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SCIENCE, FOOD TECHNOLOGY AND FOOD ENGENEERING

Post-harvest quality of *Campomanesia adamantium* (Cambess.) O. Berg. in function of storage temperature

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ABSTRACT. Brazil has a large variety of native and exotic fruit species, including the gabiroba, which can be sources of income for the population. The objective of this study was to evaluate the post-harvest behavior of gabiroba fruit by maturity stage and storage temperature. The fruits were divided into two lots and stored at temperatures of 6, 12, 24 and 30°C. The first batch was used for the physical and chemical analysis of acidity, soluble solids, firmness, percentage of green color, and visual analysis; this batch was composed of green and yellow-green fruit. The second lot was intended for breath analysis, composed of green, yellow-green, and yellow fruits. The experiment was conducted in a completely randomized design with five replications. Data were analyzed using descriptive statistics. Considering the evaluated characteristics, the gabiroba soluble solid/titratable acidity ratio values should be approximately 4.0 for the fruits to be considered acceptable for consumption. For the preservation of the post-harvest quality of gabiroba, it is indicated that the harvest is carried out at the green stage of maturation and that they are stored at a temperature of 6°C. The highest respiratory rates were observed in fruits harvested at the yellow stage, not being recommended its storage.

Keywords: gabiroba, refrigeration, breath, cerrado, maturity stage, post-harvest conditions.

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Introduction

The Cerrado is a global biodiversity hotspot (Strassburg et al., 2017) with favorable geographical and climatic characteristics for fruit production (Schiassi, Souza, Lago, Campos, & Queiroz, 2018). However, a large number variety of native and exotic fruit species that emains unexplored, despite their high nutritional and economic potential (Alves, Brito, Rufino, & Sampaio, 2008; Schiassi et al., 2018), among them the gabiroba.

Campomanesia adamantium (Cambess.) O. Berg, popularly known as gabiroba, is a fruit of the Cerrado that belongs to the Myrtaceae family and genus Campomanesia (Oliveira, Rebouças, Leite, Oliveira, & Funch, 2018). Gabiroba fruit is characterized as rounded berries ranging from 1 to 2 cm in diameter, with yellow-green color and sweet taste; gabiroba fruiting occurs from September to November and could eventually extend until February (Oliveira, Rossi, & Barros, 2011). The fruit and leaves are used to combat influenza, since the plant is rich in vitamin C, and the shells are indicated in the treatment anti-inflammatory, anti-diarrhoeal and urinary antiseptic activities, since the shells contain astringent substances (Oliveira et al., 2011; Sá et al., 2018). However, little is known about the physiology and conservation of gabiroba fruit.

The final quality of the fruit is dependent on numerous pre-harvest factors, such time when the fruit was harvested, as farming and environmental conditions (Bron & Jacomino, 2006) and post-harvest conditions, such as storage temperature and the controlled and modified atmospheres. Generally, when the fruits are removed from the parent plant, respiratory processes are intensified and biochemical changes favor decreases in post-harvest quality (Rahman, 2002). The maturity stage of the harvested fruit also determines the duration of the post-harvest life. Green harvested fruits are more susceptible to mechanical damage, physiological disorders, and water loss than fruits at other maturity stages (Kader, 1992). The ideal stage of maturation for fruit harvesting may reflect the high percentage of product acceptance (Viana et al., 2020).

The maturation stage is also associated with the storage temperature, being is one of the factors that most influences breathing. So there is an ideal temperature value for the maintenance of each fruit to ensure maximum edible quality (Chitarra & Chitarra, 2005). Fruits harvested green and packed under low temperatures can develop symptoms of chilling, as observed in red mombin fruit (Martins, Silva, Alves, & Filgueiras, 2003) the appearance of brownish stains with small initial size that become blackened and larger, and the superficial scald in the shell (Miguel, Durigan, Morgado, & Gomes, 2011).

Cooling is one of the most commonly used post-harvest techniques and reduces the metabolic rate of the fruit. Low temperatures can cause decreases or increases in O_2 consumption. The breath rate usually increases with increasing temperature, particularly in the range of 5 to 20°C; the upper temperature limits are between 30 and 35°C, but the resulting higher-temperature disorders are quite variable (Chitarra & Chitarra, 2005). The duration of storage should also be considered to obtain the best fruit quality during the shelf life (Van Wyk, Huysamer, & Barry, 2009). In this context, reduction of post-harvest losses through adequate storage is crucial to extending the post-harvest life of the product. For food security, economic growth and welfare of the society minimizing this loss has a great significance (Kasso & Bekele, 2018). Thus, the objective of this study was to evaluate the effects of maturity stages and storage temperatures on preserving gabiroba quality after harvest.

Material and methods

Gabiroba fruits (Figure 1) were collected from a single plant located on the 'Rio Doce Coqueiros' farm in the town of Rio Verde, Goias, Brazil. After collection, the fruits were transported to the Plant Ecophysiology and Productivity Laboratory at the Federal Institute of Goias - Rio Verde Campus. In the laboratory, the fruits were selected for the absence of mechanical damage and pest or pathogen attack.

The selected fruits were sanitized and distributed on stands for natural drying. Afterward, the fruits were separated into two lots, the first for the physico-chemical analysis, consisting of green and yellow-green fruit, and the second for breath analysis, composed of green, yellow-green, and yellow fruit.

Gabiroba fruits were packed *in natura* in petri dishes with a capacity of 50 cm^3 and sealed with polyvinyl chloride (PVC) plastic film. To avoid accumulation of gas and free water within the vial, small holes were made in the plastic seal. Thereafter, the bottles were stored in BOD chambers at temperatures of 6 and 12°C, and in air-conditioned rooms at temperatures of 24 and 30°C with 80 ± 5% relative humidity.

Fruits were evaluated at 0, 4, 8, 11, 13 and 15 days after initial storage, thus maintaining an interval of three days between one evaluation and another. For ripening attributes, such as the soluble solid (SS)/titratable acidity (TA) ratio (SS/TA), green color (%), firmness (N), and visual analysis, as described below.

The SS content was determined from juice samples extracted from five fruits per replicate. Two drops of juice were placed on the prism of a manual refractometer (N-1E, Atago, Nagoya, Tokyo, Japan) and a refractive index reading, expressed in °Brix, was taken.

The fruit's TA was determined by neutralization titrations with NaOH (0.1 N) until the pH reached 8.2 (Instituto Adolfo Lutz [IAL], 2008). A 1g sample from each of five fruits per replicate was extracted and macerated using a mortar and pestle. The sample was then transferred to an Erlenmeyer flask containing 50 mL of deionized water and three drops of phenolphthalein before proceeding with NaOH titration.

The acidity was then calculated according to the following Equation 1.

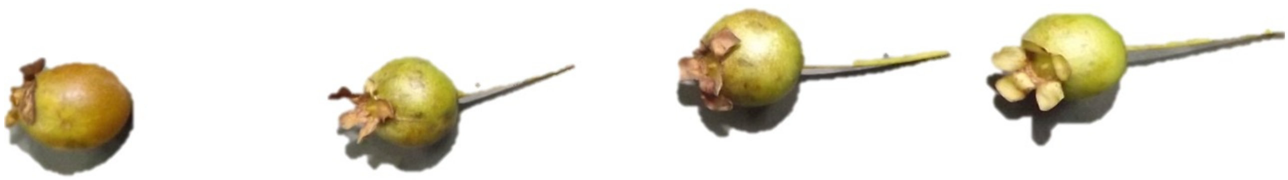

Figure 1. Gabiroba fruits.

$$\frac{V * f * 100}{P * c} = acidity \in molarsolution, \% \, v/m \qquad (1)$$

where:
V = volume in mL of NaOH solution (0.1 N) used for the titration,
f = NaOH solution factor (0.1 N),
P = mass in grams of the sample used in the titration, and
c = correction value (here, 10 because the titration was performed with 0.1 N NaOH).

Changes in the firmness of the whole fruit were obtained using a pedestal applanation instrument, in which the fruit was placed on a vertical support and a glass bowl was set on the fruit. The firmness was measured according to the following Equation 2, as the ratio of the weight of the bowl to the deformed area (Calbo & Nery, 1995).

$$A = 0.784 * d1 * d2$$
$$Fz = \frac{P}{A} * 9.8 \qquad (2)$$

where:
N = firmness (N),
P = applanation weight, and
A = area in cm^2.

To convert the firmness (kgf) to (N), the formula is multiplied by 9.8.

The color changes were determined according to a scale developed in relation to the quantity of green color present in the fruit, as seen in Figure 2.

For visual analysis, fruits were evaluated for lack of rottenness, mechanical damage, and apparent wilting.

For the breathing evaluation, fruits were deposited into 250 mL glass vials and put under temperatures of 6, 12, 24, and 30°C. For each storage temperature, there were five replicates with five fruits. In each evaluation day (0, 4, 8, 12 days of storage), the vials were adapted to an open flow system (Figure 3) using an infrared gas analyzer (IRGA) [Qubit Systems Inc., Kingston, Ontario, Canada] and 400 mL min^{-1} air flow. Instrument calibration was performed with an air reference concentration of 395 ppm. Afterward, CO_2 delta values between the air and the air reference analysis were used to calculate the fruit breath rate according to the following Equation 3 and 4.

$$RCO_2 = \frac{(\Delta CO_2 x Flow(mL.h^{-1}) x CF)}{\left(1.000.000 x FM(Kg)\right)} \qquad (3)$$

where:
RCO_2 = breath rate, expressed in mg CO_2 kg^{-1} $hour^{-1}$,
ΔCO_2 = reference air – analyzed air,
Flow = air flow through the measurement chamber during analysis,
CF = correction factor from ml CO_2 to mg CO_2*, and
FM = fresh mass of the fruits (kg) on the day of analysis.

$$CF = \frac{gramsofCO2}{22{,}415x\frac{(T+C)}{T}} \qquad (4)$$

where:
T = temperature in Kelvin (273K),
C = temperature in degrees Celsius (°C), and 22.415 = gas constant.

Figure 2. Scale of the percentage of green color in Gabiroba fruits.

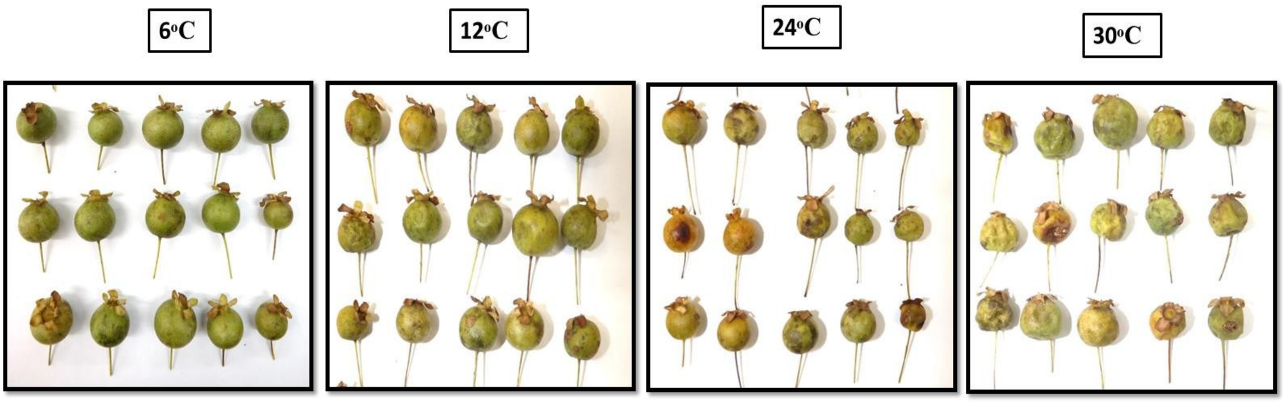

Figure 3. Gabiroba fruits after storage at temperatures of 6, 12, 24 and 30°C.

The experiment was conducted in a completely randomized design with five replications. Data were analyzed using descriptive statistics.

Results and discussion

The storage period of Gabiroba fruits harvested at the green stage and stored at 6°C was 13 to 14 days, stored at 12°C 11 to 12 days, and stored at 24 and 30°C eight days. Yellow-green gabiroba fruits stored at a temperature of 6°C lasted 12 days post-harvest, at 12°C for 11 days, stored at 24°C 8 days, and 30°C 4 to 7 days. After these periods, according to the visual analysis (supplemental material), there was the appearance of wilting, loss of firmness, strong colorations, and the appearance of fungus, therefore making the fruit unfit for consumption, as seen in Figure 3.

The preservation of post-harvest fruit and vegetable quality after harvest directly depends on the storage conditions. Temperature is one of the most important factors in preserving this quality, and low temperatures reduce metabolism by decreasing respiratory rates and activating enzymes such as pectinametilesterase, polygalacturonase (Antunes, Gonçalvez, & Trevisan, 2006) and chlorophyllase (Yang et al., 2009), as observed in this study.

The most common technology used to extend shelf-life in fruits is cold storage (Aispuro-Hernández, Vera-Guzmán, Vargas-Arispuro, & Martínez-Téllez, 2019). Cooling is very important not only from the commercial point of view, but also for controlling senescence, since temperature regulates the rates of all physiological and biochemical processes. The benefit of storage at low temperatures has been observed for various fruits of the same family (Morgado, Durigan, Lopes, & Santos, 2010; Campos, Hiane, Ramos, Ramos Filho, & Macedo, 2012; Scalon, Oshiro, & Dresch, 2012). Recently Gambi et al. (2018) in kiwi fruit the modulation in the expression of the Chl breakdown related genes staygreen (Sgr) and pheophorbide an oxygenase (PaO) by effect of storage temperatures was demonstrated.

Associated low temperatures should take into account the fruit's development stage. Green harvested fruit has reduced metabolism (Chitarra & Chitarra, 2005) and can develop certain sensory characteristics during storage, while fruit harvested in advanced maturation stages tends to be more susceptible to mechanical damage, decay, physiological changes, and decreased shelf life (Pereira, Cantillano, Gutierez, & Almeida, 2006).

Yellow fruits had higher initial respiratory rates than green and yellow-green fruits (Figure 4). The minimum respiratory rate in green fruit was 2.98 mg CO_2 kg^{-1} $hour^{-1}$, observed in fruit stored at 6°C, and the maximum was 7.3 mg CO_2 kg^{-1} $hour^{-1}$, observed in fruit stored at 12°C (Figure 4A). In yellow-green fruits, the minimum respiratory rate was 3.5 mg CO_2 kg^{-1} $hour^{-1}$ (in fruit stored at 30°C) and the maximum was 7.3 mg CO_2 kg^{-1} $hour^{-1}$ (in fruit stored at 12°C; Figure 4B). The minimum respiratory rate of yellow fruit was 5.3 mg CO_2 kg^{-1} $hour^{-1}$ (in fruit stored at 6°C) and the maximum was 11.2 mg CO_2 kg^{-1} $hour^{-1}$ (in fruit stored at 30°C; Figure 4C). Fruits stored at 6°C, regardless of the maturity stage, had less variation in respiratory rates during storage (Figure 4).

Gabiroba fruit harvested during the yellow ripening stage had a 112% increase in respiratory rates with increasing temperature; this increase reached values of 179% at 30°C (Figure 5). Fruits harvested in green and yellow-green stages had increased respiratory rates when the temperature ranged from 6 to 12°C and decreased respiratory rates at 24 and 30°C (Figure 5). No differences were found between these two maturation stages.

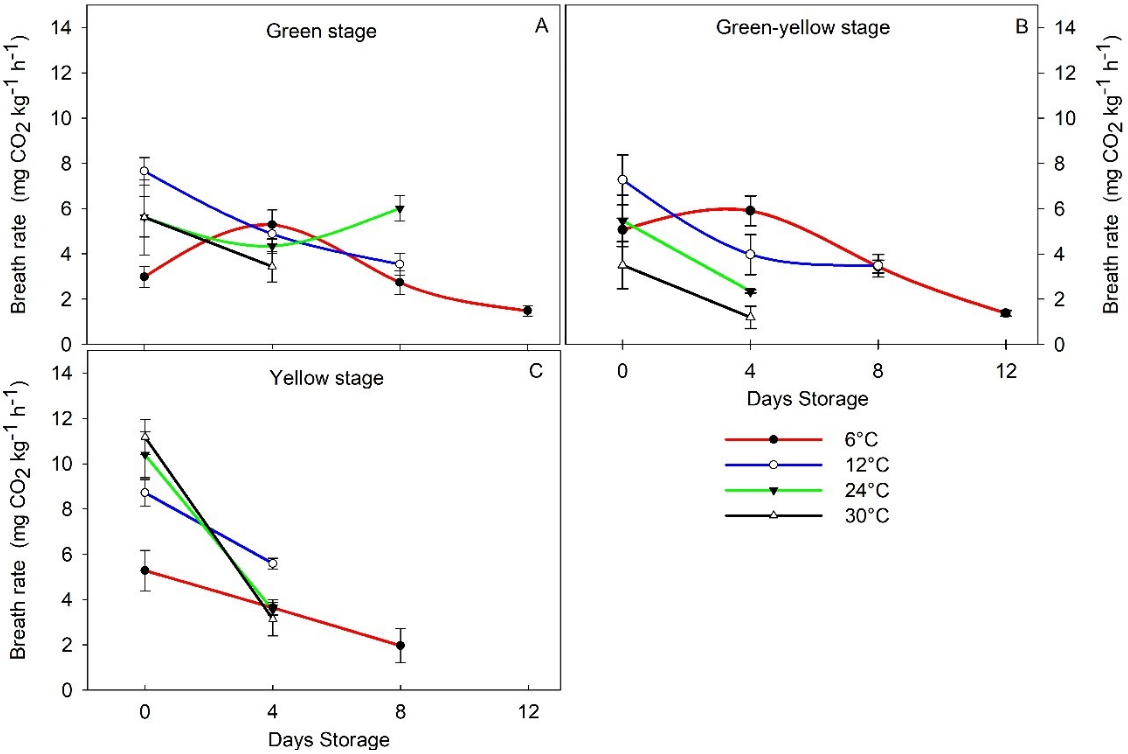

Figure 4. Breath rate (CO_2 mg kg^{-1} hour^{-1}) of green gabiroba fruit harvested at different maturation stages (A), the green-yellow stage (B), and the yellow stage (C) that were stored at temperatures of 6, 12, 24, or 30°C. Vertical bars represent the standard error of the mean (*n* = 5).

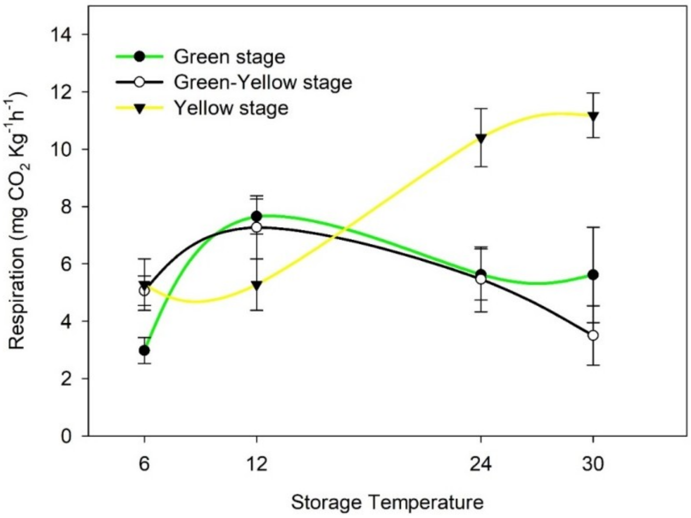

Figure 5. Breath rates in gabiroba fruits harvested at the green, yellow-green, and yellow maturity stages and stored for 24 hours at temperatures of 6, 12, 24 or 30°C (RH 80 ± 5%). Vertical bars represent the standard error of the mean.

The benefits of cold storage in association with the maturity stage can be seen in gabiroba fruit by extension of its post-harvest life. Since green fruits stored at 6°C had lower respiratory rates, contributing to the reduced consumption of respiratory substrate and less activation of degradative enzymes in the middle lamella and cell wall, the organoleptic and physico-chemical characteristics were better preserved than in yellow-green fruits. The low temperature was also important for the preservation of the physicochemical characteristics of caja manga fruits (Kohatsu, Zucareli, Brambilla, & Evangelista, 2011).

No difference was found in relation to the fruit acidity in the green stage of ripening at temperatures of 6, 12, or 30°C; there was a difference only at 24°C, with lower TA values than at other temperatures (Figure 6A), can be attributed to the respiratory process or its conversion into sugars.

In yellow-green fruits, the highest acidity values were found in fruits stored at temperatures of 6 and 12°C, followed by 24 and 30°C (Figure 6B), may be due to the action of pectinametilesterase and polygalacturonase due to fruit ripening, enhancing the release of the galacturonic acid of the cell wall.

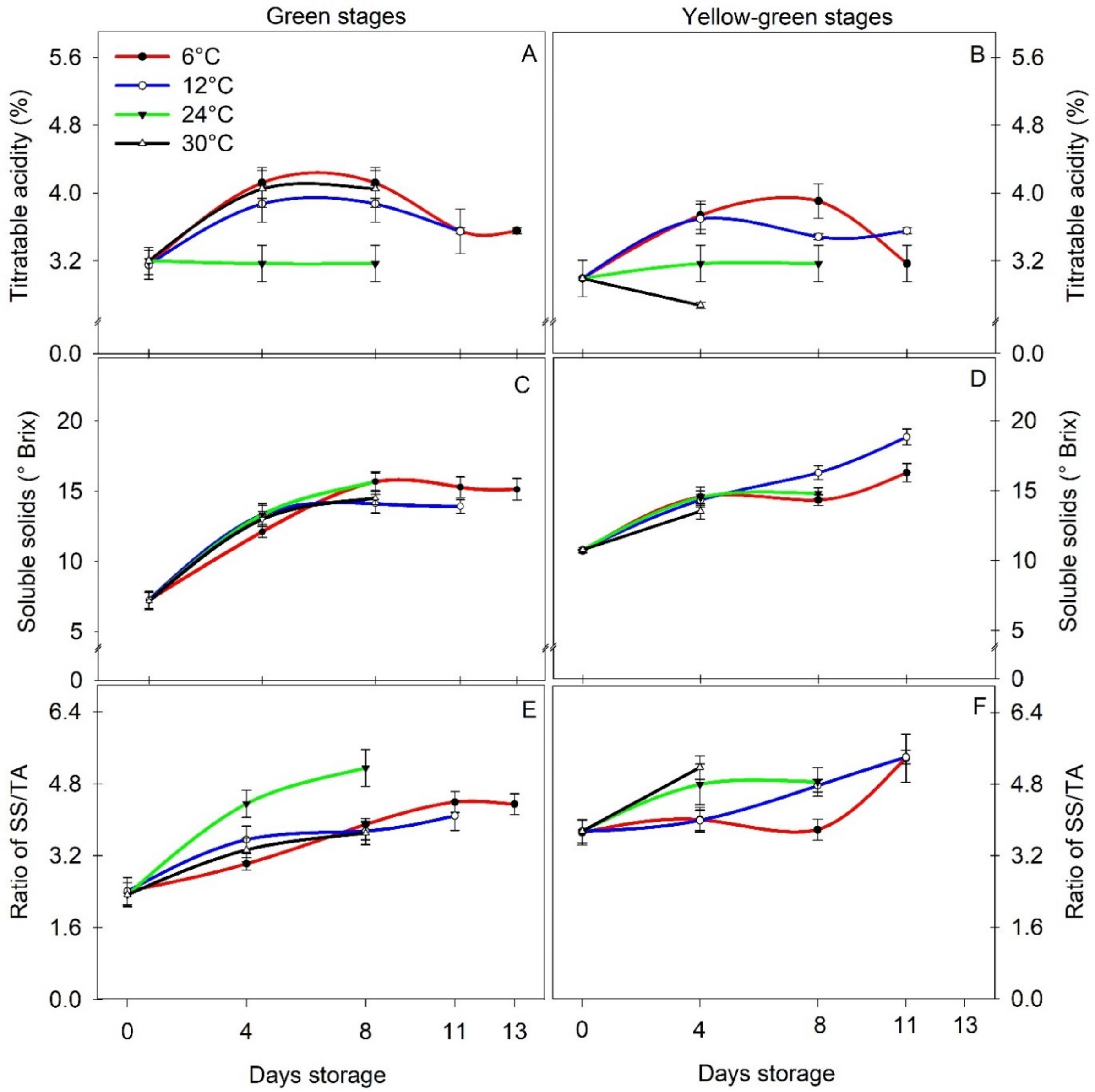

Figure 6. Titratable acidity (%) for the green fruit stage (A) green-yellow fruit stage (B), soluble solids (°Brix) for fruit in the green (C) and yellow-green (D) stages, and the ratio of soluble solids/titratable acidity in the green (E) and yellow-green (F) stages in gabiroba fruit subjected to days storage at different temperatures.

We observed increases in SS during storage at all temperatures and ripening stages, but the values in the yellow-green stage were higher than those of the green fruit. For the green stage, there was no difference between the temperatures during the storage period (Figure 6C). Increases in SS of over 100% were observed in fruits stored at 6°C to near 95% at 12°C. Yellow-green fruit stored at either 12 or 6°C showed higher SS values (Figure 6D).

The preservation of gabiroba fruits' post-harvest quality can be proven by changes in SS content. The large increases in SS content in both green and yellow-green fruits indicate biochemical changes in the fruit, since during ripening insoluble polysaccharides are transformed into soluble sugars (Chitarra & Chitarra, 2005; Aroucha, Souza, Souza, Ferreira, & Aroucha Filho, 2012). This is an important quantitative change during fruit maturation that contributes directly to the pleasant taste of the fruit (Awad, 1993).

The fruits harvested at the green stage and stored at 6°C showed the highest SS values, compared to other storage temperatures; this is likely because only a small amount of reserve was used in respiratory processes, as evidenced by the low respiratory values. The SS values observed in this study are consistent with those found in other studies conducted with gabiroba, ranging from 12.39 to 16.25 °Brix (Campos et al., 2012; Scalon et al., 2012).

The highest SS/TA values for green fruit were obtained at 24°C. No significant differences were observed between fruits stored at the temperatures of 6, 12, and 30°C (Figure 6E). Yellow-green fruits had higher SS/TA values than green fruits. The only difference was on the 8th day of storage, where the SS/TA of fruits stored at 6°C was lower than that of the others, but was equal to that of the fruit stored at 12°C on day 11 (Figure 6F).

It is through the balance between acids and sugars that the fruit's sweet taste is formed, and this balance can be estimated by the SS/TA, which can be directly influenced by the period and storage temperature (Miguel et al., 2011) to the Brazilian market, the fruits with higher SS/TA values are the most desirable (Thé, Carvalho, Abreu, Nunes, & Pinto, 2001). During ripening, it is desirable that the reduced acidity is accompanied by an increase in SS. Therefore, fruits stored at lower temperatures have reduced metabolism, allowing a higher conversion to sugars during storage, and the fruits develop improved sensory characteristics.

Gabirobas harvested at the green and yellow-green stages and stored at 24 and 12°C, respectively, had better flavor than these fruits stored at other temperatures; however, yellow-green fruits had higher accumulations of these sugars and therefore would be more desirable for consumption. To harvest Gabiroba with the proper sensory characteristics for consumption, the SS/TA values should be approximately 4.0.

Fruit firmness changed depending on the storage temperature; green fruit had decreased firmness at all temperatures. This reduction was more intense in fruits stored at temperatures higher than 6°C. In fruits stored at 6°C from day 8, firmness was increased, but decreased thereafter (Figure 7A).

The firmness in yellow-green fruits was lower than for the fruits harvested at the green stage, but no differences were observed between the temperatures of 12, 24, and 30°C. Fruits stored at 6°C had slightly higher firmness than fruits stored at the other temperatures (Figure 7B).

Gabiroba fruit harvested at the green stage of ripening and stored at 6°C retained about 90% of the green color (Figure 7C). During storage, there was a decrease of 15, 40, and 30% for fruit kept under 12, 24, and 30°C, respectively (Figure 7C). For green-yellow fruit in the first four days of storage, the percentage of green color was not different in storage temperatures of 6 and 12°C. After the 4th day of storage, the highest percentage of green coloration was observed in fruits stored at 6°C. A peak at day 8 was observed, followed by a decrease. Fruits at 30°C had a lower percentage of green than fruits stored at other temperatures (Figure 7D).

In addition to the sensory characteristics, one must consider the visual aspect of the product so that it is accepted by the consumer. Changes in the skin color may change the fruit's attractiveness for consumption. Changes in skin color also indicate changes due to maturation, fruit quality, of freshness and storage conditions (Muengkaew, Chaiprasart, & Warrington, 2016).

Gabiroba fruit packed at 6°C had a higher retention of the skin color and firmness, regardless of the maturity stage, likely due to lower chlorophyllase (Yang et al., 2009), pectin methyl esterase, and polygalacturonase activity (Antunes et al., 2006). In green-yellow fruit, the percentage of green skin increased by the 8th day of storage, probably due to weight loss, which focuses existing pigments.

After the color change, fruit softening is the most characteristic change that occurs during maturation. From an economic point of view, the firmness is very important, as it affects the post-harvest quality by providing greater resistance to mechanical damage and micro-organism attack. The loss of fruit consistency can result from two factors. The former may be due to excessive water loss leads to decreased turgor pressure of the cell, especially when the product is stored in an atmosphere with low relative humidity, and the second may result from enzymatic decomposition of the middle lamella and cell wall (Awad, 1993).

The loss of firmness in green fruits stored at 12, 24, or 30°C was most likely due to the loss of water and the activity of enzymes that act on the cell wall. The greatest firmness was observed in fruit stored at 6°C, as observed by the lower deformation area promoted by the leveler in response to increased cell turgor, except for the 11th day. During this period, the likely increase in firmness was due to decreased relative humidity in the storage environment, promoting wrinkling of the fruit. The decrease in firmness after this period is probably related to enzymatic decomposition of medium and cell wall lamella.

This study demonstrates that gabiroba fruit has great marketing potential as small fruit, but additional studies still need to be made, including studies that verify the effectiveness of implementation of other post-harvest techniques in combination with the storage temperature for the expansion of gabiroba fruit's service life.

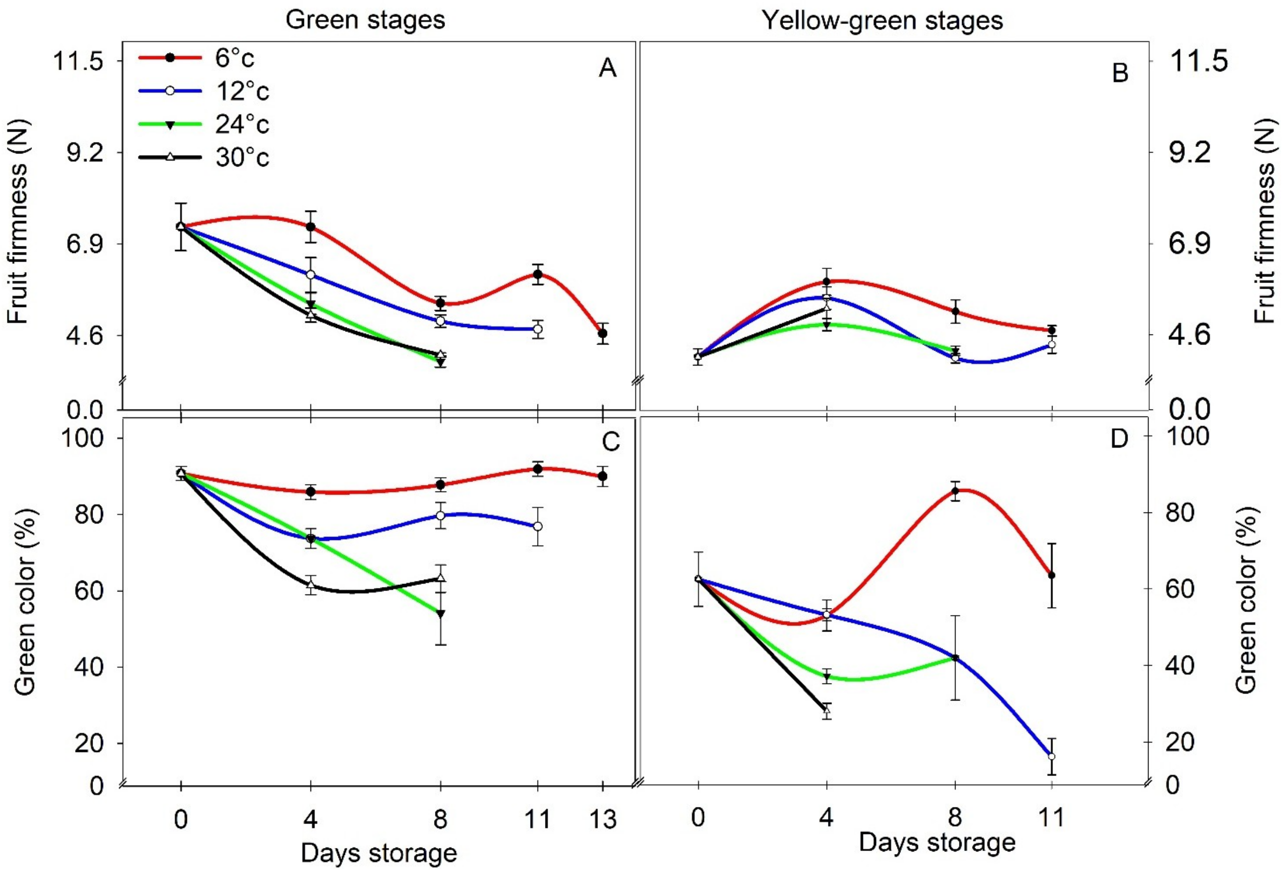

Figure 7. Firmness values (N) in the green (A) and green-yellow (B) fruit stages, green color (%) in the green (C) and green-yellow (D) fruit stages submitted to storage at different temperatures.

Conclusion

For the preservation of the post-harvest quality of gabiroba, it is indicated that the harvest is carried out at the green stage of maturation and that they are stored at a temperature of 6°C.

The highest respiratory rates were observed in fruits harvested at the yellow stage, not being recommended its storage.

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