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Growth and development of gabiroba [*Campomanesia adamantium* (Cambess.) O. Berg] fruits

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The Brazilian Savanna is one of the largest and richest tropical savannas in the world, possessing substantial biodiversity. However, little information is available about fruit development in Brazilian Savanna bushy species. Thus, the objective of this study was to physically and physico-chemically characterize the growth and development of gabiroba fruits, *Campomanesia adamantium* (Cambess.) O. Berg. After harvest, the fruits were analysed for acidity, density, volume, longitudinal diameter, cross-sectional diameter, fresh mass, dry mass, soluble solids, respiratory rate, firmness and soluble solids/acidity ratio. The data were then submitted to descriptive analyses. The developmental period of the gabiroba fruit comprised nine weeks (63 days) from the time of fruit set. The mass-accumulation curve of the gabiroba fruit resembled a double-sigmoidal pattern. The respiration rate of the fruit was low, and the climacteric phase occurred between 21 and 28 days after fruit set. Based on the analyzed attributes, authors conclude that gabiroba fruit can be harvested beginning 35 days after fruit set and extending to 56 days after fruit set. The optimum time for consumption occurs 49 days after fruit set, when fruit size, mass, SS/TA ratio and soluble solids reach their peak values, and acidity and firmness are reduced.

Key words: Cerrado, harvest, growth curve, fruit trees.

INTRODUCTION

The Brazilian Savanna is the second-largest biome in South America and covers an area of 2,036,448 km^2, approximately 22% of the Brazilian territory. This region of Brazil is known as the richest savanna in the world, harboring 11,627 cataloged native plant species. This biome also possesses great social importance because many human communities depend on its natural resources (MMA, 2013). However, few studies have examined the development of native Brazilian Savanna species, especially the growth stages such as pre-maturation, maturation, ripening and senescence (Silva et al., 2009).

One such species is gabiroba [*Campomanesia adamantium* (Cambess.) O. Berg], which belongs to the family Myrtaceae and is one of 33 species in its genus (Sobral et al., 2013). Gabiroba develops a shrubby

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shape, with many yellow branches, and can reach a height of 2 m. Its leaves are opposite, simple, ovate and entire, with translucent pits and acute to obtuse bases. The fruits are globular and 2 to 2.5 cm in diameter (Porto and Gulias, 2010). Fruits are consumed in nature or processed as juicy and ice cream (Baviati et al., 2004) and are appreciated by population considering the high Vitamin C content (Oliveira et al., 2011) and the medicine proprieties (Fernandes et al., 2014). Studies at refrigerate conditions (Campos et al., 2012) and modified atmosphere (Scalon et al., 2012) shown important to preserve the postharvest quality under 15 days of storage.

The demand for tropical fruits is increasing in both domestic and export markets due to increased awareness of the nutritional and therapeutic value of these fruits and of their diverse aromas and flavors. Brazil has a large variety of native and exotic fruit species with agro-industrial potential, which may provide future sources of income for local populations (Alves et al., 2008).

Plant growth and development depend on genetic and environmental factors, such as light, temperature, moisture and soil type. These factors promote a series of physiological and biochemical changes that ultimately determine the physico-chemical composition of the fruit (Guedes et al., 2008). Although most of these changes are well known, some still remain to be clarified (Bron, 2006). According to Bron and Jacomino (2006), understanding the regulation of the ripening process makes it possible to manipulate fruit development to obtain higher quality fruits, reduce postharvest losses and increase consumer acceptance.

Thus, the objective of this study was to characterize the growth and development of gabiroba fruits through morphological and physico-chemical analyses.

MATERIALS AND METHODS

Study area

The experiment was conducted on the Rio Doce Coqueiros farm in the town of Rio Verde, Goiás, Brazil. The farm is located at latitude 17° 56' 46'' S and longitude 51° 11' 50'' W, at an elevation of 694 m. The experiment took place from October to December 2012. The climate at study region is second to the Köppen climate classification, the type Aw (rain tropical savanna), characterized by a dry period during the winter and a rainy period during the summer, the average rainfall ranges between 1200 and 1800 mm. The temperature during experiment period change from 23.9 to 26.0°C, as the thermal amplitude was less than 4°C. The experiment took place from October to December 2012, during the rainy period with 127.9 µmol m^{-2} s^{-1} photosynthetically active radiation.

Morphophysiological evaluation

In October 2012, *C. adamantium* plants were selected, and its fruits were collected weekly from fruit set until full maturity, comprises nine weeks. Fruit set has been defined by petal fall and rapidly growing condition of the young fruit following ovary fertilization. The botanical material was herborized and deposited under 206 number in the Rio Verde Herbarium (IFRV).

Upon harvest, the fruits were immediately placed in plastic bags and then in styrofoam boxes containing ice packs and transported to the Plant Ecophysiology and Productivity Laboratory at the Federal Institute of Goiás - Rio Verde Campus. In the laboratory, the fruits were selected for the absence of mechanical damage and pest or pathogen attack.

Selected gabiroba fruits were evaluated for their respiratory rate, morphological characteristics (longitudinal diameter, cross-sectional diameter, density, fresh mass and dry mass) and physico-chemical characteristics (fruit firmness, soluble solids and acidity), as detailed as follow.

Respiratory rate

Ten fruits were placed into 250 mL glass flasks for a total of five replicates. To allow the temperature to stabilize, the flasks were kept at 25°C in an air-conditioned room for two hours. The fresh mass of the fruits was measured prior to measuring the respiratory rate.

To measure the respiratory rate, each flask was coupled to an open flow system using an infrared gas analyzer (IRGA, Qubit Systems Inc., Kingston, Ontario, Canada) under an air flow of 400 mL min^{-1}. The instrument was calibrated with a reference air concentration of 395 ppm (Naressi Neto, 2013). After measurement, the delta CO_2 value between the reference air and the analyzed air was used to calculate the respiratory rate of the fruits (Vines et al., 1965).

$$RCO_2 = \frac{(\Delta CO_2 x Flow(mL.min^{-1})\, x\, CF)}{(1{,}000{,}000\, x FW(Kg))}$$

Where: RCO_2 = respiratory rate, expressed in mg CO_2 kg^{-1} h^{-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 FW = fresh mass of the fruits (kg) on the day of analysis.

$$* \, CF = \frac{grams\ of CO2}{22.415 \text{ x } \frac{(T+C)}{T}}$$

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

Growth and physico-chemical characterization

The fruit growth was evaluated and the physico-chemical characteristics were analyzed after measuring the respiratory rate. The longitudinal diameter, cross-sectional diameter and density were measured for ten fruits in each replicate. The fruits were then divided into two lots: Lot 1 was used to assess the maturity attributes of soluble solids (SS), titratable acidity (TA) and fruit firmness, while Lot 2 was used to measure the fresh mass (g) and dry mass (g) of the fruits, as described as follow.

Diameter

The longitudinal and cross-sectional diameters were measured using a caliper with a precision of 2 mm (Worker brand). The

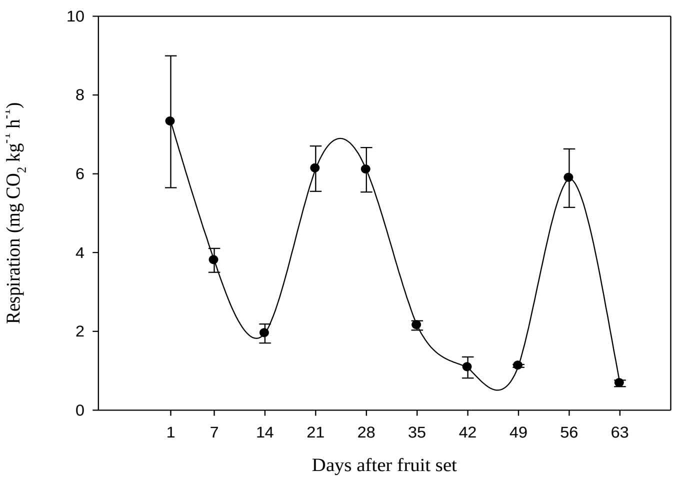

Figure 1. Respiration rate (mg CO_2 kg^{-1} h^{-1}) of gabiroba fruits from fruit set to full maturity.

longitudinal diameter corresponded to the portion of the fruit between the insertion of the pedicel and the insertion of the calyx. The cross-sectional diameter corresponded to the median portion of the fruit.

Density

The fruit density (g cm^{-3}) was obtained by first determining the volume of each fruit based on the displacement of a water column in a graduated cylinder. This value was used in the following equation: $D = \frac{mass}{volume}$

Soluble solids (SS)

The soluble solids (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.

Titratable acidity (TA)

The fruit acidity was determined by neutralization titrations with NaOH (0.1 N) until the pH reached 8.2 (Instituto Adolfo Lutz, 1985). A 1 g 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 deionized water and three drops of phenolphthalein before proceeding with NaOH titration.

The acidity was then calculated according to the following formula:

$$\frac{V * f * 100}{P * c} = acidity\ in\ molar\ solution, \%\ v/m$$

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).

Fruit firmness

Changes in the fruit firmness of 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 as the ratio of the weight of the bowl to the deformed area (Calbo and Nery, 1995).

$$A = 0.784 * d1 * d2$$

$$N = \frac{P}{A} * 9.8$$

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.

Fresh mass

The fruits were weighed individually on a semi-analytical balance (AW220, Shimadzu model). The fresh mass was expressed in grams.

Dry mass

After measuring the fresh mass, the fruits were placed in a convection oven (Marconi brand, model MA035/5/10P) at 65°C for 72 h, until they reached a constant mass. The dry mass was expressed in grams.

Statistical design

The experiment utilized a randomized-block design. For the respiratory rate, longitudinal and cross-sectional diameters and density, five replicates of ten fruits each were used. For the soluble solids, fruit firmness, titratable acidity and fresh and dry mass, five replicates of five fruits per replicate were used. The data were analyzed using descriptive statistics, including the mean and standard error of the mean.

RESULTS

The developmental period of the gabiroba fruit comprised nine weeks, or 63 days after fruit set (DAF). The highest respiratory rates were observed at the first evaluation point, with a mean value of 7.32 mg CO_2 kg^{-1} h^{-1}. Over the course of fruit development, two respiratory peaks were observed: one between 21 and 28 DAF and another at 56 DAF (Figure 1).

The longitudinal and cross-sectional diameters of the gabiroba fruits showed similar behavior over the course of fruit development. During the first 14 days, the diameter increased from 4 to 6 mm. The diameter then increased rapidly, especially between 15 and 21 DAF. The maximum value of 14 mm was reached at 49 DAF. After that point, the fruit diameters decreased (Figure 2).

The fresh mass ranged from 0.77 to 9 g, increasing rapidly between 14 and 21 DAF. Between 22 and 28 DAF, the fresh mass increased slightly. After that point,

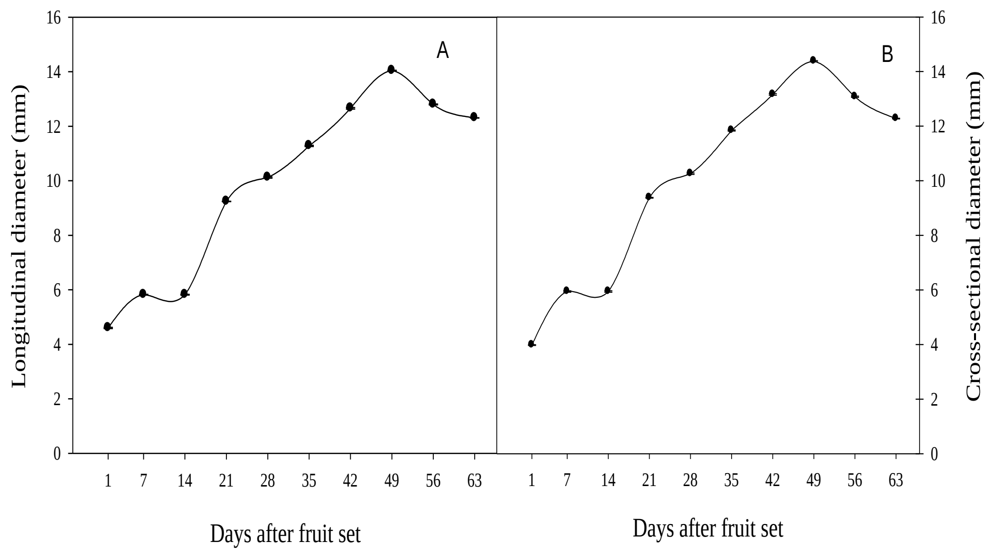

Figure 2. Longitudinal (A) and cross-sectional diameter (B) of gabiroba fruits from fruit set to full maturity.

the fresh mass increased markedly, reaching its peak at 49 DAF and decreasing thereafter (Figure 3A). The dry mass ranged from 0.17 to 1.81 g. This variable showed behavior similar to that of fresh mass, except that the peak value was reached between 49 and 56 DAF (Figure 3B).

The developmental curves of the longitudinal and cross-sectional diameters and the fresh and dry mass resembled double sigmoidal growth curves, characterized by three stages of development: an initial phase of rapid growth followed by a phase of slow growth and a final period of marked development.

At the first three evaluation points, which encompassed the first 14 days of fruit development, the fruit density was 0.80, 0.88 and 1.02 g cm^{-3}. At 21, 28 and 35 DAF these values decreased to 0.75, 0.83 and 0.90 g cm^{-3}. Subsequently, the density again increased to 1.0, 1.02, 1.02 and 1.11 g cm^{-3} at 42, 49, 56 and 63 DAF, respectively (Figure 3C).

The fruit firmness oscillated during the first 28 DAF. The greatest firmness was observed at 14 DAF (28.84 N); subsequently, the firmness decreased at 21 DAF (20.56 N), then increased (27.96 N) and finally decreased abruptly after 28 DAF (Figure 4A). The acidity values decreased until 56 DAF (from 10.3 to 2.4%). After that point, the acidity increased slightly (to 4%) (Figure 4B). The soluble solids increased progressively over time. The initial value was 1.9 °Brix, and the final value was18.9 °Brix (Figure 4C).

The SS/TA ratio increased with fruit development. This ratio showed little variation until 35 DAF. Subsequently, the SS/TA ratio increased significantly, reaching a maximum value of 6.58 at 56 DAF and then declining (Figure 4D).

DISCUSSION

The period of fruit development can vary among species, varieties and cultivars. For *C. adamantium*, the focus of this work, and *C*. *pubescens* (Silva, 2009), the developmental period is similar: approximately 60 days. In *C. lineatifolia*, the developmental period is longer than 100 days (Balaguera-Lopez et al., 2012). During fruit growth and development, numerous metabolic changes occur, including changes in respiratory activity.

The high respiratory rates observed at the beginning of fruit development mainly reflect cell division during the active growth of the fruit (Gillaspy et al., 1993). The first respiratory peak of the gabiroba fruits most likely corresponds to the climacteric phase, which is marked by a sudden increase in autocatalytic ethylene production and respiration (Chitarra and Chitarra, 2005). This event triggers numerous changes during the development of gabiroba fruits, including seed formation, changes in density, decreasing acidity and firmness and increasing soluble solids and SS/TA ratio. The second respiratory peak at 56 days after fruit set most likely corresponds to the beginning of senescence, which leads to declines in fruit size, soluble solids and weight and an increase in acidity. An increased respiratory rate at the end of the developmental period has also been observed in jabuticaba fruit (Corrêia et al., 2007).

All of these changes during the growth and development of gabiroba fruits directly influence mass accumulation and consequently growth, as reflected by the changing longitudinal and cross-sectional diameters of the fruits. The fruits of most species exhibit characteristic growth curves, such as simple-sigmoidal or double-sigmoidal curves (Srivastava, 2002). According to

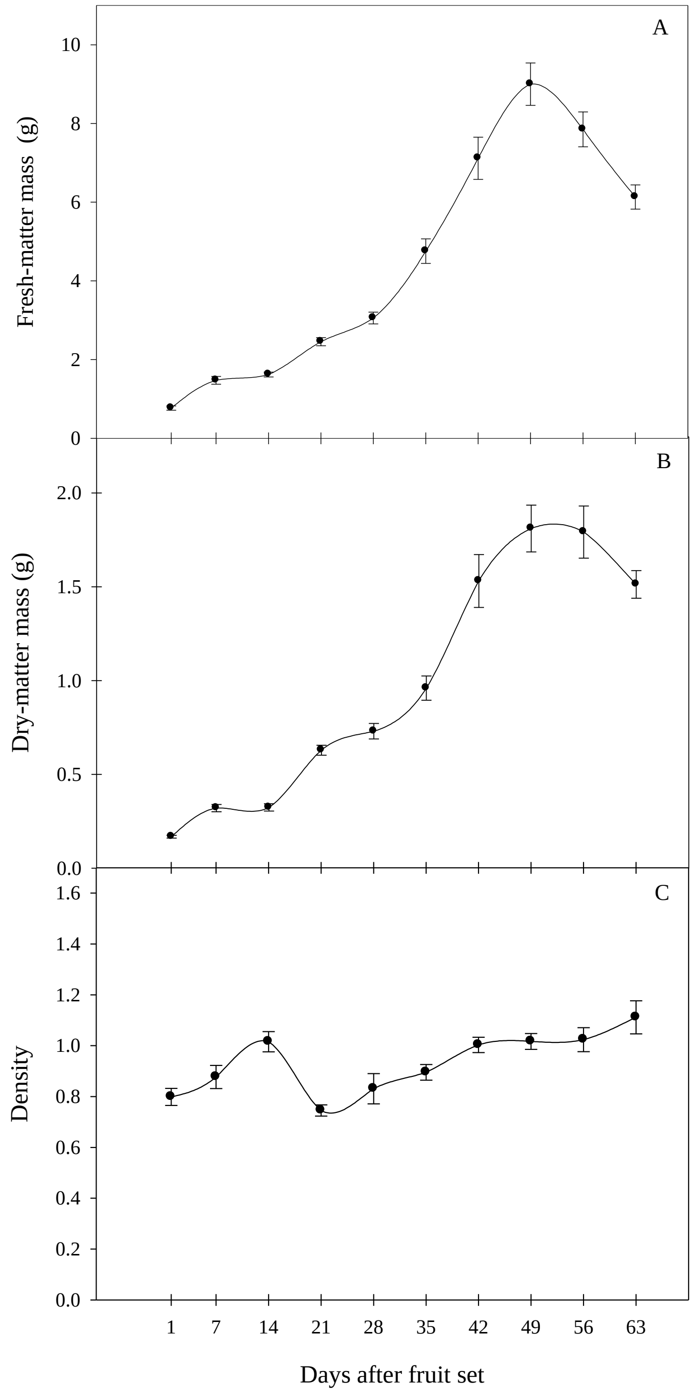

Figure 3. Fresh mass (A), dry mass (B) and density (C) of gabiroba fruits from fruit set to full maturity.

our results, the growth curve of gabiroba fruits fits a standard double-sigmoidal pattern. Double-sigmoidal curves have been observed in peach (Silva et al., 2013), guava (Serrano et al., 2008) and plum (Famiani et al., 2012) fruits, while simple-sigmoidal curves are characteristic of apple (Santos et al., 2011) and passion fruit (Alves et al., 2012).

The simple-sigmoidal curve is similar to a parabola and is divided into two phases: 1) slow growth and 2) rapid growth. The double-sigmoidal curve has three phases: 1) rapid growth due to cell division; 2) physiological and anatomical changes in the fruit, such as a decrease in the growth rate of the pulp, hardening of the pit and the final formation of the seeds, and 3) an accelerated increase in

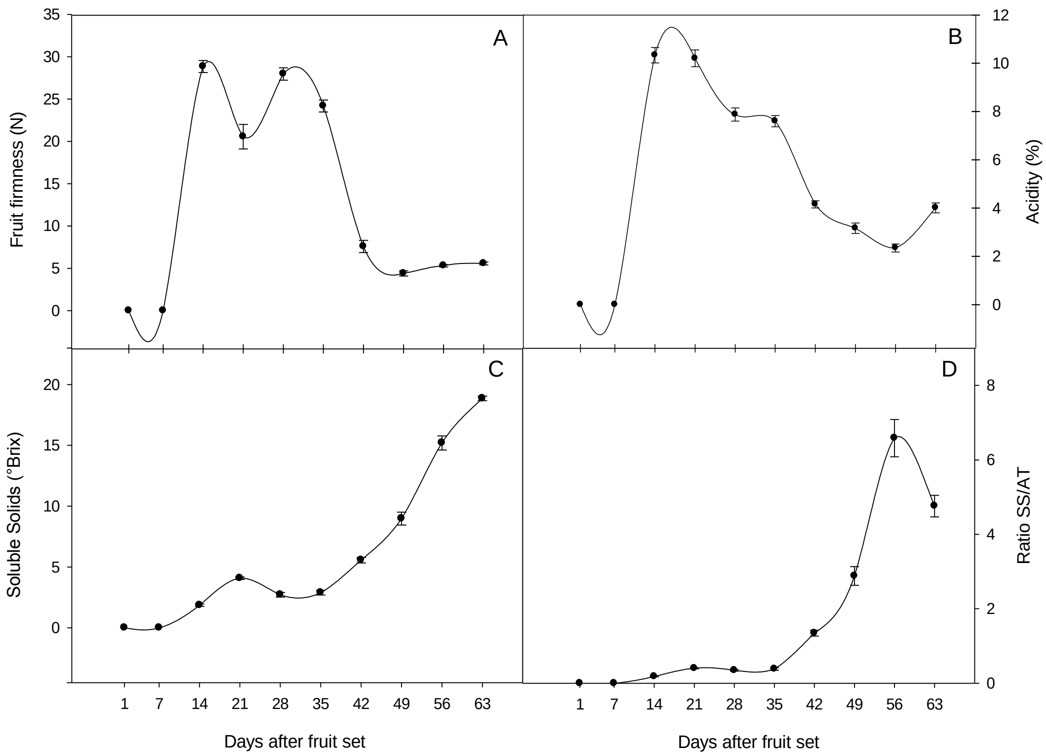

Figure 4. Fruit firmness (A), acidity (B), soluble solids (C) and soluble solids/acidity ratio (D) of gabiroba fruits.

cellular volumes and intercellular spaces, ultimately culminating in the ripening of the fruit (Barbosa et al., 1990; Chitarra and Chitarra, 2005).

The gabiroba fruits showed an initial phase of rapid growth, which was followed by a phase of slow growth and then a final period of rapid growth, as indicated by the accumulation of fresh and dry mass. The double-sigmoidal growth curve observed in the present study is similar to that observed during the flowering and ripening of *C. xanthocarpa* (Danner et al., 2010).

These events corroborate the observed results for *C. adamantium*. During Phase I, the increases in length, diameter, fresh and dry mass and density demonstrate rapid growth. The fruits exhibit stable firmness values, a maximum acidity level and low soluble solids and SS/TA ratio. At the end of this phase, between 14 and 21 DAF, the density and firmness values decrease.

This decrease in density can be explained by cellular elongation and increased intercellular spaces, which together increase the volume of the pulp. Firmness, as determined by the applanation method, reflects cell turgidity with respect to cell volume. As the cells become less turgid, the tissue sensitivity increases, resulting in a larger area of applanation and thus lower firmness values.

At the beginning of Phase II, the fruit mass increases slowly, and the fruits continue to exhibit high firmness and low SS and SS/TA. At the same time, acidity begins to decline. The fruit density increases during Phase II between 21 and 28 DAF, when the seeds undergo maturation (that is, hardening).

Longitudinal, cross-sectional diameters, and fresh and dry mass occur when Phase II transitions into Phase III, marked increases in mass after 28 DAF. In addition, significant declines in firmness and acidity increase in SS and SS/TA take place. These changes are related to climacteric respiration and thus to the fruit-ripening process. The observed changes in acidity are consistent with those found for uvilla/parilla (Arena and Coronel, 2011), pomegranate (Fawole and Opara, 2013a; Fawole and Opara, 2013b) and strawberry (Ornelas-Paz et al., 2013).

The decreases in fresh and dry mass and fruit size after 49 DAF and in SS/TA after 56 DAF are also related to source-sink relationships. As they spend more time attached to the mother plant, the fruits may begin to translocate their photoassimilated materials back into the plant, thus acting as source organs. Thus, the distribution of assimilated materials into the plant results from metabolic changes in the source-sink relationship.

Source organs produce photoassimilated materials that can be used as energy for respiratory processes or stored in reserve organs, known as sink organs. The main organs that export photoassimilated materials (sources) are adult leaves, while the main importers (sinks) are young leaves, roots, meristems and fruits (Duarte and Peil, 2010). However, if the fruit remains on the plant after its development and ripening are complete, it will most likely begin to act as a source organ, allocating its store of photoassimilated materials into new sink organs. The gabiroba fruit studied here show evidence of this process.

Understanding fruit growth curves is critical to preserving fruit quality after harvest. Density, fruit firmness, soluble solids content, titratable acidity and the SS/TA ratio are excellent indicators of fruit quality and are widely used in the harvesting and post-harvest treatment of horticultural produce.

No previous study in the literature has reported the optimum harvesting time for *C*. *adamantium*. Based on our data, the fruits of this species can be harvested beginning at 35 DAF, with their average density in 0.90 g cm^{-3}. For guava (*Psidium guajava*), the density at the time of harvest is 0.98 g cm^{-3} (Gouveia et al., 2003).

A decrease in acidity is commonly associated with an increase in soluble solids. The relationship between the sugar content and acidity of a fruit is expressed by the SS/TA ratio, which is used as a reference point for the flavor of many fruits. This variable further reinforces the ideal period for harvesting gabiroba fruit. The low SS/TA ratios during the first 35 DAF indicate that the fruit is not yet suitable for consumption due to its high acidity. Only after these values increase does the fruit become suitable for consumption; a higher SS/TA ratio contributes to the pleasant flavor of the fruit and indicates fruit ripening.

Considering all the measured attributes, we conclude that gabiroba fruits can be harvested upon reaching the following criteria: a longitudinal diameter of 11 to 14 mm, a cross-sectional diameter of 12 to 14 mm, a density of 0.90 to 1.02 g cm^{-3}, a fresh mass of 4.76 to 9.0 g or a dry mass of 0.96 to 1.81 g. Furthermore, the fruit should exhibit a firmness value of 7.58 to 4.40 N, an acidity level of 4.2 to 2.4%, a soluble solids content of 5.6 to 15.2 °Brix and an SS/TA ratio of 1.34 to 6.58.

Based on these criteria, the ideal harvesting period begins at 35 DAF and extends to 56 DAF. At 49 DAF, gabiroba fruit reaches its optimum quality for consumption, with the highest values of size, mass, SS/TA ratio and soluble solids and markedly reduced values of acidity and firmness.

Conclusions

The fruiting period of gabiroba, *C. adamantium* (Cambess.) O. Berg, comprises 63 days, begins in October and ends in December under the environmental conditions of the Rio Verde town, Goiás. The accumulation curves for the fruit fresh mass, dry mass, longitudinal and cross-sectional diameter resemble double-sigmoidal growth curves. Gabiroba fruits can be harvested between 35 and 56 days after fruit set.

Conflict of Interest

The authors have not declared any conflict of interest.

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