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Differences in cold sensitivity between passion fruit cultivars during postharvest storage

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ABSTRACT: Due to the high perishability of passion fruit in ambient conditions, refrigeration is recommended during its transport and storage. However, as a tropical crop, passion fruit is sensitive to temperatures below 6 °C, developing chilling injury symptoms. Considering that sensitivity to this physiological disorder depends on genetic material, this study investigated the susceptibility of the passion fruit cultivars BRS Gigante Amarelo and BRS Sol do Cerrado to cold injury during refrigerated storage. Fruits of both cultivars, harvested at the yellow-green maturity stage, were stored at 4 °C and 10 °C for up to 17 days. Symptoms of chilling injury manifested as the rapid wilting of the fruits. Cv. BRS Sol do Cerrado was particularly temperature-sensitive, exhibiting signs of frostbite. In contrast to what was observed in cv. BRS Gigante Amarelo, the percentage of wrinkled surface, weight loss, titratable acidity, and respiratory rate of cv. BRS Sol do Cerrado was higher at 4 °C than at 10 °C. Our results show distinct responses between the two passion fruit cultivars to refrigeration temperature, with cv. BRS Sol do Cerrado is more sensitive to chilling injury-inducing temperatures than cv. BRS Gigante Amarelo.
Keywords: chilling injury; *Passiflora edulis*; physico-chemical quality.

Diferenças na sensibilidade ao frio entre cultivares de maracujá durante o armazenamento pós-colheita

ABSTRACT: Devido à elevada perecibilidade do maracujá em condições ambientais, recomenda-se a refrigeração durante o transporte e o armazenamento. Entretanto, por ser uma cultura tropical, o maracujá é sensível a temperaturas abaixo de 6 °C, desenvolvendo sintomas de injúria por chilling. Considerando que a sensibilidade a esse distúrbio fisiológico depende do material genético, este estudo investigou a suscetibilidade das cultivares de maracujá BRS Gigante Amarelo e BRS Sol do Cerrado à injúria por chilling durante o armazenamento refrigerado. Os frutos foram colhidos no estádio verde-amarelo de maturação, armazenados a 4 °C e 10 °C por até 17 dias. Os sintomas de injúria por frio se manifestaram com o rápido murchamento dos frutos. A Cv. BRS Sol do Cerrado foi particularmente sensível à temperatura, apresentando sinais de congelamento. Ao contrário do observado na BRS Gigante Amarelo, a porcentagem de superfície enrugada, a perda de peso, a acidez titulável e a taxa respiratória da BRS Sol do Cerrado foram maiores a 4 °C do que a 10 °C. Nossos resultados demostram respostas diferentes à temperatura de refrigeração, sendo que a cv. BRS Sol do Cerrado sendo mais sensível a temperaturas indutoras de injúria por frio do que a cv. BRS Gigante Amarelo.
Palavras-chave: injúria por chilling; *Passiflora edulis*; qualidade físico-química.

1. INTRODUCTION

Passion fruit (Passiflora spp.) is a typically tropical plant whose fruits stand out for their exotic shape and flavor. The botanical form *P. edulis* (yellow passion fruit) represents about 95% of the world's passion fruit commercial production (CARR, 2014; CORRÊA et al., 2016). The Passifloraceae family, to which the Passiflora genus belongs, is usually reported to contain between 500 and 700 species (CERQUEIRA-SILVA et al., 2014). It is estimated that around 30% are native to Brazil (SIQUEIRA JUNIOR, 2021). In addition to being considered one of the greatest centers of passion fruit diversity, Brazil is highlighted as one of the world's largest fruit producers (JUNQUEIRA et al., 2016). Brazil is responsible for approximately 65% of the global production, followed by Colombia and Indonesia (FAO, 2018). In 2020, Brazilian passion fruit production reached levels above 690 Mg, with northeastern states such as Ceará and Bahia accounting for the largest share (IBGE, 2021). In the state of Tocantins, although production is considered low at the national level, the produced volume rose by more than 383% between 2001 and 2020 (from 139 to 672 Mg) (IBGE, 2021).

Despite being a very popular fruit in the country, domestic production does not meet the growing consumer market demand. Therefore, to meet the volume demanded by the agro-industrial sector, Brazil opened its borders to import passion fruit juice (JUNQUEIRA et al., 2016). Estimates indicate that, in the last five years, the volume of passion fruit juice imported by Brazil increased over 12-fold, with Vietnam supplying 78.8% of these imports (AGROSTAT, 2021). In this scenario, there is a marketing potential for passion fruit in Brazil, and to meet this growing market demand, production areas are expected to increase.

Passion fruit is sold in two segments: fresh consumption and agro-industrial processing. Among the criteria used to assess its quality in the fresh consumption market, the physical aspect of the fruit is the most relevant (RINALDI et al., 2017). Maintaining good external appearance is the main postharvest bottleneck for its sale, as weight loss and consequent wilting give a wrinkled appearance to the fruit (ARJONA et al., 1992; AHMED et al., 2021). However, from the processing industry standpoint, the physical appearance of the fruit is secondary, whereas the physico-chemical parameters assume the greatest importance. According to Normative Instruction no. 37 of the Brazilian Ministry of Agriculture, passion fruit pulp must contain at least 11% soluble solids, 2.5% acidity, and a pH of 2.7 (MINISTRY OF AGRICULTURE, 2000).

The quality of passion fruit is directly related to production factors, harvest point, and genetic characteristics of the material (BOTELHO et al., 2019). Because its metabolic machinery remains active after harvesting, changes in the product's appearance, texture, flavor, and nutritional value continue. The high respiratory rate and high ethylene production are physiological characteristics responsible for its short shelf life of around seven days in ambient conditions (PONGENER et al., 2019; AHMED et al., 2022; XYLIA et al., 2022). For this reason, postharvest technologies have been developed to reduce plant organ metabolism, thus extending their shelf life.

The use of refrigeration during the different links of the passion fruit postharvest chain is the main technique employed to delay changes resulting from physical, physiological, and pathological factors that can interfere with the preservation and physico-chemical characteristics of the fruits (AHMED et al., 2022; XYLIA et al., 2022). Typically, the optimum temperature range for storing passion fruit is between 6 and 10 °C (ARJONA et al., 1992). However, due to its tropical origin, when subjected to temperatures below the critical threshold, passion fruit develops a physiological disorder known as chilling injury (RINALDI et al., 2017).

Chilling injury is the biggest obstacle to cold chain logistics during transporting and storing passion fruit. Characteristic symptoms of this disorder include accelerated wilting, skin discoloration, and necrotic spots resulting from loss of membrane integrity and excessive production of reactive oxygen species. In addition to the time-temperature factor, the genotype also strongly influences the manifestation of chilling injury (ARAÚJO et al., 2020). While banana (OLIVEIRA et al., 2016) and sweet potato (ARAÚJO et al., 2021) cultivars tolerant and sensitive to cold have already been identified in Brazil, information on differences in the degree of sensitivity to chilling injury between cultivars of yellow passion fruit widely grown in Brazil is non-existent.

Despite the popularity and economic importance of passion fruit in Brazil, information on the differences in the degree of sensitivity to chilling injury among widely cultivated yellow passion fruit cultivars in the country is scarce. Chilling injury is a major challenge in cold chain logistics, negatively affecting fruit quality during transport and storage. Therefore, this study aimed to examine the susceptibility of the passion fruit cultivars BRS Gigante Amarelo and BRS Sol do Cerrado to chilling injury during refrigerated storage, aiming to fill this knowledge gap and improve postharvest practices.

2. MATERIAL AND METHODS

Two passion fruit cultivars (Gigante Amarelo and Sol do Cerrado) widely grown by farmers in Tocantins (TO), Brazil, were chosen for this study. Fruits from commercial orchards in Araguaína, TO, Brazil, were harvested at the yellow-green maturity stage on August 15, 2023.. After careful selection, uniformly sized fruits free from physical defects were stored at 4 °C and 10 °C for up to 17 days, at 90% relative humidity. The variables were evaluated at 0, 5, 12, and 17 days of storage.

Determined visually and expressed as a percentage of wrinkled fruit surface, following Arjona et al. (1992). Calculated as the difference between the initial fresh weight and the weight at the time of evaluation, with values expressed as a percentage, according to the formula below:

$$FWL = [(IW - FW) / IW] \times 100 \quad (01)$$

where: FWL: fresh weight loss; IW: initial weight; and FW: final weight.

Measured by refractometry, using a HI 96801 digital refractometer, from seed-free juice, values were expressed in %. Determined by acid-base titration, using approximately 5 g of sample diluted in 75 mL of distilled water. A 0.1 N NaOH solution was used as the titrant and phenolphthalein as the indicator. Values were expressed as % citric acid.

The amount of CO_2 released by the passion fruit was quantified by storing it in hermetically sealed containers, in an adapted version of the method of Isermeyer (1952). Approximately 500 g of fruit was weighed and placed in hermetically sealed containers containing 40 mL of NaOH (0.5 N) for 3 h to capture the released CO_2. The CO_2 in the container without fruit was also determined and called a "blank test". After the incubation period, the CO_2 weight was quantified by titration of the NaOH solution containing two to three drops of phenolphthalein, with HCl (0.5 N). At the turning point (pink-colorless), the spent volume of HCl was recorded. Then, four to five drops of the mixed indicator (0.1% bromocresol green plus 0.1% methyl red) were added to perform the titration again with HCl (0.5 N) until the solution changed from green to red. To determine the CO2 weight in grams, the following formula was used:

$$CO_2\ (g) = \{MW_{CO_2} \times [HCl] \times f_{HCl} \times V_{mix}) - W_{CO_2} \quad (02)$$

where: MW_{CO_2} = molecular weight of CO_2 in g/mol; [HCl] = HCl concentration in mol/L; f_{HCL} = HCl correction factor;

Vmix = volume of HCl spent using the mixed indicator; and W_{CO_2} = CO_2weight in the blank test.

The experiment was laid out in a completely randomized design with a split-plot arrangement in which the plot, subplot, and sub-plot were represented by temperature, cultivar, and storage time, respectively. Four replicates were used, with each experimental unit consisting of fifteen fruits. Data were subjected to analysis of variance and then the temperature factor was split into the cultivar × time combination. Means were compared by the F test ($p \leq 0.05$), using R statistical software (R Core Team). To check the interrelationship between the treatments and the evaluated traits, multivariate analysis of canonical variables was performed using the R candisc package.

3. RESULTS

Chilling injury is the main physiological disorder manifested in fruits under conditions below the critical temperature (YU et al., 2017). In the present study, the critical storage temperature between cultivars was different, with cv. Gigante Amarelo is more tolerant of 4 °C than cv. Sol do Cerrado. Although the symptoms of chilling injury are highly diverse and may vary with the species, under the present experimental conditions, the accelerated wrinkling of the fruits' surface was the predominant symptom (Figure 1).

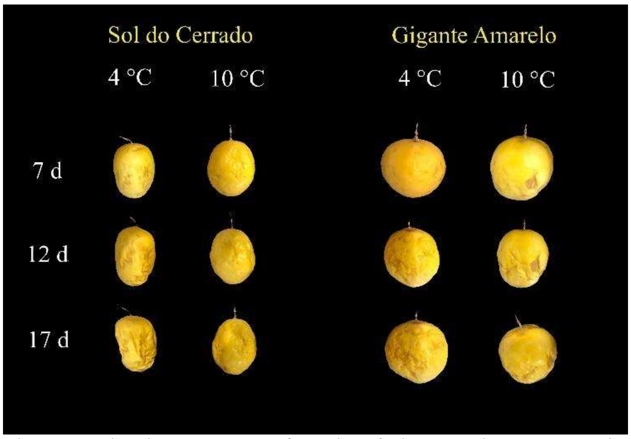

Figure 1. Visual appearance of passion fruit cvs. Gigante Amarelo and Sol do Cerrado throughout storage days at 4 °C and 10 °C.
Figura 1. Aparência visual dos maracujás Gigante Amarelo e Sol do Cerrado armazenados entre as temperaturas 4 °C e 10 °C.

The comparative analysis of the two cultivars at different temperatures reveals distinct differences in their responses to chilling injury. Cv. Sol do Cerrado shows a higher susceptibility to chilling injury at 4 °C, with severe symptoms manifesting as early as 12 days of storage. In contrast, cv. Gigante Amarelo demonstrates a relatively higher tolerance to chilling injury, with less pronounced symptoms after 17 days at 4 °C.

At 10 °C, both cultivars show better retention of visual quality, with minimal signs of chilling injury observed over the 17-day storage period. However, cv. Sol do Cerrado still exhibits a slight disadvantage compared to cv. Gigante Amarelo, as minor wrinkling and discoloration are more evident. Also, storage at 10 °C is generally more effective in preserving the visual quality of both passion fruit cultivars, reducing the incidence of chilling injury compared to storage at 4 °C. The differences in the cultivars' responses to storage conditions at 4 °C and 10 °C over 17 days were also analyzed. The results can be seen in Figure 2, which illustrates the changes in external appearance of the cultivars Gigante Amarelo and Sol do Cerrado during the storage period, highlighting how each cultivar responds to the different temperatures.

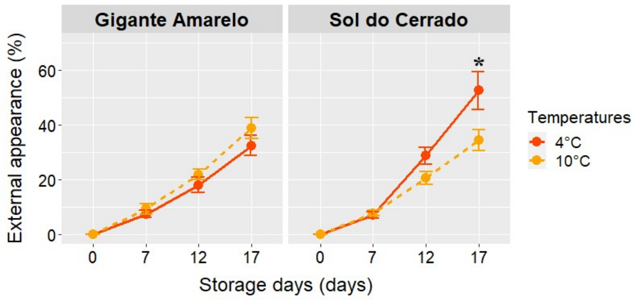

Figure 2. External appearance of passion fruit cvs. Gigante Amarelo and Sol do Cerrado stored at 4 °C and 10 °C. *indicates a significant difference between temperatures by the F test ($p \leq 0.05$).
Figura 2. Aparência externa dos maracujás das cultivares Gigante Amarelo e Sol do Cerrado armazenados a 4 °C e 10 °C. *indica diferença significativa entre as temperaturas pelo teste F ($p \leq 0,05$).

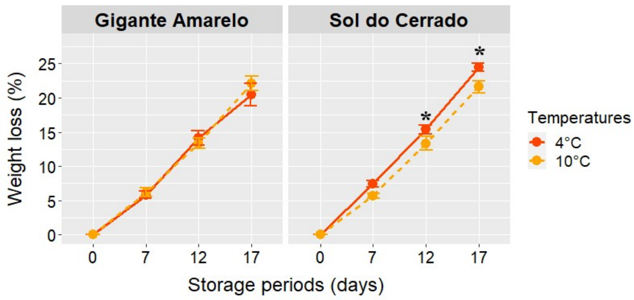

Figure 3. Fresh weight loss in passion fruit cvs. Gigante Amarelo and Sol do Cerrado stored at 4 °C and 10 ºC. * indicates a significant difference between temperatures by the F test ($p \leq 0.05$).
Figura 3. Perda de peso fresco nos maracujás das cultivares Gigante Amarelo e Sol do Cerrado armazenados a 4 °C e 10 °C. *indica diferença significativa entre as temperaturas pelo teste F ($p \leq 0,05$).

Similar to weight loss, the influence of temperature on the soluble solids content was dependent on cultivar and storage time (Figure 4), only in cv. Gigante Amarelo showed that the temperature of 10 ºC provided greater soluble solids accumulation at 7 and 12 days, compared with the temperature of 4 ºC. On the other hand, in cv. Sol do Cerrado, the temperatures did not influence the soluble solids content, which suggests that, in the present experimental conditions, the soluble solids content of passion fruit was not a parameter to describe the chilling-induced stress (Figure 4).

In contrast to soluble solids, the titratable acidity of Gigante Amarelo passion fruit was not influenced by storage temperature (Figure 5). On the other hand, after 12 days of storage, in cv. Sol do Cerrado, the temperature of 10 °C induced an up to 1.23 times greater accumulation of organic acids than the temperature of 4 °C (Figure 5).

In contrast to the respiratory rate of Gigante Amarelo passion fruit, which did not differ between temperatures, the respiratory rate of cv. Sol do Cerrado at 4 ºC was up to 2.5 times higher than at 10 ºC after 12 days of storage (Figure 6).

Canonical variable analysis was performed better to investigate the relationship between the studied variables and treatments. The first two canonical variables (CV1 and CV2) were sufficient to explain 98.8% of the total data variation. Canonical variable 1 explained 87.7% of the total variation and was negatively correlated with EA and WL. On the other hand, CV2 explained 11.1% of the total variation and correlated positively with TA and negatively with RR. Both CV efficiently separated the storage times and the fruits under chilling stress (4 ºC) from the non-stressed (10 °C) fruits of cv. Sol do Cerrado from 12 days onwards. The high score in CV1 shown by Sol do Cerrado passion fruit stored for 17 days at 4 ºC reinforces the greater cold sensitivity of this genotype compared with cv. Gigante Amarelo (Figure 7).

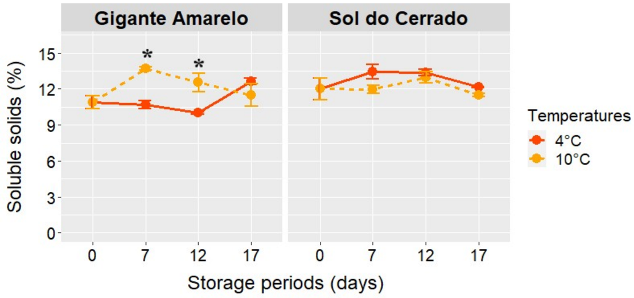

Figure 4. Soluble solids content of passion fruit cvs. Gigante Amarelo and Sol do Cerrado stored at 4 °C and 10 °C. *indicates a significant difference between temperatures by the F test (p ≤ 0.05).
Figura 4. Teor de sólidos solúveis nos maracujás das cultivares Gigante Amarelo e Sol do Cerrado armazenados a 4 °C e 10 °C. *indica diferença significativa entre as temperaturas pelo teste F (p ≤ 0,05).

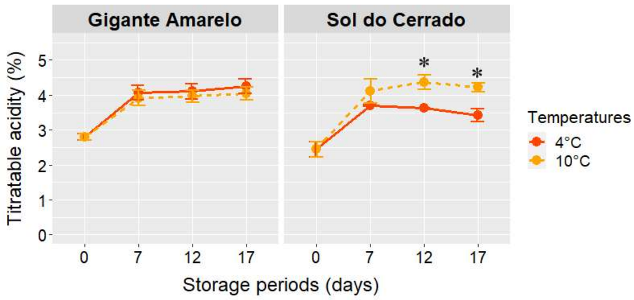

Figure 5. Titratable acidity of passion fruit cvs. Gigante Amarelo and Sol do Cerrado stored at 4 °C and 10 ºC. * indicates a significant difference between temperatures by the F test (p ≤ 0.05).
Figura 5. Acidez titulável de maracujás cvs. Gigante Amarelo e Sol do Cerrado armazenados a 4 °C e 10 ºC. * indica diferença significativa entre as temperaturas pelo teste F (p ≤ 0,05).

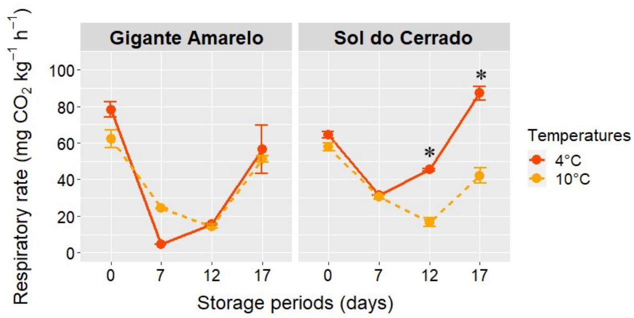

Figura 6. Taxa respiratória dos maracujás das cultivares Gigante Amarelo e Sol do Cerrado armazenados a 4 °C e 10 °C. *indica diferença significativa entre as temperaturas pelo teste F (p ≤ 0,05).
Figure 6. Respiratory rate of passion fruit cvs. Gigante Amarelo and Sol do Cerrado stored at 4 °C and 10 °C. * indicates a significant difference between temperatures by the F test (p ≤ 0.05).

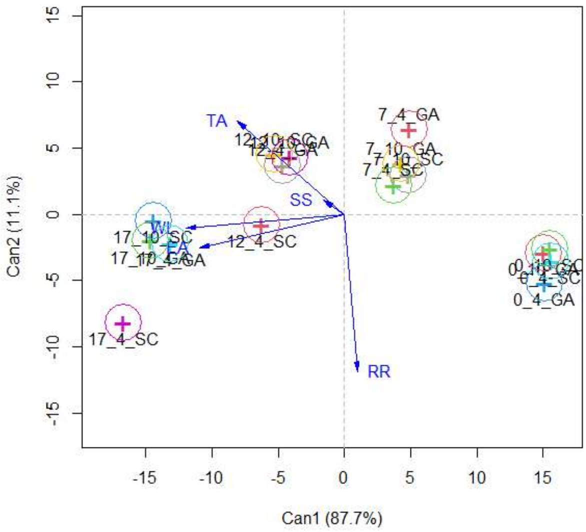

Figure 7. Biplot of canonical variables analysis applied to external appearance (EA), weight loss (WL), soluble solids (SS), titratable acidity (TA), and respiratory rate (RR) of passion fruit cvs. Gigante Amarelo and Sol do Cerrado were stored at 4 °C and 10 °C for 0, 7, 12, and 17 days. GA: Gigante Amarelo; SC: Sol do Cerrado.
Figura 7. Biplot da análise de variáveis canônicas aplicada à aparência externa (EA), perda de peso (WL), sólidos solúveis (SS), acidez titulável (TA) e taxa respiratória (RR) dos maracujás das cultivares Gigante Amarelo e Sol do Cerrado armazenados a 4 °C e 10 °C por 0, 7, 12 e 17 dias. GA: Gigante Amarelo; SC: Sol do Cerrado.

4. DISCUSSION

These results are similar to those of Shahidah et al. (2021), who found that passion fruit stored at 5°C suffers a higher percentage weight loss, resulting in unpleasant visual quality manifested in shrivelling and shrinkage. The higher tolerance of cv. Gigante Amarelo to lower temperatures may make it a more suitable choice for longer storage periods in cold chain logistics.

Fresh weight loss is one of the limiting factors for preserving passion fruit, as even if the pulp is in a good condition for consumption, the wilt and wrinkling detract from the visual aspect for sale, especially when the fruit is intended for fresh consumption. Passion fruit is generally considered wilted when it loses 8% of its initial weight (Federation of Agriculture of the State of Paraná, 2003). Therefore, as weight loss is a physical event resulting from transpiration and respiration, refrigeration and high relative humidity during storage are important factors to minimize it. Nevertheless, suppose the refrigeration temperature is below the critical level tolerated by the cultivar. In that case, chilling stress will manifest, increasing weight loss, especially in more sensitive cultivars (DIAZ et al., 2012), as seen in cv. Sol do Cerrado.

The soluble solids content constitutes one of the most practical ways to assess the degree of sweetness of fruits, considering that a large part of the soluble solids consists of sugars (70-90%). In addition to the context of fresh consumption, determining the soluble solids content in the industrial processing market is important because high concentrations of solids in the raw material mean less sugar to be added, higher product yield, and lower processing costs (PINHEIRO et al., 1984). In this respect, because the federal regulation recommends that the minimum soluble solids content of passion fruit pulp be 11%, overall, the fruits of both cultivars and storage conditions were within the parameters established by the regulations (Ministry of Agriculture, 2000).

The lower organic acid content in the Sol do Cerrado passion fruit at 4 °C is likely a reflection of the greater respiratory activity of the fruits under these conditions, as the organic acids may have been used as preferential respiratory substrates (EINHARDT et al., 2017). The respiration data reinforce this statement.

Regarding the respiratory pattern, passion fruit is a typically climacteric fruit, whose ripening is marked by a peak of respiratory activity preceded by ethylene production (PONGENER et al., 2014). However, the absence of the climacteric peak in the experimental conditions is explained by the maturation stage at which the fruits were found (yellow-green), i.e., the climacteric peak likely occurred before the beginning of the experiment. Therefore, the decrease in respiratory activity up to 7 and 12 days of storage at 4 °C and 10 ºC, respectively, can be described as the post-climacteric phase. In addition, the resumption of respiratory activity increases in both cultivars and temperatures up to 17 days may result from senescence, which is more pronounced under the stress conditions imposed by the temperature of 4 ºC during the storage of cv. Sol do Cerrado.

The analysis of the angle between the biplot vectors also allows inferences to be drawn about the linear correlation between the studied original variables (Figure 7). The acute angle between WL and EA suggests a positive and strong linear correlation between these variables, which indicates that loss of weight due to transpiration and respiration is one of the main factors that detracts from the appearance of passion fruit, especially in subcritical storage temperature conditions (ARJONA et al., 1992). On the other hand, the obtuse angle between RR and SS, as well as RR and TA, points to a negative correlation, which indicates that among the soluble solutes contained in the fruit, organic acids are substrates consumed by the respiratory process (EINHARDT et al., 2017).

5. CONCLUSIONS

The degree of manifestation of chilling injury was cultivar-dependent, and the predominant symptom was the more accelerated wilting of the fruit skin. Cultivar Sol do Cerrado was more sensitive to the chilling injury-inducing temperature.

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