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MANEJO AUTÔNOMO DA FERTIRRIGAÇÃO DO TOMATE *GRAPE* CULTIVADO EM SUBSTRATO UTILIZANDO SENSORES IRRIGÁS®

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1 RESUMO

O objetivo deste estudo foi analisar a produção e qualidade de tomates *grape* em função do manejo autônomo da fertirrigação baseado em sensores Irrigás®, em diferentes tensões hídricas do substrato de cultivo. Foi conduzido um experimento em blocos completos ao acaso, com seis repetições, e cinco níveis mínimos de umidade do substrato de cultivo para o início da fertirrigação: 3,0; 4,3; 5,6; 6,9; e 8,2 kPa. Foram avaliadas a produção e a massa de frutos, o teor de sólidos solúveis, a acidez titulável e a firmeza da polpa dos frutos. A maior produção comercial de frutos (3,4 kg/planta) foi obtida com a tensão limite estimada de 6,0 kPa. O aumento da tensão limite para o início da irrigação de 3,0 a 8,2 kPa promoveu diminuição da firmeza de frutos comerciais (4,0 a 3,4 lb), da massa de frutos da classe médio-pequeno (6,7 a 5,8 g/fruto), aumento do teor de sólidos solúveis (8,9 a 9,8ºBrix) e da acidez titulável (1,0 a 1,2%) da polpa do tomate.

Palavras-chave: *Solanum lycopersicum*, nutrição de plantas, automação, cultivo sem solo, tensiometria gasosa.

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AUTONOMOUS MANAGEMENT OF FERTIRRIGATION OF GRAPE TOMATO CULTIVATED ON A SUBSTRATE USING IRRIGÁS® SENSORS.

2 ABSTRACT

This study aimed to analyze the production and quality of grape tomatoes as a function of autonomous fertigation management based on Irrigás® sensors at different water tensions of the cultivation substrate. A randomized complete block experiment was conducted, with six replications, and five minimum levels of substrate moisture for the beginning of fertigation: 3.0; 4.3; 5.6; 6.9; and 8.2 kPa. Fruit yield and fruit mass, soluble solids content, titratable acidity and firmness of the fruit pulp were evaluated. The highest commercial fruit production (3.4 kg/plant) was obtained with an estimated limit tension of 6.0 kPa. The increase in the limit tension for the beginning of irrigation from 3.0 to 8.2 kPa promoted a decrease in the firmness of commercial fruits (4.0 to 3.4 lb) and in the weight of medium-small class fruits (6.7 to 5.8

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g/fruit) and increase in the soluble solids content (8.9 to 9.8°Brix) and titratable acidity (1.0 to 1.2%) of the tomato.

Keywords: *Solanum lycopersicum,* plant nutrition, automation, soilless culture, gaseous tensiometry.

3 INTRODUCTION

The demand for mini tomatoes is growing, and they are used to decorate dishes or small delicacies served before the main meal (ALVARENGA, 2022). For this reason, they are also called "*gourmet* " tomatoes. Given their relatively high market value, mini tomatoes have been cultivated in protected environments, and soilless cultivation systems in substrates are not uncommon (SANTIAGO, 2013).

Mini *grape tomatoes* are characterized by a smaller size and higher sensory quality (flavor) associated with higher levels of soluble solids, acidity and the production of aromatic compounds (CASALS et al., 2019; CARILLO et al., 2019; ROCHA et al., 2013a; ROCHA et al., 2013b). The soluble solids content is a characteristic that varies greatly depending on the cultivar and environmental conditions, such as light, cultural management, water availability and plant nutrition (CÉSPEDES; SANJUÁN; GAVILÁN, 2004).

Proper irrigation management is particularly important for tomato plants, as they are sensitive to both water deficit (VIOL et al., 2018; FERREIRA et al., 2019) and excess water (WAMSER et al., 2021). Excessive soil moisture also favors the progression of diseases of the plant's root and vascular systems, such as pith necrosis (a complex of bacteria of the genera *Pseudomonas and Xanthomonas*), soft rot and hollow stems (*Pectobacterum* spp. and *Dickeya* spp.*), Fusarium* wilt (*Fusarium oxysporum* f. sp. l *ycopersici*) and bacterial wilt (*Ralstonia solanacearum*) (INOUE-NAGATA et al., 2016).

Plant fertigation management in soilless crops, which is based on careful methods associated with plant physiology, substrate, climate, or integrated methods (plant-substrate-climate), allows rationalizing the use of water, nutrients, and energy and increasing productivity (SANJUÁN; GAVILÁN, 2004). Oliveira et al. (2021), evaluating the autonomous irrigation management of cherry tomatoes, reported that both fruit yield and water use efficiency increased with decreasing soil moisture tension at the start of irrigation. According to these authors, for a cherry tomato fruit yield of 11 t ha $^{-1}$, the water use efficiency is 1.92 kg m $^{-3}$. The water content in the plant growing substrate has been monitored via gravimetric methods (scale), demand trays, and conventional tensiometry (GAVILÁN, 2015). Other methods may involve electronic probes based on time domain reflectometry (TDR) (NÓIA JÚNIOR et al., 2017) and the dielectric constant (NEMALI et al., 2007), among other methods.

The Irrigás® system is a type of soil moisture sensor developed and patented by Embrapa (CALBO, 2000) that allows for the monitoring of water in crop substrates. The measurement principle is that the air passing through the porous capsule of the Irrigás® sensor remains blocked as long as the soil/substrate water tension is below a certain critical value, which is characteristic of the porosity of the capsule.

systems for continuous soil moisture readings and controlling the timing and duration of irrigation on the basis of soil water tension, as determined by an Irrigás® sensor, have recently been developed. The availability of this new equipment (combining moisture sensors with automatic irrigation controllers) enables further research to more accurately correlate soil moisture levels with the productivity and quality of products such as tomatoes (WAMSER et al., 2021). The applicability of Irrigás® for fertigation management has been proven for melon (GRATIERI et al., 2013) and bell pepper (WAMSER et al., 2017) crops grown in substrates.

The objective of this study was to analyze the production and quality of *grape tomatoes* as a function of autonomous fertigation management via Irrigás® sensors at different water tensions of the cultivation substrate.

4 MATERIALS AND METHODS

The experiment was conducted between November 2019 and February 2020 in a protected greenhouse in the municipality of Caçador, Santa Catarina. The trial was conducted in an experimental area located at 26°49'03.2" South, 50°59'24.9" West, at an altitude of 936 meters. The greenhouse has an arched roof, a four-meter ceiling height, is 16 m wide, and is 48 m long. It is covered with 150-micron plastic film and has side closures with a white screen with 20% shading. The greenhouse soil surface is covered with medium-grain gravel.

Tomato seedlings cv. Scooby (Feltrin Sementes, Farroupilha, RS, Brazil), an indeterminate hybrid that produces *grape-like fruits*, were planted on November 6, 2019. A spacing of 1.5 m between planting rows and 0.40 m between planting holes was adopted, with two seedlings per hole, totaling 33,333 plants per hectare. The plants were trained with two main stems and trained in a "V" shape via plastic ties. Lateral shoots were periodically removed, ensuring that each plant maintained two main stems. When the plants reached 2.2 m in height, the main stems were pruned, leaving three leaves above the last cluster.

Tomato plants were grown in Carolina soil substrate (Carolina Soil do Brazil, Pardinho, SP, Brazil) packaged in plastic growing bags 0.2 m wide, 0.2 m high, and 1.2 m long. The growing substrate was a mixture of sphagnum peat, expanded vermiculite, agricultural gypsum, and traces of NPK fertilizer. The physicochemical properties of the substrate were as follows: pH = 5.5 ± 0.5; EC = 0.7 ± 0.3 dS/m; density = 145 kg/m3; and water retention capacity (WHC) = 55%. The growing bags were placed over a channel made of rigid polyonda plastic, measuring 0.25 m wide, 0.10 m high, and 1.4 m long. The channels were laid on the soil with a 0.5% slope lengthwise and spaced 1.5 m apart laterally. These channels served to prevent direct contact between the growing bags and the soil and to collect the nutrient solution drained after fertigation. The drained nutrient mixture was conveyed to the end of the channel and deposited in seven-liter buckets placed inside trenches dug in the soil.

A mineral nutrient solution was applied to the cultivation substrate via fertigation via water from an artesian well with an electrical conductivity of 0.2 dS/m and a pH of 7.9. The formulation of the nutrient solution with simple salts followed the nutrient concentrations proposed by Furlani, Faquin, and Alvarenga (2004) for hydroponic tomato cultivation (Table 1). The pH of the nutrient solution was adjusted to 6.0 via nitric acid (Table 1). The average electrical conductivity of the nutrient solution throughout the experiment was 2.0 ± 0.3 dS/m. The nutrient solutions were applied by fertigation to meet plant demand according to the treatments and to exceed the moisture retention capacity of the substrate to provide drainage of 15 ± 5% of the solution volume applied daily by fertigation, as proposed by Miranda et al. (2011) for irrigation water with an EC lower than 0.6 dS m^{-1}.

Table 1. Fertilizers and acid used to prepare the nutrient solution used in the fertigation of *grape* tomato cultivar Scooby.

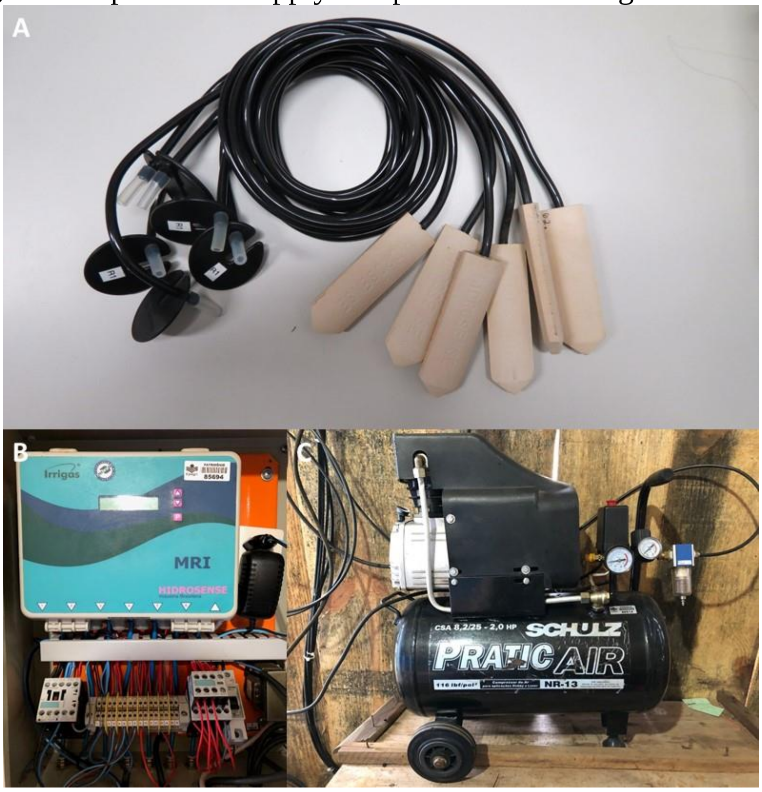
Fertilizer/Acid	Quantity (mg/L)
Ammonium nitrate	20
Calcium nitrate	700
Potassium nitrate	500
Monopotassium phosphate	140
Magnesium sulfate	370
[1] Nitric acid	0.1
[2] Micronutrients	50

[1] Value expressed in mL/L. [2] Commercial product Dripsol ® micro Rexene ® Equilíbrio (0.85% B, 0.5% Cu, 3.4% Fe, 3.2% Mn, 0.06% Mo and 4.2% Zn) (SQM Vitas Brasil, Candeias, BA, Brazil).

The nondraining online drippers (one for every two plants) had a flow rate of 4 L/h and were spaced 0.4 m apart. A 7-mm-diameter, 70-cm-long microtube was installed in each online dripper, with a distributor formed by a nonlabyrinthine dripper stake at the other end. The dripper stake was driven between two plants in the same planting hole.

Substrate moisture monitoring was performed instantaneously via Irrigás® tension sensors (Hidrosense, Jundiaí, SP, Brazil) with a bubbling voltage of 16 kPa (Figure 1A). The Irrigás® sensors were connected to an electronic irrigation controller model MRI-10/6 (Hidrosense, Jundiaí, SP, Brazil) (Figure 1B) via 8 mm diameter low-density polyethylene microtubes. An air compressor supplied compressed air (60 kPa) to the tensiometric system (Figure 1C). The sensors were arranged horizontally in the central region of the grow bag, both in height, width, and length. In this position, the sensors were just below the plants and the central drip stake of the grow bag. One Irrigás® sensor was installed per repetition. When the moisture tension of the substrate exceeded 16 kPa, the pores of the Irrigás sensor capsule were not saturated with water, allowing the system's compressed air to escape freely. As the substrate was moistened with fertigation, reducing the substrate moisture tension, the Irrigás capsule's pores became saturated with water, creating resistance to the system's compressed air exiting. This resistance was measured by MRI-10/6 pressure sensors, which, in turn, were converted into substrate moisture tension. When the moisture tension of the substrate reached the value defined for each treatment, the MRI-10/6 activated the 0.5 HP motor pump.

Figure 1. (A) Irrigás® sensors, (B) autonomous irrigation controller based on Irrigás® sensors and (C) air compressor to supply compressed air to the gas tensiometry system.



The experimental design was a completely randomized block design with six replicates. The treatments consisted of five minimum substrate moisture levels (Ψ_w water potential): 3.0 (highest moisture content), 4.3, 5.6, 6.9, and 8.2 kPa (lowest moisture content). Whenever the substrate moisture content reached the minimum level for each treatment (average of the six replicates), fertigation was applied for a period of time sufficient for the moisture content to reach saturation tension (substrate field capacity = 1 kPa) and promote 15±5% drainage. This time was programmed in the MRI-10/6. Thus, the cultivation substrates were maintained in five ranges of soil water tension variation (moisture ranges): 1 to 3.0 kPa, 1 to 4.3 kPa, 1 to 5.6 kPa, 1 to 6.9 kPa and 1 to 8.2 kPa. The plot consisted of a growing bag containing six plants.

The fertigation time was determined by installing a control dripper and a drainage collection bucket in each replicate of each treatment. Each drainage collection bucket collected all the drainage from a grow bag through the channels placed above the soil and below the grow bags. The drainage percentage was calculated via the following formula:

$$D(\%) = [\ Vd/(NG.\ Vf)].100 \qquad (1)$$

where:

D(%) = percentage of drainage in relation to the volume of fertigated nutrient solution, in %;

Vd = average drained volume for all culture bags used as controls, in mL/container;

NG = number of drippers present per grow bag used as a control;

Vf = average fertigated volume by all drippers used as a control, in mL/dripper.

When the daily drainage percentage was above 20% or below 10%, the fertigation time was adjusted according to the MRI-10/6.

The harvest of ripe fruits (with red coloration on 100% of their surface) was carried out weekly between 09/01/2020 and 03/20/2020, totaling 12 harvests. The total production, commercial (fruits classified as large-giant, with masses greater than 8 g, and medium-small, with masses between 2 and 8 g) and discarded fruits (with masses less than 2 g, with physiological defects (style rot, open locules and cracking), phytopathological and insect damage) were evaluated, according to the classification proposed by Perin et al. (2016) for *grape tomatoes*.

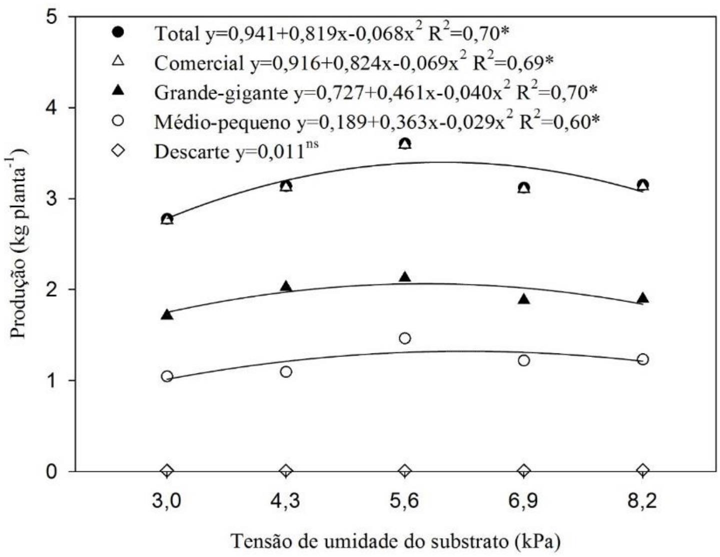
Fruit quality was evaluated on the basis of soluble solids (SS), titratable acidity (TA), the SS/TA ratio, and pulp firmness. Thus, samples of ten fruits classified as large-giant, without visual defects, with red coloration over 100% of their surface, harvested on February 3, 2020, February 20, 2020, and March 3, 2020, were used for physicochemical analyses one day after harvest. The pulp firmness of each fruit was measured via a motorized electronic penetrometer with a 2-mm tip (Güss, South Africa) in the equatorial region of each fruit after removal of the skin. The SS and TA contents were determined in the juice of 10 fruits per replicate, which were prepared with a centrifugal juicer (Plastaket Mgf, United States). The SS content (%) was measured via a digital refractometer with automatic temperature compensation (Atago, Japan). AT (% citric acid) was determined by titrating 3 mL of juice diluted in 20 mL of distilled water with 0.1 N NaOH to pH 8.2 via an automatic titrator (Radiometer, France).

The data were subjected to analysis of variance via the F test at a 5% probability of error, and when statistical significance was detected, polynomial regression analysis was performed. Statistical analyses were performed via the SISVAR v.5.6 program.

5 RESULTS AND DISCUSSION

There were differences in the production variables between the treatments (minimum substrate moisture for the initiation of fertigation), with the exception of discarded fruit production (Figure 2). The average discarded fruit production was 0.015 kg/plant, representing only 0.5% of the total average production obtained per plant in the experiment. Low discarded fruit production of *grape tomatoes* was also reported by Perin et al. (2016), with 98.7% of the harvested fruits considered commercial. The low incidence of physiological and fungal disorders is possibly associated with the genetic characteristics of *grape tomatoes* and the absence of rain and direct solar radiation, as well as the lower incidence of insect damage in the protected environment (greenhouse), in addition to the precise control of substrate moisture with gas tensiometry.

Figure 2. Total commercial production, in the large-giant and medium-small classes, and discarding of *grape tomatoes* cv. Scooby as a function of substrate moisture tension for the start of fertigation.



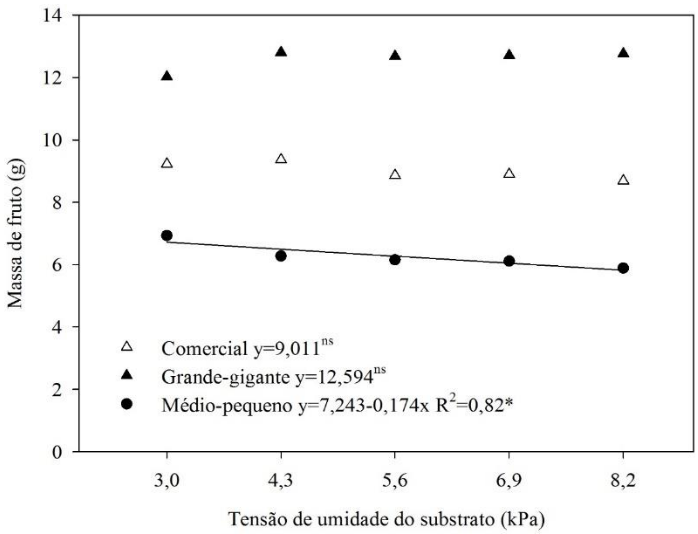
*Polynomial regression significant at a 5% probability of error.
ns There were no significant differences between treatments according to the F test at a 5% probability of error.

There was a significant fit of quadratic models for the total, commercial, and large- and medium--small-fruit production data as a function of the minimum substrate moisture content for the initiation of fertigation (Figure 2). The maximum fruit production per plant was estimated at substrate moisture tensions of 6.0, 5.8, and 6.3 kPa for the total (3.4 kg/plant), commercial (3.4 kg/plant), large-giant (2.1 kg/plant), and medium-small (1.3 kg/plant) classes, respectively. According to Fermino (2014), the volume of water in the substrate available to plants is between 1 and 10 kPa. However, the range of 1--5 kPa is considered to include water readily available to plants. The tensions ranging from 5 to 10 kPa include the substrate reserve water, also called buffer water. At pressures greater than 10 kPa, water is difficult to obtain. Therefore, the pressures stipulated for maximum fruit production (5.8 to 6.3 kPa) in this study fall within the moisture range considered with reserve or buffer water. This range is considered adequate for a water volume ranging from 4--10% of the total substrate volume (Fermino, 2016). Thus, in this substrate moisture range (5.8--$^{6.3}$ kPa), water can be quickly depleted if it is not promptly replenished through fertigation. The Irrigás® sensors connected to the autonomous irrigation controller thus allow working within these substrate moisture limit pressures to achieve higher yields, since the system allows for prompt restoration of substrate moisture to its retention capacity (1 kPa) when the critical pressure is reached.

In this study, we consider 6 kPa as the limiting stress for fertigation to achieve maximum commercial fruit yield (Figure 2). This value is the first reference for *grape tomato management* via autonomous irrigation management based on Irrigás® sensors. In soil-grown tomato cultivation in a protected environment, Wamser et al. (2021) obtained similar behavior by evaluating stresses from 20 to 60 kPa with Irrigás® sensors, with the highest commercial fruit yield being achieved at a stress of 44 kPa. These authors believe that the rapid establishment of soil moisture through autonomous irrigation management based on Irrigás® sensors allows a 7.5% increase in commercial fruit yield compared with irrigation management via conventional tensiometry, which is not connected to irrigation automation systems. This finding corroborates the results of this study because of the benefits of prompt restoration of substrate moisture upon reaching the stipulated critical stress.

The effect of the minimum substrate moisture content for the initiation of fertigation on the average fruit weight occurred only for fruits in the medium–small class (Figure 3), and a linear model fit the observed data was obtained. The lower the moisture content is, the smaller the fruit weight of this category. The average weights of commercial fruits and those in the large-giant class were 9.0 and 12.6 g, respectively. According to Céspedes, Sanjuán, and Gavilán (2004), a reduction in fruit size in salad tomatoes is expected with increasing water stress, caused by decreased substrate moisture availability or increased salinity. However, for these authors, the size of mini tomatoes, such as *grapes* and *cherries*, is less affected by water and salinity stress. Notably, the decrease in the mass of medium–small fruit at a tension of 8.2 kPa, in relation to a tension of 3.0 kPa, was only 0.9 g or 13.4%, corroborating the low influence of water availability on the size of grape tomato fruit reported by Céspedes, Sanjuán and Gavilán (2004).

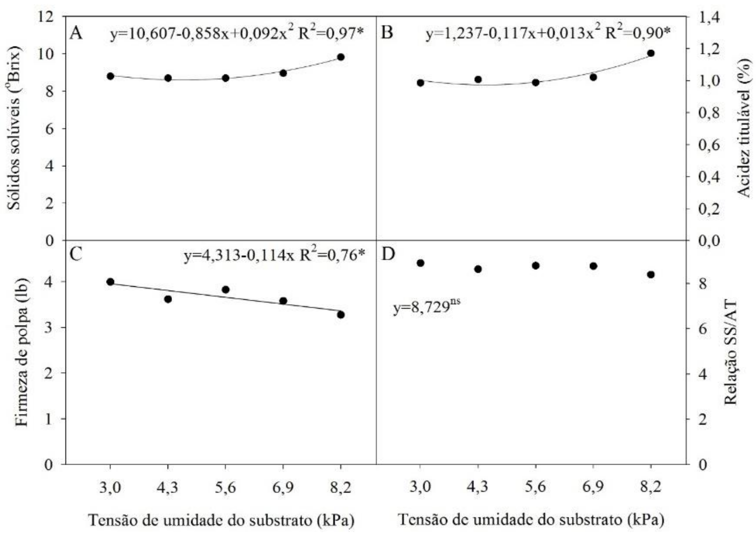
Figure 3. Commercial fruit mass and in the large-giant and medium-small classes of *grape tomato* cv. Scooby as a function of substrate moisture tension for the start of fertigation.



*Polynomial regression significant at a 5% probability of error. ns There were no significant differences between treatments according to the F test at a 5% probability of error.

titratable acidity as a function of the substrate moisture tension (Figures 4A and 4B). Both the soluble solids content and titratable acidity increased with decreasing substrate water availability (higher tension) at a tension of 5.6 kPa. Thus, the SS/AT ratio had no effect on the soil moisture level (Figure 3D). The maximum soluble solids content (9.4 °Brix) and titratable acidity (1.16%) were obtained at a tension of 8.2 kPa. Similar results were reported by Santiago et al. (2018), who evaluated irrigation depths in mini-tomato cultivation. The use of water stress, primarily by increasing the salinity of the nutrient solution, is a strategy used by many producers to increase the soluble solids and acidity contents of tomato pulp and thus improve the organoleptic quality of the fruit (ADAMS, 2004). In the present study, no increases in soluble solids or titratable acidity contents were observed up to the substrate moisture tension required to obtain the maximum commercial fruit yield (6 kPa) (Figures 4A and 4B). Similarly, the strategy of improving fruit quality by increasing the critical substrate moisture tension for the initiation of irrigation should be carefully considered by producers, since the gains in soluble solids and titratable acidity contents, from the 6 kPa tension to the 8.2 kPa tension, were 1.0 Brix and 0.15%, respectively, in absolute numbers. For apples, differences of 1.0 Brix in soluble solids content and 0.08% in titratable acidity are sufficient for tasters to identify variations in flavor (sweeter and more acidic, respectively) (HARKER et al., 2002). Even so, further studies need to be conducted to assess whether consumers would be willing to pay more for fruits with higher soluble solids contents. For these same substrate moisture tension ranges, the loss in commercial fruit productivity would be 9.6%.

Figure 4. (A) Soluble solids (SS), (B) titratable acidity (TA), (C) firmness and (D) SS/TA ratio of *grape tomato pulp* cv. Scooby as a function of substrate moisture tension at the beginning of fertigation.



*Polynomial regression significant at a 5% probability of error. ns There were no significant differences between treatments according to the F test at a 5% probability of error.

Flesh firmness decreased linearly with increasing substrate stress at the start of fertigation (Figure 4C). A similar result was reported by Rodrigues (2017), who evaluated the firmness of tomato pulp in a salad group as a function of soil moisture stress at the start of irrigation. According to this author, the decrease in fruit firmness may be related to reduced calcium translocation into the fruit, interference with cell wall formation, or decreased cellular turgor of the fruit pulp in situations of reduced water availability.

6 CONCLUSIONS

The productivity and quality of *grape tomato* cv. Scooby varies depending on the water tension of the substrate at the start of fertigation.

The *grape* tomato cultivar Scooby was obtained with a limit voltage of 6.0 kPa for the start of fertigation via Irrigás® sensors.

titratable acidity of the pulp of the *grape* tomato cultivar Scooby.

The Irrigás® sensors with the autonomous irrigation controller made it possible to manage the fertigation of *grape tomatoes* grown in the substrate, accurately establishing the substrate moisture level to increase the productivity or quality of mini tomatoes.

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