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QUALIDADE FÍSICO-QUÍMICA DE FRUTOS DE MARACUJAZEIRO EM FUNÇÃO DAS FORMAS DE PROPAGAÇÃO E POTENCIAIS DE ÁGUA NO SOLO

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1 RESUMO

No presente estudo foram avaliadas a qualidade físico-química de frutos de maracujazeiro (*Passiflora edulis* Sims, 'BRS Gigante Amarelo') propagado a partir de sementes e estaquia sob diferentes potenciais de água no solo. O experimento foi realizado em casa de vegetação, entre os meses de novembro de 2019 e junho de 2020, na Universidade Federal do Recôncavo da Bahia, Cruz das Almas, BA. O maracujazeiro foi cultivado em lisímetros de drenagem, cada um com área superficial de 1,44 m² e altura de 0,6 m, preenchidos com solo de textura franco-arenosa. Adotou-se o delineamento experimental inteiramente casualizado em esquema fatorial 2 x 4: duas formas de propagação vegetativa (semente e estaquia) e quatro potenciais matriciais de água no solo (-6, -10, -20 e -33 kPa), com quatro repetições. Avaliaram-se as massas frescas do fruto e da polpa, diâmetro e comprimento do fruto, razão comprimento/diâmetro do fruto, rendimento da polpa do fruto, espessura da casca, sólidos solúveis totais, acidez total titulável, razão entre sólidos solúveis totais/acidez total titulável e pH da polpa. As formas de propagação afetaram as principais variáveis da qualidade física dos frutos do maracujazeiro. A qualidade química da polpa dos frutos do maracujazeiro não foi afetada pelos fatores em estudo.

Palavras-chave: *Passiflora edulis* Sims, manejo da irrigação, reprodução vegetal.

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PHYSICAL AND CHEMICAL QUALITY OF PASSION FRUIT UNDER PROPAGATION METHOD AND WATER POTENTIAL IN THE SOIL

2 ABSTRACT

In this study, the physicochemical quality of passion fruit (*Passiflora edulis* Sims, 'BRS Gigante Amarelo') propagated from seeds or cuttings and subjected to different soil water potential was evaluated. The experiment was conducted in a greenhouse, between November

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2019 and June 2020, at the Federal University of Recôncavo of Bahia, Cruz das Almas, BA. The passion fruit was grown in drainage lysimeters, each one with a surface area of 1.44 m² and 0.6 m high, and filled with sandy loamy soil. The experiment was performed in a completely randomized design in a 2 x 4 factorial scheme: two forms of vegetative propagation (seed or cuttings) and four soil water potential (-6, -10, -20, and -33 kPa), with four replicates. Fruit fresh weight, fresh weight of the fruit pulp, fruit diameter and length, fruit length/diameter ratio, fruit pulp yield, rind thickness, total soluble solids, total titratable acidity, total soluble solids/total titratable acidity ratio and pH of the pulp was evaluated. The forms of propagation affected the main physical quality variables of the fruits of passion fruit. The chemical quality of the passion fruit pulp was not affected by the factors under study.

Keywords: *Passiflora edulis* Sims, irrigation management, vegetative propagation.

3 INTRODUCTION

Brazil is far below its production capacity and is the largest producer of passion fruit. Increasing passion fruit productivity is imperative to meet demand, as the volume offered does not satisfy domestic or international markets due to the increased consumption of *fresh fruit* and juice production (MALACRIDA; JORGE, 2012; CAVALCANTE et al., 2016).

In 2019, national production was approximately 600,000 tons in an area of 42,000 hectares (average of 14 t ha $^{-1}$), an average that has been cultivated for at least five years (IBGE, 2019). However, studies indicate the possibility of this number reaching between 30 and 50 t ha $^{-1}$ (HAFLE et al., 2009; CAVICHIOLI et al., 2011). For this increase in passion fruit production to occur, crop management needs to be improved in terms of phytosanitary control, pollination, water and nutritional supply, in addition to conducting pruning (FALEIRO; JUNQUEIRA, 2016).

Improving passion fruit quality is as important as increasing productivity. To this end, significant technological advances have been made in various areas related to the vegetative reproduction of different passion fruit species (*Passiflora* spp.) (FALEIRO et al., 2019). The use of methods such as grafting and cuttings has allowed successful acquisition of plants resistant to diseases, pathogens, salinity and water deficit, in addition to the generation of productive, uniform cultivars with fruits with better physical-chemical attributes (GOMES et al., 2018; LIMA et al., 2018; SCHMILDT et al., 2018; SOUZA et al., 2018; PEREIRA et al., 2019; CHEN; CHANG; LIN, 2020; JOSEPH; SOBHANA, 2020; MAVI; UZUNOĞLU, 2020; LIMA et al., 2020; MOURA et al., 2020a; MOURA et al., 2020b).

Water readily available to plants in the correct volume and timing is a decisive factor for crop success. Lozano- Montaña et al. (2021) estimated that at least 40% of global crop losses are related to water stress, which could become even more severe with existing climate change. Furthermore, the global population has been growing rapidly , which has already required increased agricultural production (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2018). In this context, it is essential to estimate crop water needs more accurately, which requires rational and optimized planning and management of water use (SILVA et al., 2015b).

Studies have been carried out to identify effective irrigation management strategies for passion fruit cultivation, including water deficit techniques. Under controlled deficit irrigation (66% of reference evapotranspiration – ETo) for passion fruit (*Passillora*) cultivation *edulis* Sims), Rodríguez -Yzquierdo et al. (2020a) reported no losses in productivity or fruit quality. Souza et al. (2018) evaluated the biometric, physiological, and anatomical responses of plants of different passion fruit species subjected to water deficit and reported that *P. alata* and *P. setacea* were more tolerant to water deficit than were *P. edulis*, *P. gibertii* and *P. cincinnata.*

In the study by Dutra et al. (2018), with the passion fruit hybrid 'BRS Gigante Amarelo' (*Passiflora edulis*) irrigated in the Brazilian semiarid region, the authors reported that water replacements between 100 and 133% of the reference evapotranspiration, ETo (776 and 1032 mm year $^{-1}$, respectively), promoted higher production and better fruit quality. In the study by Francisco et al. (2020) carried out in the southeastern Brazilian Amazon, the chemical quality of passion fruit was not affected under rainfed cultivation compared with cultivation under irrigation.

Despite advances in research addressing the water relationships of passion fruit crops, some gaps remain, such as the forms of vegetative propagation of plants in interaction with irrigation management on the basis of different soil water potential ranges. Therefore, the objective of this study was to evaluate the physical and chemical qualities of passion fruit (*Passiflora edulis).* Similarly, 'BRS Gigante Amarelo') propagated from seeds and cuttings under different soil water matrix potentials.

4 MATERIALS AND METHODS

4.1 Plant material, design and experimental conditions

The cultivation of passion fruit (*Passiflora edulis)* Sims, 'BRS Gigante Amarelo') was conducted in a greenhouse (east/west orientation) in the experimental area of the Graduate Program in Agricultural Engineering at the Federal University of Recôncavo da Bahia (UFRB), Cruz das Almas, BA (12° 40' S, 39° 06' W, ~ 226 m altitude). The greenhouse (with an area of 180 m²) was of the simple arch type, laterally protected up to the height of the ceiling height (3 m) by a screen with 50% shading, and the roof was covered with a 150 µm thick polyethylene film (Figures 1B and 1D). The experiment took place between November 2019 and June 2020, a period corresponding to the second year of the crop production cycle.

Figure 1. Distribution of treatments in the experimental area (A) and in plants at 50 (B), 100 (C) and 500 days after transplanting (DAT).

The local climate is Am according to the Köppen-Geiger classification (ALVARES et al., 2013), with an average annual precipitation of 1200 mm and an average air temperature of 24°C. During the study period, the average temperature inside the greenhouse was 27 ± 2°C, and the relative humidity was 74 ± 5%. The data were measured continuously via a thermohygrometer sensor. model HMP50 (Campbell Scientific, Inc., Logan, Utah, USA), connected to a datalogger model CR 1000 (Campbell Scientific, Inc., Logan, Utah, USA). Sensor readings were taken every 15 seconds, and the average was recorded every 15 minutes. The thermohygrometer was installed on a support positioned 1.8 m above the ground.

The experimental design was completely randomized in a 2 × 4 factorial scheme: two forms of vegetative propagation (seed and cutting) and four soil water matrix potentials (-6, -10, -20 and -33 kPa), with four replicates, totaling 32 experimental units (Figure 1A).

The passion fruit seedlings propagated via seeds and cuttings were obtained from Embrapa Cassava and Fruit Growing, which are located in the municipality of Cruz das Almas, Bahia. The cuttings were obtained from a mother plant that was already in the productive phase.

4.2 History of the experimental area

In February 2018, the experimental structure was implemented, consisting of 36 drainage lysimeters (fiberglass reservoirs), each with a surface area of 1.44 m² and a height of 0.6 m. At the base of each reservoir, a drainage system was installed, including perforated PVC pipes (32 mm diameter), gravel, and sand. Over the drainage system, 0.65 m³ of sifted, air-dried soil (64% sand, 6% silt, and 30% clay) was placed. The soil used was classified as a dystrocohesive yellow Latosol, with a global density of 1.31 kg dm $^{-3}$, a particle density of 2.69 kg dm $^{-3}$, and a total porosity of 51.3%. The soil hydraulic parameters, retention curve and saturated hydraulic conductivity were obtained via inverse modeling via Hydrus 1-D software (ŠIMŮNEK; VAN GENUCHTEN; ŠEJNA, 2016), as described by Silva, Pinheiro and Jong Van Lier (2020).

Dolomitic limestone was applied according to the recommendations of Sousa et al. (2004), and fertilization with macro- and micronutrients was carried out according to Borges (2004) and Costa et al. (2009), respectively. In April of the same year, the preselected seedlings (standardized at 0.3 m in height) were transplanted to the lysimeters, adopting a spacing of 2.0 × 1.5 m.

A drip irrigation system with self-compensating emitters was used to irrigate the passion fruit plants. The irrigation lines were distributed over the lysimeters (Figures 1B and 1C), with one emitter (with a flow rate of 4.2 L h $^{-1)}$ per plant at a distance of 0.05 m from the stem. After the irrigation system was installed, a water distribution uniformity test was performed, and the Christiansen uniformity coefficient (CUC = 96%) was subsequently calculated.

training system, with wire at a height of 1.8 m from the base of the plant.

In the period (between April and December 2018) preceding this study, passion fruit plants propagated via seeds and cuttings were subjected to two soil water potentials (-10 and -20 kPa) (FREITAS, 2019). Between January and October 2019, the plants were irrigated at the same irrigation depth for orchard maintenance. In October, pruning was performed; flower buds, flowers, and fruits were completely removed; and the number of leaves was partially removed, with the aim of homogenizing the experimental plots and rearranging the canopy for a new study.

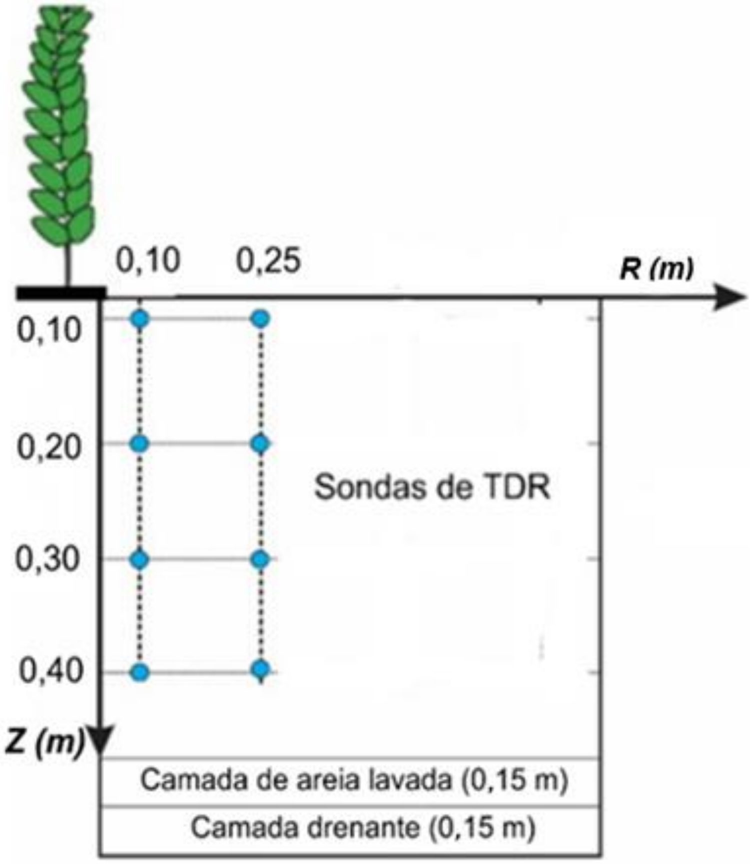
4.3 Crop management and irrigation management

The period covered by this study was between November 2019 and June 2020, according to the experimental design described in the subitem “Plant material, design and experimental conditions”.

On the basis of the soil water retention curve, irrigation was carried out with a fixed watering shift every two days, and the return of soil moisture was observed to be close to the values corresponding to matric potentials of -6, -10, -20 and -33 kPa, which defined the irrigation time.

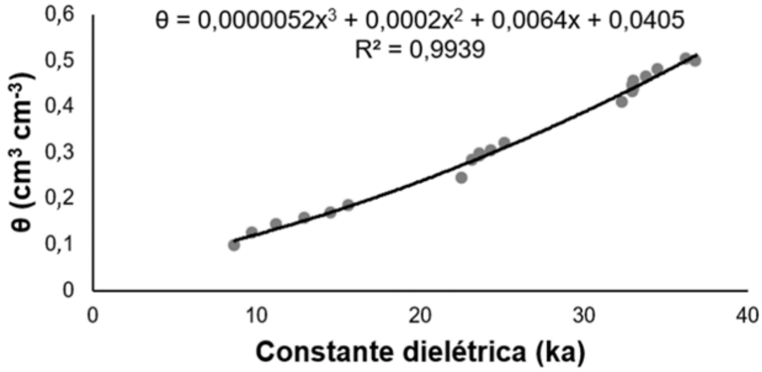
Continuous soil moisture monitoring was performed per treatment with eight TDR probes (three 0.1 m rods spaced at 0.017 m) integrated with the TDR 100 (Campbell Scientific, Inc., Logan, Utah, USA), SDMX50 multiplexers (Campbell Scientific, Inc., Logan, Utah, USA) and CR 1000 datalogger for data acquisition (Campbell Scientific, Inc., Logan, Utah, USA). The TDR probes were installed two-dimensionally (4 × 2) in the soil profile (on a single side of the plant): four depths (Z) (0.1, 0.2, 0.3 and 0.4 m) and two horizontal distances from the root collar (R) (0.10 and 0.25 m) (Figure 2).

Figure 2. Two-dimensional schematic drawing representing continuous soil moisture monitoring.



The TDR probes were calibrated on the basis of the relationship between the apparent dielectric constant (ka) values and the soil water content values obtained via oven drying and weighing. We then obtained a cubic polynomial equation that allowed us to estimate soil moisture on the basis of TDR readings (Figure 3).

Figure 3. Relationship between the volumetric humidity (cm ^{3} cm $^{-3}$) and dielectric constant (ka) obtained from TDR probes.



To calculate the irrigation depth, the soil water content data obtained were subjected to Equation (1).

$$IRN_r = \sum_{Z-0,10\,m}^{Z-0,40\,m}(\theta trat - \theta atual) * Z (1)$$

where IRNr is the actual irrigation required for probes installed at distances of 0.10 to 0.25 m from the center of the lysimeter (mm); θtrat is the soil water content corresponding to the matric potential of a given treatment (cm ^{3} cm $^{-3}$); θactual is the current moisture content before each irrigation (cm ^{3} cm $^{-3}$); and Z is the moisture control depth (mm).

The actual irrigation required at the irrigation intervals was obtained by averaging the values calculated for R = 0.10 m and R = 0.25 m, according to Equation 2.

$$IRN_{média} = \frac{(IRN_{0,10\,m} + IRN_{0,25\,m})}{Nr} \quad (2)$$

where Nr is the number of readings used to calculate the irrigation depth.

The irrigation conditions were adjusted to the conditions of the area wetted by the emitters via Equation 3.

$$IRN_{ajustada} = IRN_{média} * Aw \quad (3)$$

where IRNajustada is the actual irrigation adjusted for the area wetted by the drippers (L) and where Aw is the area wetted by the drippers (m²).

The area wetted by the emitter corresponded to the wetted radius in the middle portion of the bulb (0.50 m²).

4.4 Variables evaluated

Artificial pollination was performed manually between 1:00 pm and 3:00 pm, four days a week. Fruit harvesting took place between January and June 2020, with an average interval of three days per week. The criteria for harvesting the fruit were intact fruit, partially or completely yellow, and/or fallen to the ground.

The fruits intended for physical–chemical analysis were collected randomly, with 10 fruits being evaluated per repetition.

4.4.1 Physical analysis of fruits

The physical analysis of the fruits included the following variables: fresh fruit mass (MFF, g), fruit diameter (DF, mm), fruit length (CF, mm), the CF/DF ratio, fruit peel thickness (ECF, mm), fresh fruit pulp mass (MFPF, g) and fruit pulp yield (RPF, Equation (4)).

$$RPF\ (\%) = \left(\frac{MFPF}{MFF}\right) x\ 100 \quad (4)$$

4.4.2 Chemical quality of fruit pulp

The chemical analysis of the fruits included the following variables: total soluble solids (TSS, °Brix) via a refractometer; total titratable acidity (TTA, %) according to Zenebon, Pascuet and Tiglea (2008); and the SST/TTA ratio and pulp pH via a potentiometer.

4.5 Statistical analysis

The data were subjected to analysis of variance via the F test, with the means obtained on the basis of the propagation forms compared via the Tukey test at a probability level of 0.05 and the matrix potentials via polynomial regression analysis.

5 RESULTS

5.1 Physical analysis of fruits

There was no significant effect (p>0.05) of the soil water matric potential on the variables fruit diameter (DF), fruit length (CF), CF/DF ratio or fruit pulp yield (RPF); however, it significantly influenced fruit peel thickness (ECF), fresh fruit mass (MFF) and fresh fruit pulp mass (MFPF). With the exception of the CF/DF ratio, the propagation form had a significant effect (p<0.01) on the other variables evaluated (DF, CF, ECF, MFF, MFPF and RPF). There was a significant interaction effect between the propagation form and soil water potential on the ECF and RPF (Table 1).

Table 1. Summary of analysis of variance and means for fruit diameter (DF, mm), fruit length (CF, mm), the CF/DF ratio, fruit peel thickness (ECF, mm), fresh fruit mass (MFF, g), fresh fruit pulp mass (MFPF, g) and fruit pulp yield (RPF, %) of passion fruit from two propagation forms (FPs) cultivated under different soil water matrix potentials (PMs).

FV	GL	DF	CF	CF/DF	ECF	MFF	MFPF	RPF
FP (A)	1	248.4 **	832.3 **	0.018 ^{ns}	18.0 **	9336.9 **	7510.2 **	372.8 **
PM (B)	3	36.0 ^{ns}	119.2 ^{ns}	0.006 ^{ns}	3.5 *	5485.6 **	2285.8 **	46.0 ^{ns}
A x B	3	10.4 ^{ns}	22.1 ^{ns}	0.002 ^{ns}	3.76 *	2405.35 ^{ns}	1026.79 *	17.09 ^{ns}
Error	24	-	-	-	-	-	-	-
CV (%)		6.44	9.40	6.65	15.67	20.73	23,22	10.29
FP					Averages			
Cuttings		81.36a $^{\#}$	94.45a	1.16a	- ^{x}	165.21a	- ^{y}	52.80a
Seed		75.79b	84.25b	1.11a	-	131.05b	-	45.97b

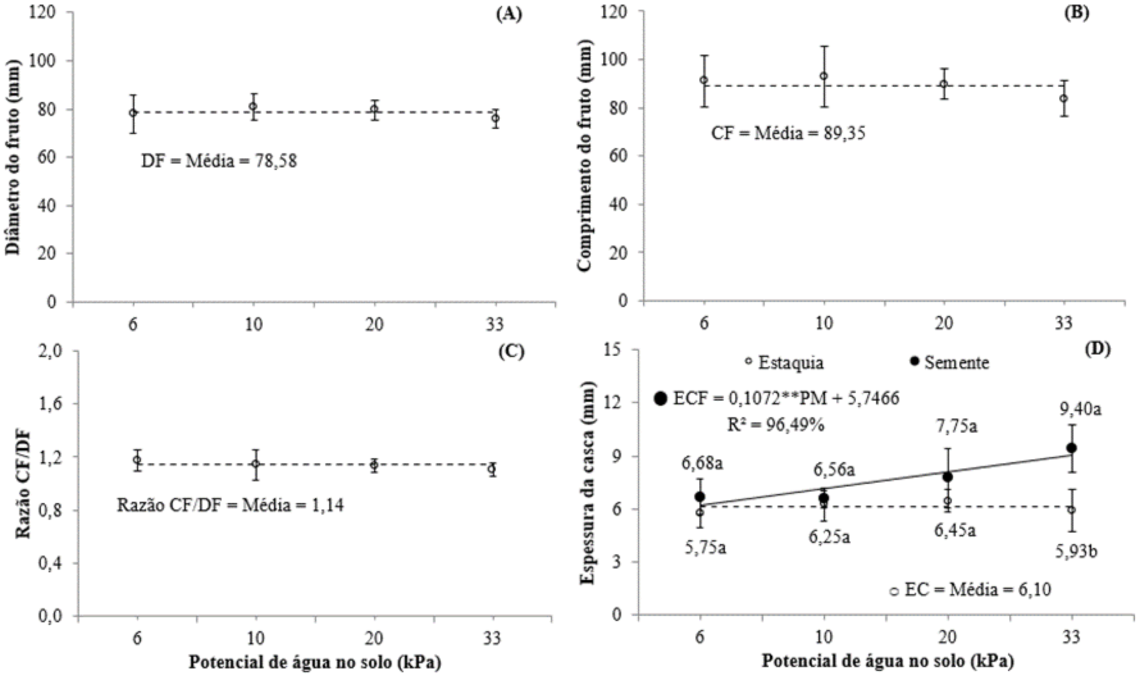
FV – source of variation; GL – degree of freedom; CV – coefficient of variation; *, ** – significant at the 0.05 and 0.01 probability levels, respectively, and ns – not significant according to the F test; $^{\#}$ Means followed by the same letter in the columns do not differ statistically according to Tukey's test at 0.05 probability; ^{x} – breakdown in Figure 4D; ^{y} – breakdown in Figure 5B.

Compared with those originating via seeds, plants propagated by cuttings presented greater means of the DF and CF variables, resulting in larger fruits and, consequently, greater MFF. Depending on the propagation form, the CF/DF ratio varied between 1.11 and 1.16 (Table 1), indicating that fruits are greater in length than in diameter, indicating a spherical oval shape (CF/DF > 1).

In terms of the soil water potential, the overall averages for the DF, CF, and

CF/DF ratios were 78.58 mm (Figure 4A), 89.35 mm (Figure 4B), and 1.14 (Figure 4C), respectively. In the breakdown of the factors under study for the ECFs (Figure 4D), under potentials of -6, -10, and -20 kPa, there was no significant difference ($p>0.05$) between the average values according to the propagation form; the values differed only under the potential of -33 kPa, when a higher average ECF was recorded during propagation via seeds.

Figure 4. Fruit diameter – DF (A), fruit length – CF (B) and the CF/DF ratio (C) of passion fruit cultivated under different soil water potentials; breakdown of the interaction between propagation forms and soil water potentials for fruit peel thickness – ECF (D).

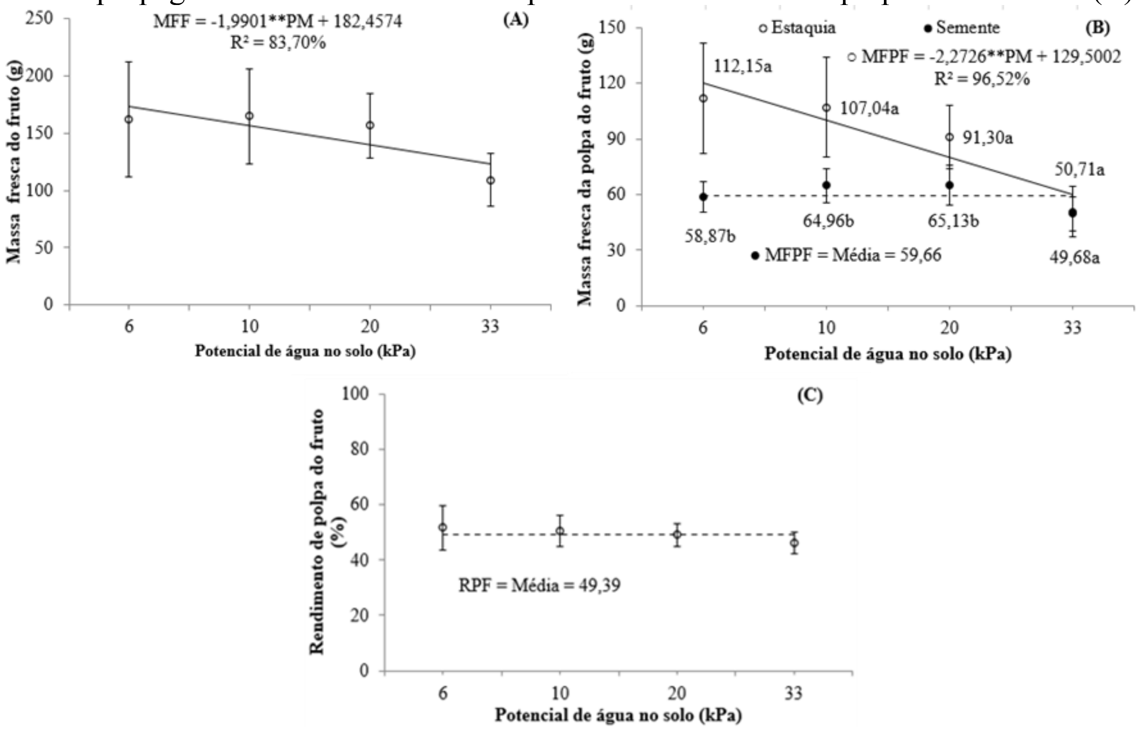


** Significant at 0.01 probability by Student's t test; bars in the means represent the standard error; in Figure D, within each matric potential (MP), means followed by the same letter do not differ statistically by Tukey's test at 0.05 probability.

In the evaluation of matrix potentials in each form of propagation, for cuttings, there was no adjustment of any mathematical model (average of 6.10 mm), whereas for propagation via seeds, there was an increase in ECF as the potentials became more negative (Figure 4D).

There was a decrease in the MFF as the soil moisture decreased (lower soil water matric potential) (Figure 5A). In the breakdown of the factors under study for the MFPF variable (Figure 5B) for potentials of -6, -10, and -20 kPa, the highest averages were obtained under propagation via cuttings, whereas under the potential of -33 kPa, there was no significant difference between the averages according to the propagation forms. In the analysis of the matric potentials in the propagation forms, there was a decrease of approximately 55% in cuttings under the potential of -33 kPa (lower water availability) in relation to the potential of -6 kPa (higher water availability); in propagation via seeds, there was no adjustment of any mathematical model (with an average of 59.66 g). For RPF, the overall average was 49.39% (Figure 5C).

Figure 5. Fresh fruit mass – MFF (A) and fruit pulp yield – RPF (C) of passion fruit cultivated under different soil water potentials; unfolding of the interaction between propagation forms and soil water potentials for fresh fruit pulp mass – MFPF (B).



** Significant at 0.01 probability by Student's t test; bars in the means represent the standard error; in Figure B, within each matrix potential (MP), means followed by the same letter do not differ statistically by Tukey's test at 0.05 probability.

5.2 Chemical quality of fruits

With the exception of the pH of the fruit pulp (with a significant effect on the matrix potential), the other variables (total soluble solids (TSS), total titratable acidity (TTA) and the TSS/TTA ratio) were not significantly influenced (p>0.05) by the factors under study (Table 2).

Table 2. Summary of the analysis of variance for total soluble solids (TSS, °Brix), total titratable acidity (TTA), the TSS/TTA ratio and the pH of passion fruit pulp from two propagation forms (FPs) cultivated under different soil water potentials (PMs).

FV	GL	SST	ATT	SST/ATT	pH
FP (A)	1	0.0091 ^{ns}	0.75 ^{ns}	0.045 ^{ns}	0.0001 ^{ns}
PM (B)	3	0.0157 ^{ns}	1.43 ^{ns}	0.660 ^{ns}	0.0082 **
A x B	3	0.0026 ^{ns}	1.21 ^{ns}	0.653 ^{ns}	0.0026 ^{ns}
Error	24	-	-	-	-
CV (%)		0.43	14.54	18.06	1.36
Overall average		15.05	5.31	2.99	3.06

FV – source of variation; GL – degree of freedom; CV – coefficient of variation; ** – significant at the 0.01 probability level; ns – not significant according to the F test.

6 DISCUSSION

Providing water to plants in the appropriate volume allows for increased translocation of assimilates to the fruits, contributing to their effective development, increasing productivity, and improving juice quality (DUTRA et al., 2018; FISCHER; MELGAREJO; CUTLER, 2018). The soil moisture content relative to field capacity determines this possibility.

In our study, irrigation was carried out across a range of soil moisture (soil water matric potential) values that represented predefined field capacity levels (-6 to -33 kPa) defined on the basis of the soil water retention curve. Matricial potentials between -3 and -6 kPa in sandy-textured soil, -10 kPa in medium-textured soils, and -33 kPa in clayey soils reach field capacity levels (SOUSA et al., 2004). The soil in our experiment has a sandy loam texture. This fostered the hypothesis that lower matric potentials (-20 and -33 kPa) could imply water stress to the plant, inducing changes in the physicochemical variables of passion fruit.

This study highlighted the comparison between the quality of fruits from plants reproduced from mother plants (cuttings), which present high uniformity (SALOMÃO et al., 2002), with fruits from plants propagated by seeds (vulnerable to genetic variability), both under different rates of water availability in the soil.

6.1 Physical analysis of fruits

The observed physical characteristics of passion fruit indicate that the matrix potential did not affect the DF, CF, or the CF/DF ratio, suggesting that the matrix potential had no effect on fruit growth (Table 1). This may be related to the minimum water supply required for productive development of the plants in the experiment. With the exception of the CF/DF ratio (no significant difference), the propagation methods indicated that the fruits of plants originating from cuttings presented better responses to the analyzed variables. This is likely related to the genetic variability existing in seed-propagating plants (SALOMÃO et al., 2002), which do not exhibit the characteristic production pattern of the mother plant common to plants propagated by cuttings and, in this case, possibly also have characteristics of adaptation to conditions of reduced soil water supply.

Determining the length and diameter of the fruits is essential, as the commercial demand for passion fruit destined for the *fresh market* prefers large, oval fruits, as these present higher pulp yields (CAVICHIOLI et al., 2011). The CF/DF ratio is decisive in this characterization. Greco, Peixoto, and Ferreira (2014) state that this relationship allows the fruits to be classified as round (CF/DF = 1) or oval (CF/DF > 1). This variable was not significantly affected by any of the sources of variation studied, although the averages obtained indicate minimal superiority (4.31%) for the fruits of plants propagated via cuttings. Furthermore, both plants propagated by cuttings and those propagated by seeds presented values greater than one (Table 1), constituting oval fruits according to the commercially desired standard.

The average diameter and length of the evaluated fruits were 78.58 (Figure 4A) and 89.35 mm (Figure 4B), respectively. These values are relatively higher than those obtained by Figueiredo et al. (2015), who evaluated different planting densities of yellow passion fruit and reported average diameters and lengths of 73.6 and 88.1 mm, respectively. In the study by Pereira et al. (2018), the physical characteristics of fruits of three species of passion fruit (*Passiflora edulis* flavicarpa cv. FB200; *Passiflora edulis* flavicarpa and *Passiflora alata*) produced in southwestern Goiás. The authors reported average fruit diameter values between 66.43 and 91.85 mm.

The matric potential had a significant effect ($p<0.05$) on fruit peel thickness. In passion fruit marketing, thinner-skinned fruits are more desirable because they present a proportionally higher pulp yield per kg obtained (HAFLE et al., 2009). According to Figure 4D, fruit peel thickness increased as the matric potential became more negative for plants propagated via seeds. However, the same did not occur for plants propagated by cuttings, in which no influence of matric potential was observed. Plants propagated by seeds were more sensitive in this regard, exhibiting approximately 37% greater fruit peel thickness than plants propagated by cuttings subjected to a soil water potential of -33 kPa. That is, under relatively low soil water content, plants propagated by seeds presented fruits with relatively thick fruit peels. Similar to the present study on propagation via seeds (Figure 4D), Rodríguez -Yzquierdo et al. (2020a) reported greater skin thickness of passion fruit under deficit irrigation (33% of the reference evapotranspiration [ETo]) than under irrigation with 66% and 100% ETo.

Larger passion fruit diameters have a direct effect on pulp mass and yield (NEGREIROS et al., 2007). In accordance with the characteristics indicated by the variables of fruit length and diameter, the plants propagated via cuttings presented larger fruits. Under cutting propagation, the average fresh fruit mass and pulp yield were 20.7 and 12.9%, respectively, higher than those obtained via seed propagation (Table 1). Similar results were reported by Junqueira et al. (2006), when evaluating a passion fruit clone under three propagation methods (grafting, cuttings, and seeds), reported higher fresh fruit mass yields during cutting propagation.

In general, the fruits harvested in the present study were half of their mass and composed of pulp (yield of 49.39%) (Figure 5C). This pulp yield is in agreement with that reported by Weber et al. (2016), who, when evaluating the cultivation of yellow passion fruit under different planting densities in Rio Grande do Sul, reported a yield equal to 51.4%. Higher passion fruit pulp yields were reported by Dutra et al. (2018), between 55 and 72%, under cultivation in the semiarid region of Brazil with different irrigation depths (33, 66, 100, and 133% ETo).

6.2 Chemical quality of fruits

Meeting the expectations of the passion fruit consumer market requires understanding the general quality characteristics of the fruit, which go beyond its external appearance. For agroindustrial processing, passion fruit requires primarily pulp yield and chemical quality to meet rigorous technical standards. Regulated by the Brazilian Ministry of Agriculture through Normative Instruction No. 1/2018 (IN 01/2018), the analytical parameters for fruit juices and pulps establish basic quality standard criteria. For passion fruit, the juice content must present total soluble solids (TSS) values greater than or equal to 11.0 °Brix, a minimum pH of 2.7, and a minimum titratable total acidity (TTA) of 2.5% citric acid and a maximum of 18% total sugars (BRASIL, 2018). In the present study, of these chemical quality parameters, only total sugars were not determined.

Research indicates that the chemical variables of passion fruit are rarely affected by different sources of variation. The pH and TSS content of yellow passion fruit are not influenced by the applied potassium dose (ARAÚJO et al., 2006). The rootstock and grafting type did not affect the TSS content, TTA, or TSS/TTA ratio (CAVICHIOLI et al., 2011). In the study by Koetz et al. (2010), under different soil water tensions (-15 to -60 kPa) in a protected environment and in a natural environment (in an open field), the chemical quality of passion fruit was not influenced. Similarly, Carvalho et al. (2014) reported no loss of chemical quality of passion fruit under water deficit (soil water tension at -60 kPa). Under other cultivation conditions, the chemical quality of passion fruit is not influenced by the planting density (FIGUEIREDO et al., 2015), fruit ripening stage (SILVA et al., 2015a), soil texture (UCHÔA et al., 2018), irrigation with saltwater (MORAIS et al., 2020; MOURA et al., 2020a) or application of various nitrogen doses (RODRÍGUEZ-YZQUIERDO et al., 2020b).

With the exception of pH, no mathematical models were adjusted to the data. The variables SST, ATT, and the SST/ATT ratio were not affected by the soil water matric potential or by the vegetative propagation method (Table 2). This allows us to infer that the chemical quality of passion fruit was not influenced by the soil water potential range under study (between -6 and -33 kPa), regardless of the plant propagation method (seeds and cuttings).

The TSS content is one of the most accurate ways to measure fruit sweetness. It is generally associated with individual fruit sugars (fructose, glucose, and sucrose) present in fruits until their abscission (MANIWARA et al., 2014). In passion fruit processing agribusiness, the preference is for fruits to have TSS values above 13 °Brix (FERREIRA; ANTUNES, 2019). In the present study, the average TSS content was 15.05 °Brix (Figure 4A). This result is above that required both by agribusiness and by Brazilian regulations for the quality standardization of fruit juices and pulps (BRASIL, 2018). Similarly, within the standards, the average values of ATT (5.31%) and pH (3.06) (Table 2) constitute excellent quality fruits. In industry, a pH of approximately 2.8 allows flexibility to correct the sugar content in ready-to-drink beverages (OLIVEIRA et al., 2020).

In the present study, the average SST/ATT ratio was 2.99 (Table 2). This variable is used to determine the palatability of fruits, and the higher the value is, the more pleasant the fruit juice is to the palate (GRECO; PEIXOTO; FERREIRA, 2014). The average SST/ATT ratio in the present study is within the range reported in other studies, between 3.33 and 3.51 (FIGUEIREDO et al., 2015), between 2.31 and 2.91 (HURTADO-SALAZAR et al., 2015), 3.48 (SILVA et al., 2016) and 2.01 (WEBER et al., 2016).

7 CONCLUSIONS

Under the conditions of this study, the different forms of vegetative propagation affected the main variables affecting passion fruit physical quality. The soil water matrix potential affects fruit skin thickness, fresh fruit mass, and fresh fruit pulp mass.

The chemical quality of passion fruit is not compromised by the different forms of vegetative propagation or by the different soil water matrix potentials in the range between -6 and -33 kPa.

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