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Calcium carbide in anticipation and standardization of ripening in Cajá-manga fruits

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Abstract – Fruit ripening promoted by the exogenous application of ethylene analogs, such as calcium carbide, has commercial advantages. Thus, the knowledge of the responses of fruits treated with ethylene-inducing agents is essential to optimize the use of these substances. This work aimed to evaluate the influence of exposure to calcium carbide on the anticipation and standardization of postharvest ripening of cajá-manga fruits. Physiologically mature fruits were exposed to calcium carbide for 24 hours at concentrations 0, 20, 40, 80, and 110 g m^{-3}. The fruits were stored at a temperature of 28±2 °C and evaluated at 0, 2, 4, and 6 days for the loss of fresh mass, color of the epidermis and pulp given by the CIELAB color space, titratable acidity, soluble solids content, the ratio between soluble solids content and titratable acidity, and vitamin C content. Cajá-manga fruits treated with different concentrations of calcium carbide had their ripening anticipated without compromising their characteristics. The concentrations of 20, 40, and 80 g m^{-3} of calcium carbide allowed the anticipation and standardization of fruit ripening within four days during storage, while for the highest concentration (110 g m^{-3}), complete maturation was accelerated, occurring between two and four days of storage.

Index terms: *Spondias dulcis* P., fruit climatization, acetylene.

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Carbureto de cálcio na antecipação e na uniformização do amadurecimento de frutos de Cajá-manga

Resumo – O amadurecimento de frutos promovido pela aplicação exógena de análogos de etileno, como o carbureto de cálcio, tem vantagens comerciais. Assim, o conhecimento das respostas de frutos tratados com agentes indutores de etileno é essencial para otimizar o uso dessas substâncias. Este trabalho teve como objetivo avaliar a influência da exposição ao carbureto de cálcio na antecipação e na padronização do amadurecimento pós-colheita de frutos de cajá-manga. Frutos fisiologicamente maduros foram expostos ao carbureto de cálcio nas concentrações de 0; 20; 40; 80 e 110 g m^{-3} por 24 horas. Os frutos foram armazenados a uma temperatura de 28±2 °C e avaliados aos 0; 2; 4 e 6 dias quanto à perda de massa fresca, cor da epiderme e polpa dada pelo espaço de cor CIELAB, acidez titulável, teor de sólidos solúveis, relação entre o teor de sólidos solúveis e a acidez titulável, e teor de vitamina C. Frutos de cajá-manga tratados com diferentes concentrações de carbureto de cálcio tiveram seu amadurecimento antecipado sem comprometer suas características. As concentrações de 20; 40 e 80 g m^{-3} de carbureto de cálcio permitiram a antecipação e a padronização do amadurecimento dos frutos em quatro dias, durante o armazenamento, Enquanto para a maior concentração (110 g m^{-3}), a maturação completa foi acelerada, ocorrendo entre dois e quatro dias de armazenamento.

Termos para indexação: *Spondias dulcis* P., climatização, acetileno.

Introduction

The cajá-manga (*Spondias dulcis* Parkinson) is a species native to Polynesian islands well adapted to the Brazilian Cerrado conditions, which belong to the Anacardiaceae family and the *Spondias* genus. Its fruits are climacteric based on the ethylene synthesis and respiration pattern, in which the ripening process changes the fruits' chemical composition and nutritional value (SILVA et al., 2020).

Fruits of the *Spondias* genus present high nutritional value, being rich in bioactive compounds and having antioxidant potential (DANTAS et al., 2016). Among these fruits, cajá-manga has potential for fresh market and processing, as it is rich in nutrients and has good sensory characteristics (CHAVES NETO; SILVA, 2019). It is of great importance in the agroindustry due to its various uses, which include processing to be used in juices, cocktails, liqueurs, and ice cream, besides being a lot appreciated for fresh consumption (CHAVES NETO, 2019).

The pulp of the cajá-manga, when it is fully ripe, presents a sweet and slightly acidic flavor, with a higher soluble solids content than other species of the same genus (CHAVES NETO et al., 2018). The ripening characterizes as the change in the epidermis color and is widely used as a standard to determine the fruit maturation degree (BOTELHO et al., 2019) This change did not only contribute to fruit appearance but also influences on consumers' acceptability (MOTTA et al., 2015; SILVA et al., 2012a). In the commercialization of fruits, especially in the Brazilian market, consumers seek to acquire a product with a more attractive color, indicating that the fruit is immediately ready for consumption (RIBEIRO et al., 2019).

In Brazil, this species is in the phase of domestication and expansion to agroindustries, and it can become of great potential for industries. It has a high economic and social value throughout the country, mainly in the north and northeast regions, which are the largest producers of fruits due to their climatic conditions. However, this species is still obtained by extractivism and is vastly explored by small producers, having the characteristic of being highly perishable with a short period of commercialization, which makes it necessary to anticipate the harvest (LIMA et al., 2019), besides presenting an irregular maturation (CHAVES NETO et al., 2018).

Climacteric fruits such as cajá-manga, which have a peak ethylene production, can have the ripening process artificially accelerated by metabolic reactions catalyzed by acetylene, a gas similar to ethylene that simulates the physiological effect of this hormone on fruits' tissues and generates uniform maturation, and can be obtained through the exogenous application (SIQUEIRA et al., 2017). Ethylene analogs such as calcium carbide are commonly employed to promote the flowering of various fructiferous and ornamental species (KOSERA NETO et al., 2018; SOARES et al., 2022).

Fruit climatization (induction of ripening) can be performed by small-scale farmers in completely sealed maturation chambers by applying acetylene, a gas obtained at a low cost by adding water with calcium carbide, which is the cheapest source of ethylene and can be bought in building material stores. However, the required dose depends on several factors, including the amount of fruit and the safety limit of gas accumulation to minimize the risk of explosions, and many producers use doses higher than necessary, increasing production costs and the risk of explosions, in addition to reducing the postharvest life of the fruits, affecting the marketing of fruit (OLIVEIRA et al., 2001; NOGUEIRA et al., 2007).

Silva et al. (2012b) evaluated the effect of acclimatization in "Ubá" mango with calcium carbide at concentrations of 20, 40, 80, and 160 g m^{-3} in a chamber for 24h at a constant temperature of 18.1 ± 0.7 °C and 90 ± 3% of relative humidity, after the treatment, the authors kept the fruits under the same conditions of temperature and RH and evaluated them at 0, 1, 3, 6, 9, 12, and 15 days of storage. The authors concluded that calcium carbide anticipated ripening, promoting uniformity in the color of the epidermis and pulp, in addition to a high content of soluble solids and firmness of the pulp.

Despite its economic importance in the north and northeast regions and the need for uniform fruit maturation, studies with ethylene analogs in the ripening of cajá-manga are still incipient. Therefore, this work aimed to evaluate the influence of exposure to calcium carbide to anticipate and standardize the postharvest ripening of cajá-manga fruits (*Spondias dulcis*).

Material and Methods

The cajá-manga fruits (*Spondias dulcis*) were harvested in the municipality of Jataí – GO (latitude 17° 52' 33" S, longitude 51° 43' 17" W and 731 m in altitude). The fruits were harvested physiologically mature (with green epidermis) at 120 days after anthesis, which is the harvest point for storing fruits of the genus *Spondias*. After harvest, the fruits were transported to the laboratory, where they were selected and standardized by weight (178.0 ± 4.0 g), washed in 0.2% aqueous detergent solution, treated with fungicide solution (Athos 100®), following the recommendations described in the label and then dried at room temperature. After drying, the fruits were placed in climatization chambers containing hydrated calcium carbide (CaC_2) at concentrations 0, 20, 40, 80, and 110 g m^{-3} and kept in such conditions for 24 h at room temperature (28±2 °C).

After exposure to calcium carbide in climatization chambers, the fruits were stored in polypropylene trays covered with low-density polyethylene film (60 x 45 cm) and kept at room temperature (28±2 °C). Samples were taken at 0 (24 hours after exposure), 2, 4, and 6 days for the evaluation of the characteristics: pulp and epidermis color, loss of fresh mass, titratable acidity, soluble solids content, the ratio between soluble solids content and titratable acidity, and vitamin C.

The color of the epidermis and pulp was given through the coordinates L*, a*, b*, C*, and h° using a Minolta® colorimeter. Two readings were performed on opposite faces of the fruits. The parameter L* represents the brightness of the sample, with values between 0 (less bright) and 100 (brighter), the coordinate a* represents the colors: green (from 0 to -60) and red (from 0 to +60), the coordinate b* represents the colors: yellow (from 0 to +60) and blue (from 0 to -60), the parameter C* represents the saturation of the color, and the h° represents the hue angle (from 0 to 360°), that indicates the quadrant in which the color of the sample is. Based on the characters L*, a*, and b*, the color difference was calculated, which is a parameter that represents the difference between the initial and final colors of the fruits.

The pulp was extracted with a blender without adding water and a nylon sieve. The soluble solids content was measured by placing three drops of pulp in a portable refractometer Atago® model PAL-1, and the results were expressed in °Brix. The vitamin C content was obtained by titration with a 2,6-Dichlorophenolindophenol sodium salt hydrate solution, and the results were expressed as mg of ascorbic acid 100 g^{-1}. The titratable acidity was obtained by titration using a NaOH solution and phenolphthalein 1% as indicator, and the results were expressed as g of citric acid 100 g^{-1}. For soluble solids, vitamin C content, and titratable acidity, the methodologies proposed by AOAC International were adopted (AOAC, 2016).

The experiment was conducted in a split-plot scheme with the 5 concentrations in the plots and the 4 evaluation days in the subplots, in a completely randomized design, with three replications and three fruits per experimental unit, totaling 180 fruits. The data were submitted to the analysis of variance, and the interactions were unfolded, being significant or not. The averages were submitted to regression analysis, and the choice of equations was based on the significance of the regression coefficients by the "t" test (Student), the coefficient of determination (R^2), and the potential to explain the biological phenomenon.

Results and Discussion

The difference in epidermis color and pulp color of cajá-manga fruits treated with different concentrations of calcium carbide varied over the six days after exposure, showing a quadratic behavior for all concentrations (Figures 1A and B).

The concentration of 110 g m^{-3} provided the change of the color of the epidermis in a shorter time because between two and four days the fruits already had a yellow col-

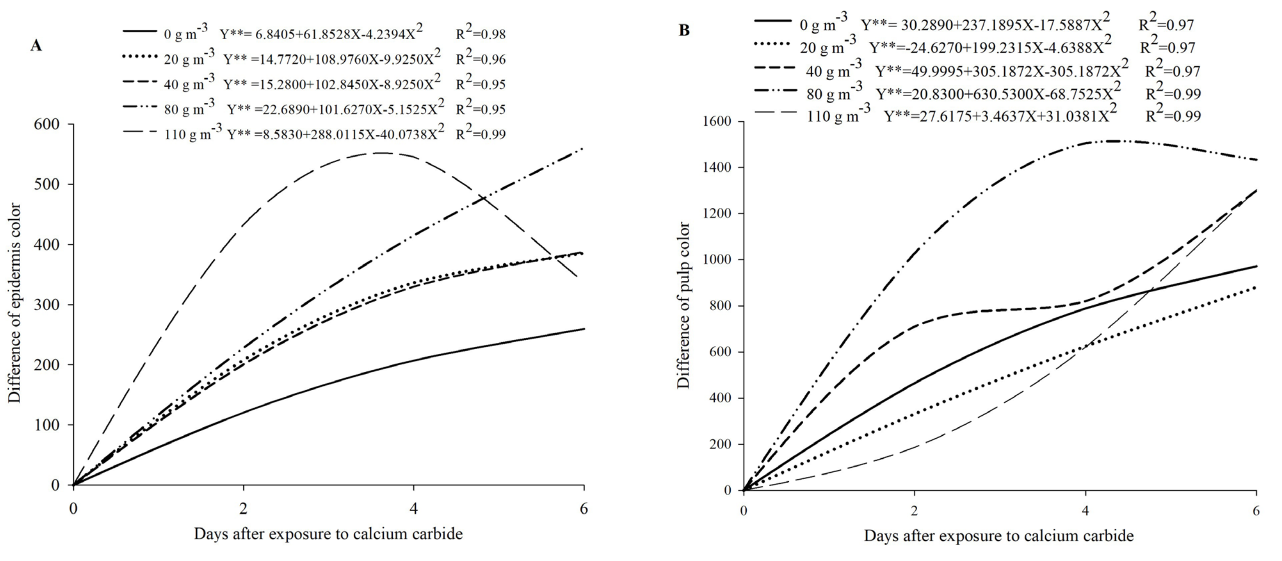

Figure 1. Difference of color from epidermis (A) and pulp (B) of cajá-manga fruits treated with different concentrations of calcium carbide.

or, which is the predominant color in mature cajá-manga fruits. However, from 4.06 days, there was a decline in color difference, indicating the beginning of the darkening process of the epidermis. The intermediate concentrations showed similar behavior up to 1.11 days, and from there, the concentration 80 g m^{-3} showed an accentuated growth until reaching the highest color difference at 4.84 days. In the absence of exposure to calcium carbide (0 g m^{-3}), the fruits showed a gradual and unequal reduction in the color difference of the epidermis (Figure 1A).

For the color difference of the pulp, the exposure to the concentration of 80 g m^{-3} promoted the highest increase, which reached its maximum value at 4.02 days and presented a decline from this point. The concentration of 40 g m^{-3} also has increased this characteristic, with its maximum value at 5.98 days. The concentration of 110 g m^{-3} showed the lowest color difference until 3.48 days, when there was an accentuated increase in color difference, which presented a result equal to that of the concentration 40 g m^{-3} at 5.98 days. Concentrations 0 and 20 g m^{-3} showed the lowest color difference from 4.85 and 4.15 days, respectively, and at 5.98 days, the concentration 20 g m^{-3} showed the lower color difference among all concentrations (Figure 1B).

The color difference tends to increase along with the storage period, indicating a change in the initial color of the fruits (ALVES et al., 2019). It was observed in the present study that calcium carbide anticipated the transition of the color of the epidermis from green to yellow and the color of the fruit's pulp. Color is a significant characteristic of fruits, being used as an indicator of quality since the main apparent change during ripening is the change in epidermis color (MONTESLORA et al., 2018).

Chlorophyll degradation and the synthesis of carotenoid pigments are some of the factors involved in color change during ripening. Carotenoids tend to be more frequent as the fruit ripens and takes the cajá-manga fruits to reduce the greenish color and predominate the yellow color (KAPOOR et al., 2022). It is emphasized that using calcium carbide at concentrations higher than 20 g m^{-3} is efficient at the beginning of the climacteric increase in respiration and promotes early and uniform ripening (SAMPAIO et al., 2007; SILVA et al., 2012b).

The hue angle of the epidermis decreased over the days, indicating a change of color. All concentrations presented an exponential behavior. The hue angle varied from 111 to 123° on day 0, indicating that the fruits were in the green color quadrant, and reached on the sixth day after exposure 80.94° for the concentration 0 g m^{-3}, 76.71° for the concentration of 20 g m^{-3}, 80.74° for the concentration 40 g m^{-3}, 90.72° for the concentration of 80 g m^{-3}, and 71.16° for the concentration of 110 g m^{-3}. The hue angle of 90°, which indicates complete yellow fruits, was reached at 3.31 days for 20 g m^{-3}, 3.40 days for 110 g m^{-3}, 3.70 days for 40 g m^{-3}, 4.87 days for 0 g m^{-3}, and 5.31 days for 80 g m^{-3} (Figure 2A).

Calcium carbide concentrations showed an exponential behavior for the hue angle of the pulp. There was a reduction in the hue angle over the days, indicating a variation in the color of the pulp. The hue angle ranged from 106 to 116° on day 0, indicating that the fruit pulp still had a greenish shade. On the sixth day after exposure to calcium carbide, the fruit pulp presented a hue of 83.27° to 0 g m^{-3}, 86.50° to 20 g m^{-3}, 92.67° to 40 g m^{-3}, 95.62° to 80 g m^{-3}, and 85.56° to 110 g m^{-3}, indicating that the color of the pulp was little affected by the concentrations of calcium carbide (Figure 2B).

According to Castricini et al. (2019), higher hue values indicate a higher intensity of the predominant color in fruits, with hue values closer to 90° representing completely yellow fruits. The hue angle is an efficient coordinate to evaluate the changes in color during ripening, in which increased respiration in climacteric fruits activates the chlorophyll enzyme that causes the fruits to change their visual appearance (BARBOSA et al., 2019). The increase in ethylene concentration also induces the synthesis of carotenoids (NOBRE

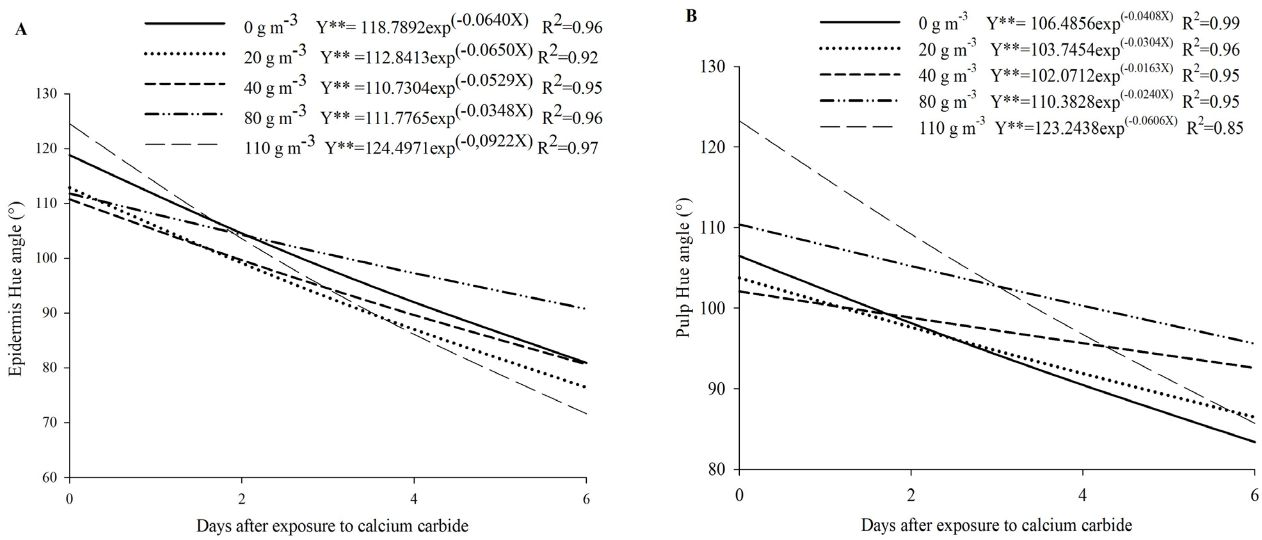

Figure 2. Hue angle of epidermis (A) and pulp (B) of cajá-manga fruits treated with different concentrations of calcium carbide.

et al., 2018), and these pigments are responsible for intensifying yellow coloration (CHAVES NETO et al., 2018).

The hue angle closer to 90° for the concentrations evaluated in the present study occurred by the accentuation of the yellowish color of the epidermis by the action of ethylene (OLIVEIRA et al., 2012), indicating that these fruits became ripe since the ethylene and ethylene analogs promote early and uniform ripening of fruits (SILVA et al., 2012b).

All concentrations showed a reduction in chroma (C*) of the epidermis over the days, indicating a change in color saturation. Calcium carbide concentrations showed exponential behavior. The concentration of 110 g m^{-3} had the highest C* values throughout the experimental period, which ranged from 34.72 on day 0 to 16.73 six days after application. The concentration of 80 g m^{-3} presented the lowest C* values, which started from 23.90 on day 0 to 5.32 on day 6. Concentrations 0, 20, and 40 g m^{-3} showed similar C* from 3.64 days on, being that at 5.98 days, the concentration of 20 g m^{-3} showed a decline in color intensity, while the concentration of 40 g m^{-3} showed a slight increase in the color intensity of the epidermis (Figure 3A).

Pulp C* showed exponential behavior, decreasing over the days after exposure. The absence of exposure to calcium carbide promoted little reduction in the intensity of fruit pulp color, starting from 23.66 to 12.66 on the sixth day. The chroma ranged from 32 to 34 on day 0, reducing on the sixth day after exposure to 7.79, 8.50, 2.96, and 13.50 for concentrations 20, 40, 80, and 110 g m^{-3}, respectively (Figure 3B).

The chroma determines the color intensity, and the higher this value, the more intense the color (SANCHES et al., 2018). The reduction of chroma during storage for both the epidermis and pulp indicates that there was a reduction in color intensity, possibly caused by the change from green to yellow, which is typical of the ripening process caused by calcium carbide (SILVA et al., 2012b; OLIVEIRA et al., 2016). Therefore, in the present study, the efficiency in anticipating and standardizing the color of the cajá-manga fruits with ethylene analogs was observed for the coordinates evaluated.

The fruits of cajá-manga showed an increase in the loss of fresh mass over the days, in which the higher the concentration of calcium carbide, the lower the mass loss. The fruits that did not have exposure to calcium carbide (0 g m^{-3}) presented the highest loss of fresh, with a loss of 8.35% on the sixth day of evaluation. Exposure to concentrations of 20, 40, 80, and 110 g m^{-3} led, on the sixth day, to a loss of fresh mass of 7.95%, 7.77%, 6.68%, and 6.63%, respectively (Figure 4).

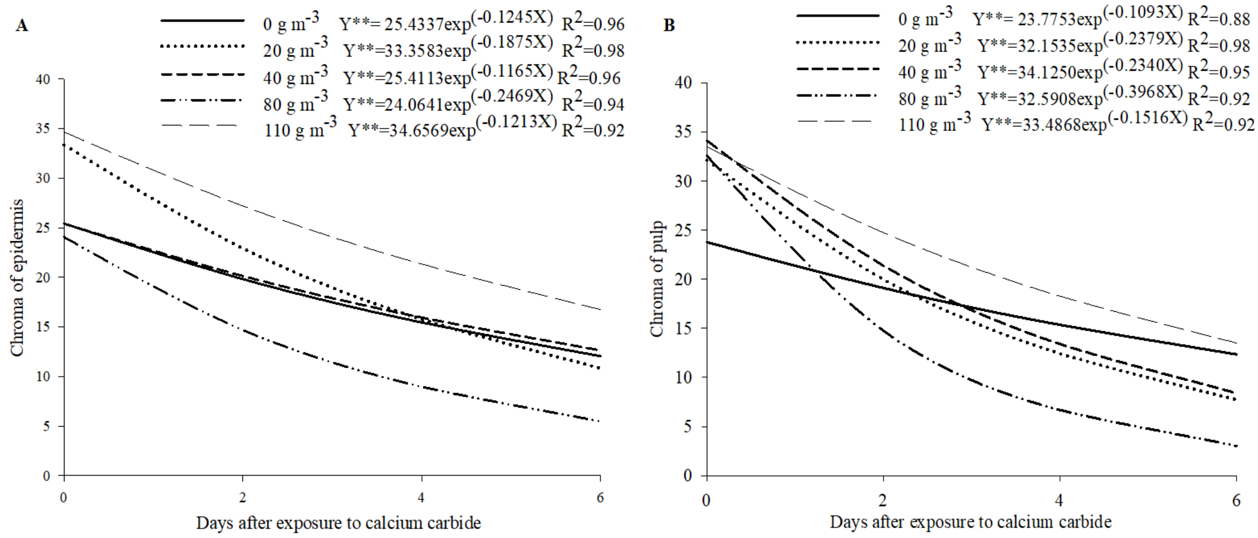

Figure 3. Chroma of epidermis (A) and pulp (B) of cajá-manga fruits treated with different concentrations of calcium carbide.

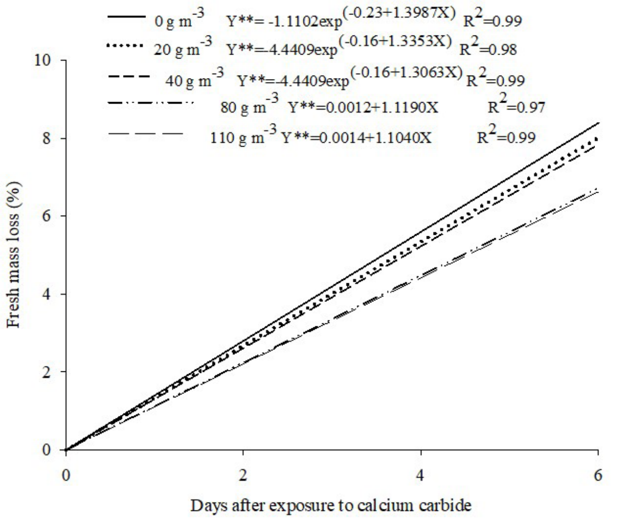

Figure 4. Fresh mass loss (%) of cajá-manga fruits treated with different concentrations of calcium carbide.

The reduction of fruit moisture during ripening is one of the major causes of the loss of fresh mass, in which more mature fruits have a higher release of ethylene generated by excessive respiration of fruit tissues, which causes mass loss (SILVA et al., 2018). The consumption of fruits' nutrients by their metabolism can also cause losses (NOBRE et al., 2018). However, in the present study, the fruits not exposed to calcium carbide recorded higher weight loss. PINTO et al. (2012), evaluating the loss of fresh mass in stored peaches, observed an inversely proportional relationship between ethylene production and mass loss, in which the fruits with the highest loss of fresh mass had lower ethylene production.

The vitamin C content of cajá-manga fruits showed an exponential behavior, increasing along evaluated days. The fruits exposed to concentrations 80 and 110 g m^{-3} presented, on the sixth day, the highest vitamin C contents, which is 67.76 and 65.88 mg of ascorbic acid 100 g^{-1}, respectively, while the fruits exposed to concentrations 20 and 40 g m^{-3} presented, on the sixth day, 57.17 mg of ascorbic acid 100 g^{-1} and the fruits not exposed to calcium carbide presented vitamin C content of 60.33 mg of ascorbic acid 100 g^{-1} on the sixth day (Figure 5).

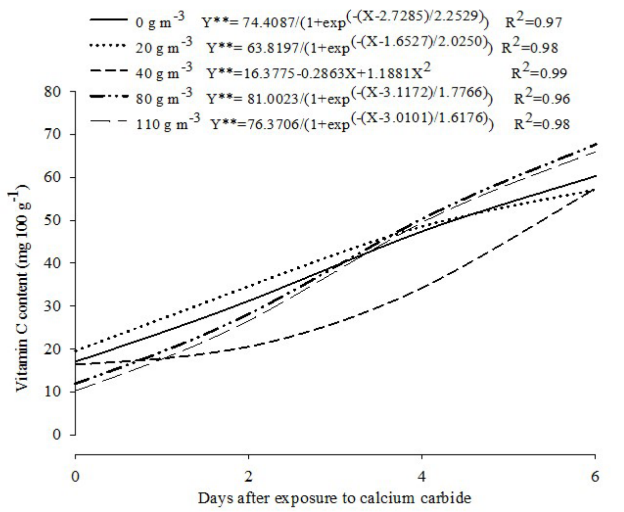

Figure 5. Vitamin C content (mg of ascorbic acid 100 g^{-1}) of cajá-manga fruits treated with different concentrations of calcium carbide.

According to Chaves Neto et al. (2018), fruits of this species are characterized by having a high content of vitamin C, with values between 30 and 60 mg of ascorbic acid 100 g^{-1}. Perfeito et al. (2015) observed that there is an increase in vitamin C content during ripening in fruits of mangaba (*Hancornia speciosa*) and report that this fact is common in some species of fruits and vegetables, and a probable explanation is the fact that ascorbic acid act as an antioxidant for reactions that occur during ripening, increasing the synthesis of intermediate metabolites and promoting the synthesis of glucose-6-phosphate, which is an immediate precursor of ascorbic acid.

The titratable acidity content presented a decreasing linear behavior. The fruits exposed at the concentration of 20 g m^{-3} had the most accentuated reduction in titratable acidity contents. The fruits not exposed to calcium carbide presented on the sixth day an acidity content of 0.83 g of citric acid 100 g^{-1}, while the concentrations of 20, 40, 80, and 110 g m^{-3} presented 0.63, 0.67, 0.71, and 0.75 g of citric acid 100 g^{-1} in titratable acidity on the sixth day after exposure, respectively (Figure 6).

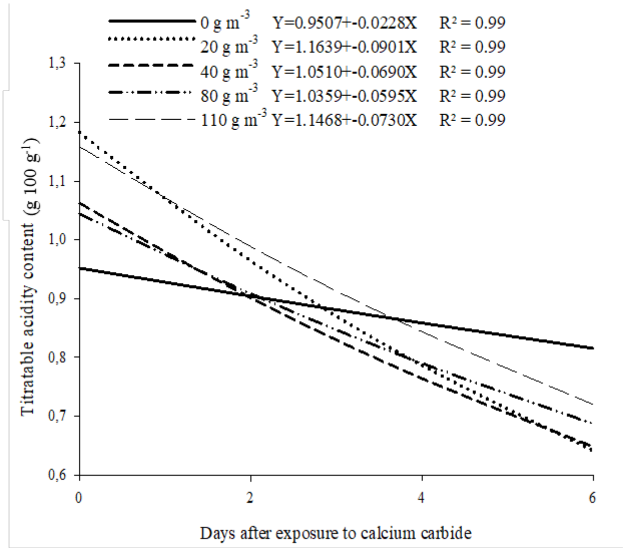

Figure 6. Titratable acidity content (g of citric acid 100 g^{-1}) of cajá-manga fruits treated with different concentrations of calcium carbide.

Acidity represents the sensory quality of fruits, and for fresh consumption, fruits with high acidity content do not have good acceptance by consumers (SOUZA et al., 2018). The acidity content is higher in the fruits at the beginning of ripening, but with the ripening advance, there is a reduction in acidity contents, a fact that occurs due to the use of organic acids in the synthesis of sugars (MACIEL et al., 2010). According to Nassur et al. (2016), acidity influences fruit maturation and senescence, as organic acids are intermediaries in metabolic processes such as respiration and photosynthesis.

The acidity content is a decisive characteristic for the identification of commercially more flavored fruits, and the industries prefer fruits with an acidity content greater than 1.0% to prevent pulp degradation by microorganisms and reduce the use of citric acid for pulp standardization (CHAVES NETO et al., 2018).

The pulp of cajá-manga fruits exposed to calcium carbide showed an increase in soluble solids content over the days after application. On the sixth day after exposure to calcium carbide, the fruit pulp presented 15.48, 15.72, 14.26, 13.69, and 14.13 °Brix for concentrations of 0, 20, 40, 80, and 110 g m^{-3}, respectively (Figure 7).

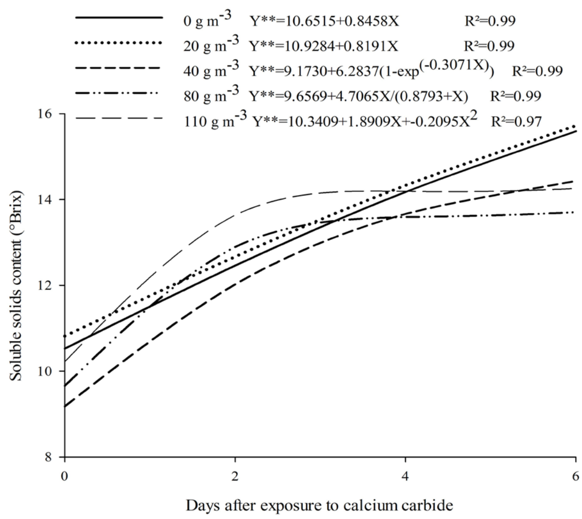

Figure 7. Soluble solids content (°Brix) of cajá-manga fruits treated with different concentrations of calcium carbide.

The soluble solids content indicates the portion of sugars present in the fruit pulp, which are responsible for the flavor of the pulp, and this content tends to increase during ripening due to sugar biosynthesis or through the degradation of polysaccharides (CHAVES NETO et al., 2018). Brito et al. (2009), evaluating cajá-manga fruits, reported a soluble solids content of 10.73 ºBrix, while for fruits harvested in the municipalities of Ubaíra, Amargosa, and Tancredo Neves, in the State of Bahia, Pinto et al. (2003) reported a soluble solids content ranging between 7.07 and 14.0 °Brix.

The ratio between soluble solids and titratable acidity showed a slight increase during the days evaluated, adjusting to the linear model for the concentration of 0 g m^{-3} calcium carbide and exponential growth for concentrations of 20, 40, 80, and 110 g m^{-3}. At the end of the experimental period, the concentrations presented similar ratio values, except for the concentration of 20 g m^{-3}, which presented the highest value (26.62), indicating that the fruits exposed to this concentration showed a balance between sugars and acids. The fruits not exposed to calcium carbide had the lowest ratio value (18.80) at the end of the experimental period (Figure 8).

The ratio between soluble solids and titratable acidity is related to genetic and environmental factors, and higher values relate to a more advanced ripening stage, implying that the fruits have better flavor (CHAVES NETO et al., 2019). Fruits with a good relationship between soluble solids and titratable acidity have better acceptance in the market (CHAVES NETO et al., 2018).

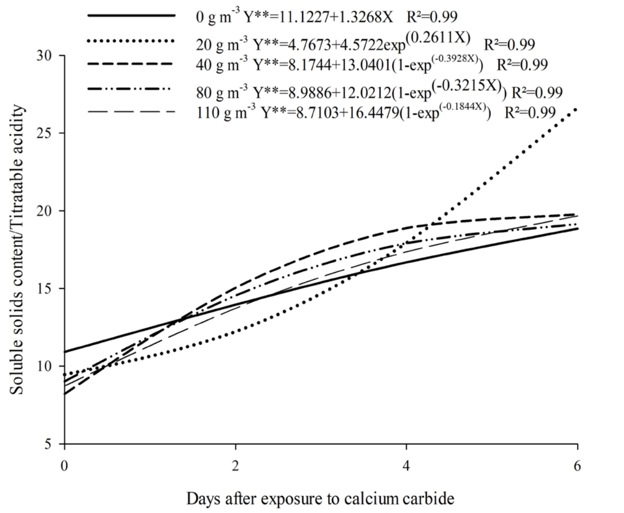

Figure 8. Soluble solids content/titratable acidity of cajá-manga fruits treated with different concentrations of calcium carbide.

Conclusions

Cajá-manga fruits treated with different concentrations of calcium carbide had their ripening anticipated without compromising their characteristics. The concentrations of 20, 40, and 80 g m^{-3} of calcium carbide allowed to anticipate and standardize the fruit ripening within four days during storage, while for the highest concentration (110 g m^{-3}), complete maturation was accelerated, occurring between two and four days of storage, therefore, when the fruits are marketed away from the harvest site, it is recommended to use lower concentrations, such as 20 and 40 g m^{-3}, which promotes color change but does not affect the characteristics of the pulp. Calcium carbide is a low-cost product with easy employment by smallholder farms that allows anticipating the harvest and keeps the quality characteristics of the fruits.

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