ID can increase the efficiency of water and nutrient use, reducing irrigation frequency and production costs, allowing for the control of vegetative growth and canopy density, and leading to higher qualitative yields per unit of water applied. The response of plants to ID can be summarized as a factor of accumulation of root growth stimuli, maintenance of high leaf water potential,

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osmotic regulation of leaf-turgor pressure, and adaptation to existing soil water status, for example, reduction of leaf elongation and stomatal closure (Dodd et al., 2015). Water deficit is a strategy where the amount of water supplied to the plant is kept below its maximum demand, however, in an amount in which the plant development/growth is not significantly impaired. Zheng et al. (2013) point out that knowing the exact moment of water application is essential for the successful implementation of ID, since tomato is sensitive to water stress in the different stages of phenological development. According to Marouelli and Silva (2007), the application of controlled ID during the vegetative stage promotes better development and growth of tomato roots without affecting the leaf area and soluble solids content of table tomato. According to Zheng et al. (2013), the efficiency of ID is notorious for concentrating the flavor and the nutritional components in the fruits, by concentration or accumulation effect. Ripoll et al. (2014) emphasize that ID practices are a way of managing fruit flavor, exploring the morphological, physiological, and molecular changes that occur in plants under this cultivation strategy. In the present study, deficit irrigation was carried out during the vegetative growth stage, considering different seedling transplanting periods. Aiming to identify the effect of regulated deficit irrigation on the qualitative standards of tomato cultivar N-901 for industrialization purposes.

2. Materials and methods

The experiment was carried out in a greenhouse at the School of Agronomy of the Federal University of Goias (UFG), (coordinates are: 16°32’ S latitude, 49° 21’ W longitude, and altitude of 730 m). Indoor climatic conditions were controlled at a temperature of 25 °C and relative air humidity of 48% (Alvarenga, 2013). The cultivar used was N-901. Seedlings were transplanted to pots with 0.50 x 0.30 m (depth x diameter), with 0.028 m^3 soil. Initially, tomato seeds were germinated in organically enriched peat, in open plastic trays with a vermiculite cover to facilitate aeration. Standard cultural practices were adopted during the crop-growing season. A total of 50 kg N ha^{-1}, 300 kg P_2O_5 ha^{-1}, and 50 kg K_2O ha^{-1} fertilizer was applied according to recommendations based on soil analyses, Table 1. During the growing season, weeding was performed manually and neonicotinoid insecticide (Evidence 700 WG®) was applied according to commercial recommendations every seven days from 10 to 50 DAT. The experimental design was a randomized complete block with three replicates, in a 2 x 4 factorial arrangement. The plots were made by combining two periods of irrigation deficit (10 and 20 days after transplanting - DAT) and four soil water tension thresholds (30; 40; 60; and 70 kPa). Drip irrigation was performed through self-compensating online dripper (4 L h^{-1}), Click Tif - HD PC, developed by NaanDanJain. Lateral lines were composed of 16-mm polyethylene tube, PN 30, and each treatment had an independent control valve at the beginning of each lateral line. Soil moisture monitoring was based on the soil dielectric constant, using a Time Domain Reflectometer (TDR, model EC-5), installed at 0.2 m depth. Data were recorded by an Em50 datalogger. Volumetric moisture content at field capacity (FC) and permanent wilting point (PWP) were determined using a pressure plate apparatus (Richards, 1965). The measured FC (-11.6 kPa) and PWP (-1505.7 kPa) averaged 36 and 21 %, respectively (Walker, 1989).
To evaluate the effect of the different soil water tension levels on the agronomic characteristics of N-901 tomato, root dry matter and whole plant dry matter (stem, leaf, and flower) were measured using a balance with a resolution of 0.01 g. Drying was performed at 65 °C for 72 hours in a forced-circulation oven until constant weight, at harvest. Growth was monitored by measuring plant height (distance between the ground level and the apical bud) and stem diameter (in the plant neck) every 10 days to stabilize plant growth. A manual scanner was used to determine the leaf area once a week in the reproductive stage of the tomato.
Each treatment was harvested when ripe fruit rate reached about 85%. Ripe tomato fruits were manually harvested, graded, and some qualitive characteristics of the fruit were investigated based on samples of red fruit collected at random from each treatment plot. The number of tomato fruits per plant (NFP) and total yield-Y (t ha^{-1}) were observed at each harvest. The fresh weight (FW) of each tomato fruit was measured using a balance with a resolution of 0.01 g. Firmness (N) was measured by flattening method, with a horizontal flattener; this equipment was developed to yield rapid and accurate compression responses, represented by the ratio between the applied force and the measured flattened area, according to Calbo and Nery (1995). Total soluble solids (TSS, ^{o}brix) was measured with a handheld digital refractometer, and the titratable acidity of tomato fruit pulp (TA, %) was determined by titrating against standard NaOH solution 0.1 Mol/l until pH 8.1, using phenolphthalein as an indicator, and expressed as anhydrous citric acid per 100 g (AOAC, 1997 - method 942.15). The irrigation water productivity WP_{irrig}, expressed in kg ha^{-1} mm^{-1}, was computed as Eq. (1), according to Zheng et al. (2013):

$$WP_{irrig} = \frac{Y_a}{IWU} \tag{1}$$

Where IWU is the seasonal irrigation water use (mm) and Y_a is the total tomato fruit yield (kg ha^{-1}). The experiment was highly controlled, without runoff or deep percolation. Data were subjected to analysis of variance (ANOVA) using SISVAR software (Ferreira, 2011). The significance of the irrigation treatments was determined with an F test at the 0.05 probability level.

3. Results and discussion

Table 1 presents information on the physical and chemical properties of the soil.

Table 1: Physical and chemical characteristics of the soil.

Texture			Organic matter (%)	pH	P (mg dm^{-3})	K (cmol dm^{-3})	Ca (cmol dm^{-3})
Sand (%)	Silt (%)	Clay (%)					
46.0	20.0	34.0	2.2	6.8	37.9	4.6	2.9

Table 2 present the results of the analysis of variance for the parameters plant growth and fruit quality of processing tomato under different deficit irrigation strategies.

Table 2: Results of the analysis of variance of growth parameters of tomato as affected by different deficit irrigation strategies.

SV	D.F.	PH	SD	LA	RDW	SDW	FDW	*Y*	F	TSS	TA	WP_{irrig}
Ψ	3	179.74*	0.004^{ns}	1380.05*	5.22^{ns}	253.23*	1.77*	453.82^{ns}	1.05^{ns}	0.23*	0.0045*	349.29^{ns}
BT	1	7.37^{ns}	0.0001^{ns}	10.37^{ns}	31.72^{ns}	75.58^{ns}	0.01^{ns}	66.10^{ns}	2.27^{ns}	0.04^{ns}	0.0002^{ns}	814.56^{ns}
Ψ x BT	3	51.88^{ns}	0.01^{ns}	140.20^{ns}	11.86^{ns}	71.85^{ns}	0.06^{ns}	77.24^{ns}	1.82^{ns}	0.07^{ns}	0.0001^{ns}	293.90^{ns}
Blocks	2	8.07	0.09	925.02	65.11	5840.11	0.75	4956.43	2.81	0.01	0.0001	12213.57
Error	14	46.67	0.01	249.50	56.73	51.70	0.46	212.39	0.89	0.03	0.0001	489.62
Total	23	-	-	-	-	-	-	-	-	-	-	-
C.V	-	10.37	6.51	16.05	22.15	7.63	18.57	18.74	17.23	3.72	2.87	17.97

SV – Source of Variation; Ψ - soil water tension thresholds; BT – Begin Times; D.F. – Degrees of Freedom; PH – Plant Height (cm); SD – Stem Diameter (mm); LA – Leaf Area (cm^2); RDW. - Root Dry Weight (kg); SDW – Stem Dry Weight (kg); FDW. - Fruit Dry Weight (kg); *Y* – Total Yield (t ha^{-1}); F - Firmness (N); TA – Titratable Acidity (%); TSS. - Total Soluble Solids (°Brix); WP_{irrig} - Water Productivity (kg ha^{-1} mm^{-1}); CV - Coefficient of Variation; ^{ns} Nonsignificant; *Significant at the 5% probability level (*P*<0.05).

Observing the effect of the tensions, the variables root dry weight, fruit dry weight, plant height, and leaf area were significantly affected at 5% probability, and the variables titratable acidity and soluble solids were significant at 5% probability. The initial period of water deficit and its interactions did not significantly affect the growth and fruit quality of N-901 tomato for industrial purposes.

Al-Yahyai et al. (2010) observed increased total soluble solids of fruits when studying tomato cultivation under saline field conditions, noting that the presence of salt reduced the water absorption by the plants and, consequently, by the fruits. These results corroborate with those identified in this study.

Table 3 shows the means and minimum differences (MSD) of the variables evaluated in this study for analysis of the effect of the initial period of water deficit. The variables were not statistically different from each other, that is, they were not significantly affected by the initial period of water deficit.

Table 3: Results of the means and minimum significant differences for analysis of the effect of the initial period of water deficit.

DAT	P.H. (cm)	S.D. (mm)	L.A. (cm^2)	R.D.W. (g)	Y (t ha^{-1})	TSS (°Brix)	Titratable Acidity (%)	WP_{irrig} (kg mm^{-1})
10	65.29^a	1.23^a	65.29^a	35.14^a	79.41^a	5.02^a	3.92^a	128.3^a
20	66.40^a	1.23^a	66.40^a	32.84^a	76.09^a	4.94^a	3.86^a	117.8^a
DMS	5.98	0.07	13.83	6.59	12.76	0.16	0.09	19.37

Values followed by different lowercase letters in the same column differ significantly by Tukey test at the 0.05 probability level.

The average productivity, Table 4, was 79.41 e 76.09 t ha^{-1}, respectively, 10 e 20 DAT, accounting for the values, (89.67; 69.27; 84.85; and 73.88 t ha^{-1} for 10 DAT) and (89.67; 73.75; 72.75 and 68.23 t ha^{-1} for 20 DAT), obtained in response to soil water tension. Reis et al. (2013) found superior value, with a mean of 123 t ha^{-1}. Wang et al. (2011) reported a range of 41.83 a 68.47 t ha^{-1} for greenhouse tomato under different amounts of deficit irrigation.

There were no significant differences in water use efficiency. Machado and Oliveira (2005) also did not observe significant differences in irrigation water use for tomato yield. Carvalho et al. (2011) point out that increased soil water availability tends to decrease WP_{irrig}. Figures 1 and 2 present the behavior of the variables that were statistically affected by soil water tension: plant height, stem dry weight, leaf area, fruit dry weight, total soluble solids, and titratable acidity (see Tables 2).

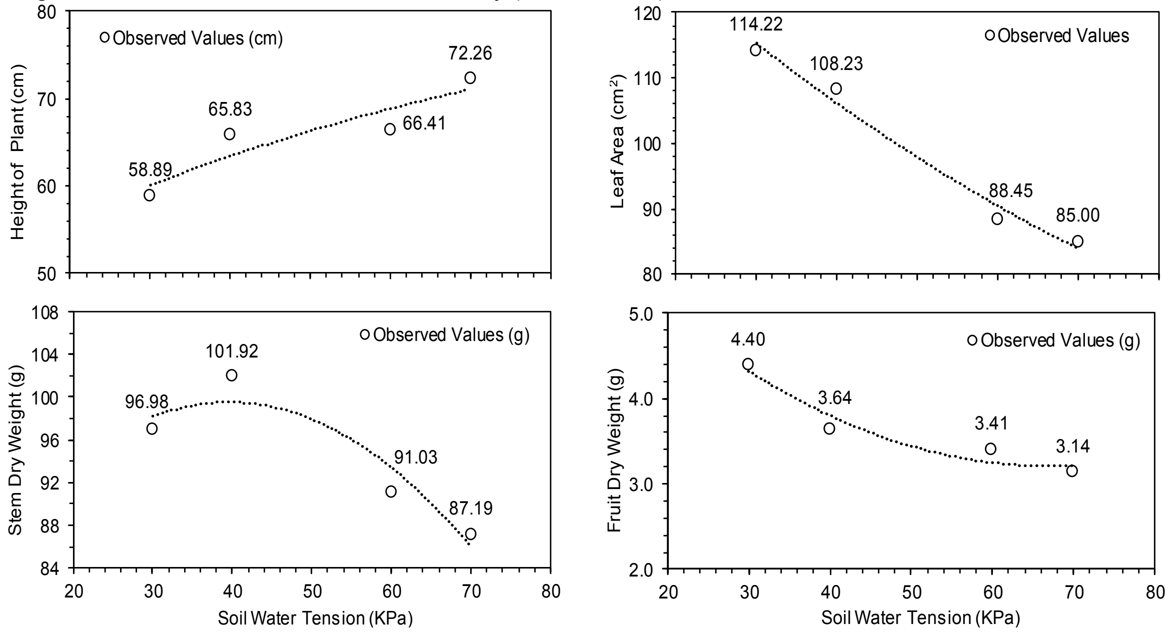

Figure 1: Relationship between soil water tension and of growth parameters of tomato: [A] plant height; [B] stem dry weight; [C] leaf area and [D] fruit dry weight

The plants reached the highest heights with soil water tension at 70 kPa, and the lowest heights at 30KPa (respectively, 71.04 and 60.11 cm). Nangare et al. (2016) observed the opposite behavior and emphasize that the smaller the water restriction for tomato, the greater the plant height. Soares et al. (2012), studying different evapotranspiration replacement rates in protected environment, observed a linear decrease in the height of tomato plants and an increase in stem diameter with increasing replacement rate, a pattern similar to that observed in our analyses, where plant height increased with increasing water restriction.

Water restriction affected the development of the leaf area; with the increase of soil water tension, there was a decrease of leaf area, since at 30 kPa the plant reached 106.55 cm^2, higher than the 96.12 cm^2 reached at 70 kPa. Dellai et al. (2005) explain that the leaf area is related to the interception of solar radiation, photosynthesis, and phytomass accumulation; consequently, it is a function of soil water stress, since the expansion depends on the water potential. Thus, the response of plants to stem dry weight loss under higher stress is justified, since the lower the L.A., the lower the dry weight, regardless of the increase in P.H.

Regarding fruit dry weight (Figure 4), there is a decreasing behavior in relation to the increase of soil water tension, 4.32 g at 30 kPa and 3.22 g at 70 kPa (in average values). Schwarz et al. (2013), testing several commercial hybrids, found a dry weight between 4 and 5.2% lower than those identified in this study. Raupp et al. (2007) point out that the industry requires fruits with higher dry weight, which provide a higher pulp yield.

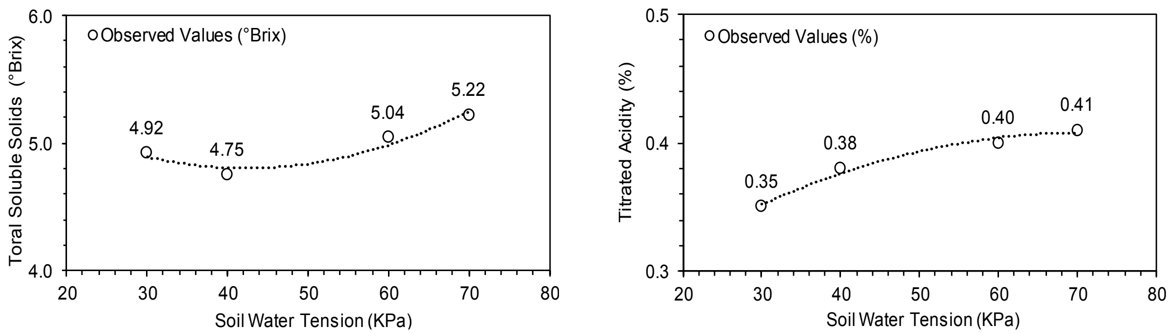

Figure 2: Relationship between soil water tension and of quality parameters of tomato: [A] total soluble solids and [B] titrated acidity.

Figure 2 shows an increase of the total soluble solids content (°Brix) as a function of increased water restriction to the plant, that is, the increase of the soil water tension led to an increase in TSS. The fruits at the tensions of 30 and 40 kPa obtained, in average, 4.89 and 4.80 °Brix, respectively; at 60 and 70 kPa, in turn, these values were 4.98 and 5.25 °Brix. Zheng et al. (2013) found average values between 3.6 and 5.0 °Brix at 10 and 50 kPa. This behavior was similar to those found by Albert et al. (2016) and Zhai et al. (2016).
The fruits obtained the following values of titratable acidity (TA): 0.35; 0.38; 0.40; and 0.41%, respectively, at tensions of 30, 40, 60, and 70 kPa, being considered adequate to the industrial requirements for processing tomato in Brazil. Paula et al. (2015) obtained TA means between 0.35 and 0.62% for the AP-529 and Tinto hybrids. Silva & Giordano (2000) point out that TA values below 0.35% require an increase in processing time and temperature to avoid the proliferation of microorganisms in processed products.

4. Conclusions

The soil water tension provided different agronomic development profiles. The water deficit was shown to reduce the total volume of water applied during the cycle, increasing the soluble solids content in the fruits and maintaining titratable acidity in the standards of processing industries, in addition to increasing pulp yield when compared to processing industries. The tensions of 60 and 70 kPa applied at 10 DAT were the ones that most intensified the soluble solids content without significantly affecting the agronomic development of the crop.

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