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Gabiroba (*Campomanesia pubescens*): Physicochemical and physiological characteristics of fruit during the development

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ABSTRACT: Among the fruit species found in the Cerrado biome of Brazil, Campomanesia pubescens stands out. It produces fruits with a sweet and sour taste, known as gabiroba, which are consumed fresh or processed. This study aimed to evaluate *Campomanesia pubescens* fruits from Campos das Vertentes – MG, Brazil, regarding their phenological and physicochemical characteristics throughout development. The experiment was conducted in a completely randomized design consisting of seven evaluation periods (9, 18, 27, 36, 45, 54, and 63 days post-anthesis), with 3 repetitions. The fruits harvested at each developmental stage were subjected to analyses of color, mass, longitudinal and transversal diameter, relative growth rate, respiration rate, firmness, soluble and total pectin, pH, titratable acidity, soluble solids, and total sugars. The results obtained were subjected to analysis of variance, followed by polynomial regression at the 5% significance level, and grouped according to their similarities based on the Kohonen self-organizing map. *Campomanesia pubescens* fruits showed cumulative increases in longitudinal and transversal diameters and mass during the 63 days of development, displaying a simple sigmoidal growth pattern. The growth initiated after anthesis overlapped the maturation stage, extending until full ripening at 63 days of development. The fruits exhibited typical climacteric fruit respiration behavior. The Kohonen self-organizing map allowed for the more effective and intuitive identification of similarities and correlation trends.

Key words: Cerrado biome; maturation stages; neural network

Gabiroba (*Campomanesia pubescens*): Caracaterísticas físico-químicas e fisiológicas do fruto durante o desenvolvimento

RESUMO: Dentre as espécies frutíferas encontradas no bioma Cerrado do Brasil, destaca-se Campomanesia pubescens, que produz frutos com sabor agridoce, conhecidos como gabiroba, consumidos in natura ou processados. O presente trabalho teve por finalidade avaliar frutos de *Campomanesia pubenscens* provenientes do Campos das Vertentes –MG, Brasil, quanto às características filológicas e físico-químicas ao longo do desenvolvimento. O experimento foi conduzido em delineamento inteiramente casualizado simples constituído por sete períodos de avaliação (9, 18, 27, 36, 45, 54 e 63 dias pós-antese), com 3 repetições. Os frutos colhidos em cada estádio de desenvolvimento foram submetidos às análises de cor, massa, diâmetro longitudinal e transversal, taxa de crescimento relativo, taxa respiratória, firmeza, pectina solúvel e total, pH, acidez titulável, sólidos solúveis e açúcares totais. Os resultados obtidos foram submetidos à análise de variância, seguida de regressão polinomial, ao nível de 5% de significância, bem como separados em grupos, de acordo com suas semelhanças, como base no mapa auto organizável de Kohonen. Os frutos de *Campomanesia pubenscens* apresentaram aumento cumulativo nos diâmetros longitudinal, transversal e massa, durante os 63 dias de desenvolvimento, notando-se um comportamento sigmoidal simples de crescimento. O crescimento iniciado após a antese se sobrepôs ao estádio de maturação se estendendo até o pleno amadurecimento, aos 63 dias de desenvolvimento. Os frutos apresentaram comportamento respiratório típico de frutos climatéricos. O mapa auto-organizável de Kohonen permitiu a identificação de semelhanças e tendência de correlação de forma mais eficaz e intuitiva.

Palavras-chave: bioma Cerrado; estádios de maturação; rede neural

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Introduction

The Brazilian savanna, known as Cerrado, is one of the six biomes found in Brazil, covering approximately 25% of the country's territory. It mainly extends across the central plateau and spans over 11 Brazilian states (Sano et al., 2010; IBGE, 2019). In terms of area, it is second largest Brazilian biome, only smaller than Amazon (Klink & Machado, 2005).

Among the fruit-bearing species found in this biome, *Campomanesia pubescens*, known as gabirobeira, stands out. It is a shrub ranging from 60-80 centimeters in height. It typically bears fruit between September and October (Cardoso et al., 2010; Silva et al., 2009). Its fruits have a sweet flavor and can be consumed fresh or processed into various products such as flour, pulp, juices, liqueurs, candies, soft drinks, puddings and shakes or even infused in spirits (Dousseau et al., 2011; Cardoso et al., 2010; Silva et al., 2009).

Fruit development encompasses several stages including formation, growth, and maturation, driven by genetically programmed physiological and biochemical processes that ultimately lead to senescence and cell death. Respiration is considered the primary process by which potential energy is converted into kinetic energy during plant and fruit development. Sucrose and starch, the main reserve carbohydrates, undergo complete oxidation in the presence of oxygen, producing carbon dioxide and water while generating ATP and NADPH (Eskin & Hoehn, 2015). Despite this, there are few studies detailing the development stages of fruits.

It is known that fruit quality is built throughout its development, through physical and chemical changes arising from metabolism. If adequate pre- and post-harvest techniques are not adopted, this quality may be compromised, which may lead to losses. Furthermore, sensory, nutritional, and functional attributes are directly related to fruit quality. Since fruits, even after harvest, are living and metabolically active entities, changes in these attributes are observed during development, which interferes with their quality. Among the main sensory changes, those associated with appearance, flavor, and texture stand out.

Fruits of *Campomanesia pubescens* present, throughout development, changes in their metabolism that culminate in the yellowing of the skin and in the increase in soluble solids, pH, soluble pectin and reduction in titratable acidity and firmness of the pulp of the ripe fruit (Silva et al., 2009). However, fruits of the same species may have a different chemical composition, and there are several reports in the literature that prove the aforementioned fact (Silva et al., 2009; Morzelle et al., 2015; Bianchini et al., 2016; Emer et al., 2018; Souza et al., 2018; Schmidt et al., 2019; Souza et al., 2019; Abreu et al., 2020; Verruck et al., 2020).

In fact, a similar study was carried out by Silva et al. (2009). However, the fruits analyzed by these authors come from another region. We are currently experiencing major climate change, which significantly affects native species and the development of their fruits, as they are exposed to the most diverse environmental conditions. Therefore, the purpose of this work was to evaluate *Campomanesia pubenscens* fruits from Campos das Vertentes – MG, Brazil, regarding their philological and physical-chemical characteristics throughout development.

Materials and Methods

Experimental design

The experiment followed a simple completely randomized design (CRD), comprising seven evaluation periods for gabiroba (9 to 63 days after anthesis, with a 9-day harvest interval), with three replications. Fruit assessment continued until the 63rd day, when the fruit attained the typical ripe yellow peel color.

Plant material

Fruits of *Campomanesia pubescens* were harvested from a native pasture area exhibiting typical Cerrado formation and predominance of this species, located at Fazenda Bela Vista, approximately 7 km from the municipality of Santana do Garambéu, in Campos das Vertentes, Minas Gerais, Brazil (Latitude: 21° 34' 30'' South, Longitude: 44° 4' 49'' West, altitude: 1,044.52 m). About 150 *Campomanesia pubescens* specimens were marked with numbered plates and monitored from the onset of flowering, which began in August and peaked in September. Flowering events were identified using differently colored woolen threads to standardize harvest dates. Harvesting occurred in September, October, and November 2021, encompassing seven distinct stages of development, ranging from nine to 63 days after anthesis, with a 9-day harvest interval.

Approximately 2 kg of fruits were harvested at each developmental stage, divided into three replications of approximately 670 g each. They were then transferred, in polystyrene boxes containing ice, to the Fruit and Vegetable Postharvest Laboratory of the Federal University of Lavras for further preparation and analysis. Fruits showing signs of pathogens, pests, or defects were discarded. A portion of the fresh fruits was analyzed on the day of collection for firmness, color, and respiratory activity. The remaining fruits were pulverized in liquid nitrogen and stored in an ultrafreezer (Coldlab- CL374-86V) at -80 °C until further analyses could be conducted.

Analyzes performed

Coloration

Thirty fruits per replication were analyzed for skin color, at their equatorial region, using the Konica Minolta CR-400 colorimeter, in the International Commission on Illumination (CIE) color space, employing the L*, a*, and b* color scale system, chroma (C*), and hue angle (h°). Additionally, a color palette was developed using the Lab Tools Color Analysis

program, version 7.0.0, based on photographs of the fruits throughout their development.

Mass

The mass of 10 fruits per repetition was evaluated using a Mettler semi-analytical balance, model PC 2000, and the results were expressed in grams (g).

Diameters

The transverse and longitudinal diameters of 12 fruits per repetition were determined using a digital caliper (Mitutoyo) and expressed in millimeters (mm).

Relative growth rate

The Relative Growth Rate (RCR) was calculated based on the variables mass and transverse and longitudinal diameters (Equation 1).

$$TCR = \frac{(V_1 - V_0)}{(T_1 - T_0)} \quad (1)$$

where: V_1 - final value of each variable; V_0 - initial value of each variable; T_1 - final post-anthesis time; and, T_0 - initial post-anthesis time.

Respiratory rate

Four replicates, each consisting of approximately three grams of fruit, were placed in separate 50 mL glass containers. The containers were tightly sealed with a plastic lid equipped with a silicone septum, through which internal sample aliquots were extracted using the PBI Dansensor gas analyzer after resting for 1 hour and 30 minutes. The results, expressed as % CO_2, were converted into mL CO_2 kg^{-1} h^{-1}, considering the container volume, fruit mass and the time that the container remained closed.

Firmness

Firmness was determined on 35 fruits per replication at the equatorial region using a Stable Micro Systems model TA texture analyzer, XT2i. The TA39 cylindrical probe (2 mm in diameter) was used, with pre-test speed of 1 mm s^{-1}, test speed of 2.0 mm s^{-1}, post-test speed of 10.00 mm s^{-1}, and a force of 5 g. Results were expressed in Newtons (N).

Soluble and total pectin

Total and soluble pectin were extracted through precipitation in a hydroethanolic solution (95%) following the McCreaddy & McComb method (1952). Quantification was performed using a colorimetric method at 530 nm, with carbazole as the chromogenic agent, as described by Bitter & Muir (1962). The results were expressed in milligrams of galacturonic acid per 100 grams of sample.

pH, titratable acidity (TA), and soluble solids (SS)

Samples were crushed in water at a ratio of 1:3 (m/v) and filtered through organza. The filtrate was used to determine pH, titratable acidity (TA), and soluble solids (SS). The pH was measured using a TECNAL® pH meter, which was calibrated previously with buffer solutions (pH 4.0 and 7.0). Titratable acidity (TA) was determined by titration with 0.1 N sodium hydroxide (NaOH) solution, using phenolphthalein as an indicator, following the method outlined in AOAC (2019). The results were expressed in milligrams of citric acid per 100 grams of sample. Soluble solids (SS) were determined using an ATAGO PR-100 digital refractometer (Tokyo, Japan) with automatic temperature adjustment. The results were expressed as a percentage (%), following the procedure described in AOAC (2019).

Total sugars

Total sugars were extracted in 95% ethanol and determined spectrophotometrically at 620 nm. After evaporation of the alcohol, anthrone was used as the chromogenic agent, following the method described by Dische (1962). The results were expressed as grams of glucose per 100 grams of tissue.

Statistical analysis

Statistical analyses of the variables were conducted using the SISVAR program (Ferreira, 2010). In case of significance of the F test ($p < 0.05$), the means of the evaluation periods (day intervals) were subjected to polynomial regression. The models were selected based on the significance of the F test ($p < 0.05$) of each model and the coefficient of determination.

The data obtained from the analysis of firmness, pH, soluble solids (SS), titratable acidity (TA), longitudinal and transverse diameters, mass, growth rates, respiration rate, soluble pectin, and total sugars were utilized to generate a Kohonen self-organizing map (SOM). This map classified the fruits into clusters based on the similarity of their properties. The SOM Toolbox 2.1 package (Vatanen et al., 2015) was employed within the Matlab R2015a program, with necessary modifications made to enhance the acquisition and validation of clusters. The Davies-Bouldin and Silhouette indices were utilized for cluster validation.

Results and Discussion

The flowering of *Campomanesia pubescens* in the municipality of Santana do Garambéu, Southeast of Minas Gerais, Brazil, began in August 2021, with the peak flowering occurring in September. It was observed that the peak flowering of most *Campomanesia pubescens* specimens occurred on the same day. At 63 days after anthesis, the fruits were predominantly ripe.

Based on the color changes and dimensions illustrated in Figure 1, it is suggested that the fruits collected at 9, 18, and 27 days were immature, while those collected at 36 days were likely mature.

Indeed, significant changes in the peel color of gabiroba were confirmed throughout its development (Figure 2; p <

Figure 1. Evolution of gabiroba fruit during the development.

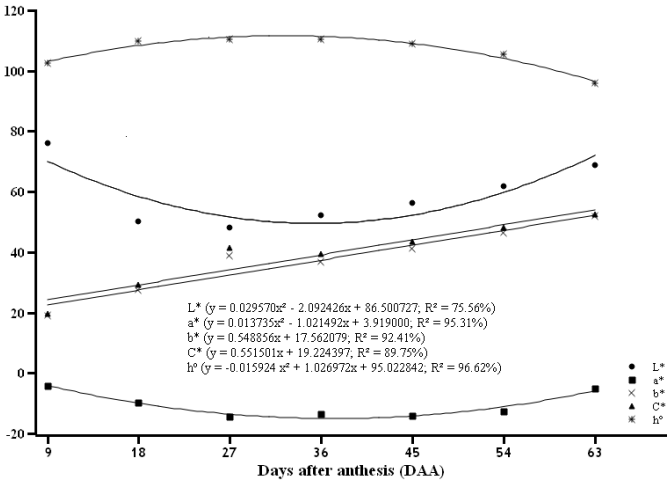

Figure 2. Changes in coloration of gabiroba fruit during the development.

0.05). A quadratic behavior was observed for the variables L*, a*, and h°, while variables b* and C* exhibited a linear increase. The values of L* and a* decreased during the first 36 days of development, subsequently increasing, while the behavior of h° was inverse. The results indicate a yellowish hue on the surface of newly formed fruits, transitioning to green up to 36 days of development, and then returning to a yellowish hue. The development was also marked by an increase in the intensity of fruit surface coloration, as well as darkening and subsequent lightening of the peel. These color changes in gabiroba align with the alterations illustrated in Figure 1.

The variations observed in the L* and a* variables are similar to those reported by Silva et al. (2009), who also studied fruits of *Campomanesia pubescens* throughout development, and by Abreu et al. (2020), who investigated fruits of *Campomanesia rufa* at two developmental stages. The increase in the means of b* and C* is also similar to that observed by Abreu et al. (2020), although the results of h° are different when compared to those reported by these authors. The behavior of b* was also distinct to that reported by Silva et al. (2009). Discrepancies in results may be explained by the effect of genotypes, as well as by the edaphoclimatic conditions to which the plants were subjected.

The cumulative growth and growth rate of gabiroba are illustrated in Figure 3. According to this figure, the average mass value per ripe fruit was 1.55 g, approximately three times lower than that reported by Silva et al. (2009), who studied fruits of the same species from another region. Nevertheless, the values of longitudinal and transverse diameters found were similar to those reported by these

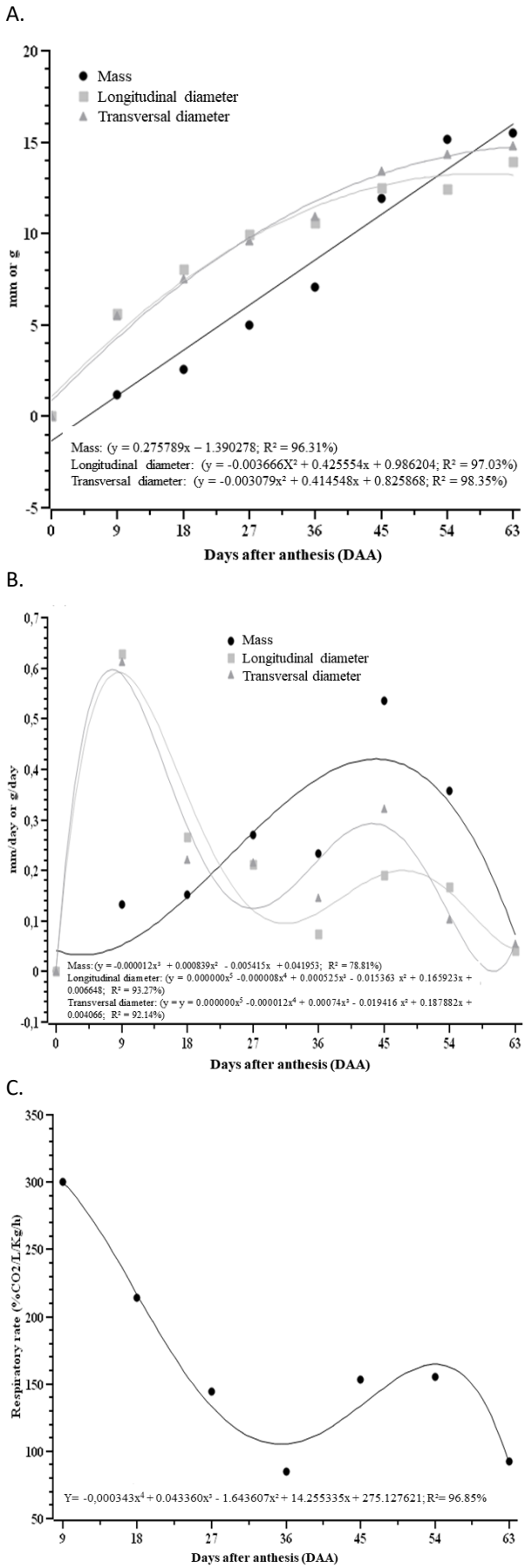

Figure 3. Changes in (A) cumulative growth, (B) growth rate, and (C) respiratory rate in gabiroba fruit during the development.

authors. The difference noted in mass could be attributed to different edaphoclimatic conditions to which the plants were subjected, as well as genetic factors, despite the fact that the fruits were obtained from plants of the same species. Since the fruits were obtained from native plants subject to natural cross-pollination and sexually propagated, genetic variation is expected, even within the same species. A wide range of mass and diameter values for fruits of different species of the *Campomanesia genus* is reported in the literature (Silva et al., 2009; Alves et al., 2013; Santos et al., 2015; Bianchini et al., 2016; Lima et al., 2016; Emer et al., 2018; Souza et al., 2019; Abreu et al., 2020), which reinforces the effect of genetics on these variables. Indeed, the genetic component of different plant species causes them to respond physiologically differently to similar biotic and abiotic stimuli (Ali et al., 2021).

The fruits under study exhibited a cumulative increase in longitudinal and transverse diameters and mass during the 63 days of development (Figure 3A). Considering the growth rates of gabiroba, based on their diameters and mass, a simple sigmoidal growth pattern is observed (Figure 3B). This behavior is consistent with that reported by Silva et al. (2009) for fruits of the same species but from another region. The first 9 days after anthesis were marked by the most rapid growth acceleration, based on fruit volume, culminating in a growth rate of approximately 0.6 millimeters per day. Subsequently, a deceleration of the growth rate was observed until around 0.2 millimeters per day at 36 days after anthesis, a rate that remained relatively stable until 54 days, dropping close to zero at 63 days post-anthesis. The growth rate relative to mass accelerated in the first 45 days after anthesis, decreasing thereafter until 63 days

The similarity between the longitudinal and transverse diameters throughout development gives gabiroba its spherical shape. If we consider the average of the longitudinal and transverse diameters of the fruits in the calculation of their volume, assuming them to be spheres [(4 πr3)/3), we notice a reduction in fruit density (d = m/v) from approximately 1.32 at 9 days to around 1.05 at 63 days. The reduction in density suggests fruit expansion due to the accumulation of air in the intercellular space during the development.

It is noteworthy that the growth initiated after anthesis overlapped with the maturation stage, extending until the full ripening of gabiroba, as observed by Silva et al. (2009). Typically, fruit growth ceases before ripening (Chitarra & Chitarra, 2005), a fact not observed for gabiroba. However, it is worth noting that the growth rate (longitudinal, transverse, and mass) from 54 to 63 days, a period associated with ripening, was extremely low, close to zero. The reduced growth rate observed during ripening may be associated with the maintenance of gene expression responsible for cell expansion and elongation, albeit at low levels (Fenn & Giovannoni, 2021).

A reduction in the respiratory activity of gabiroba was observed in the first 36 days of development, followed by an increase, peaking at 154 mL CO_2 kg^{-1} h^{-1} at 54 days (Figure 3C), typical of climacteric fruits. The climacteric behavior observed is consistent with that reported by Silva et al. (2009) when studying fruits of the same species. The results suggest that the fruits collected at 45, 54, and 63 days were in the ripening phase, initiated between 36 and 45 days and completed at 63 days of development.

The evolution of firmness was marked by a quadratic behavior, with an increase in the first 36 days followed by a decrease ($p < 0.05$; Figure 4A). There was an increase in total pectin content over the first 36 days of development, followed by a decrease (Figure 4B), as observed for firmness (Figure 4A). The increase in total pectin in the first 36 days of development is associated with synthesis processes and is necessary to provide support and protection to the fruits. Therefore, its accumulation is consistent with the increase in firmness. Indeed, pectin is a heterogeneous polysaccharide present in high concentrations in the cell wall of plants, providing mechanical and functional properties to the cell wall throughout different stages, as well as during the harvesting and storage of fruits and vegetables (Kyomugasho et al., 2015; Mahmud et al., 2021). Pectic polysaccharides with various compositions and physical structures are dispersed throughout the primary wall, forming a gel matrix coextensive with the cellulose-hemicellulose network (Watkins, 2019).

During ripening, pectin undergoes depolymerization, resulting in the solubilization of low molecular weight compounds and softening of the fruit, as evidenced by the increase in soluble pectin content and decrease in firmness after 36 days of development (Figures 4A and B). These results are consistent with those of Silva et al. (2009), who associated the softening of gabiroba during ripening with pectin solubilization catalyzed by hydrolytic enzymes. Part of the soluble pectin can be converted into other compounds and used as an energy source, contributing to the reduction of total pectin during the ripening of gabiroba.

The softening of gabiroba, associated with respiratory climacteric and changes in peel coloration, along with the stabilization of growth rate based on diameters, suggests the onset of ripening between 36 and 45 days after anthesis. Silva et al. (2009), Santos et al. (2015), and Abreu et al. (2020), studying fruits of different species of the *Campomanesia genus* (*C. rufa*, *C. adamantium*, and *C. pubescens*), also observed greater softness in ripe fruits compared to green ones, as is common for most fruits. While Silva et al. (2009) noted a maximum firmness of *C. pubescens* fruits of around 18 N at 21 days after anthesis, the maximum firmness of the fruits in the present study was approximately 8 N, observed at 36 days.

A reduction in titratable acidity (Figure 4C) of gabiroba was observed, reflecting an increase in pH (Figure 4D) throughout development. While the reduction in titratable acidity occurred until the onset of ripening (45 days), the elevation of pH extended until full ripening (63 days). Indeed, the pH increase is usually due to the reduction in

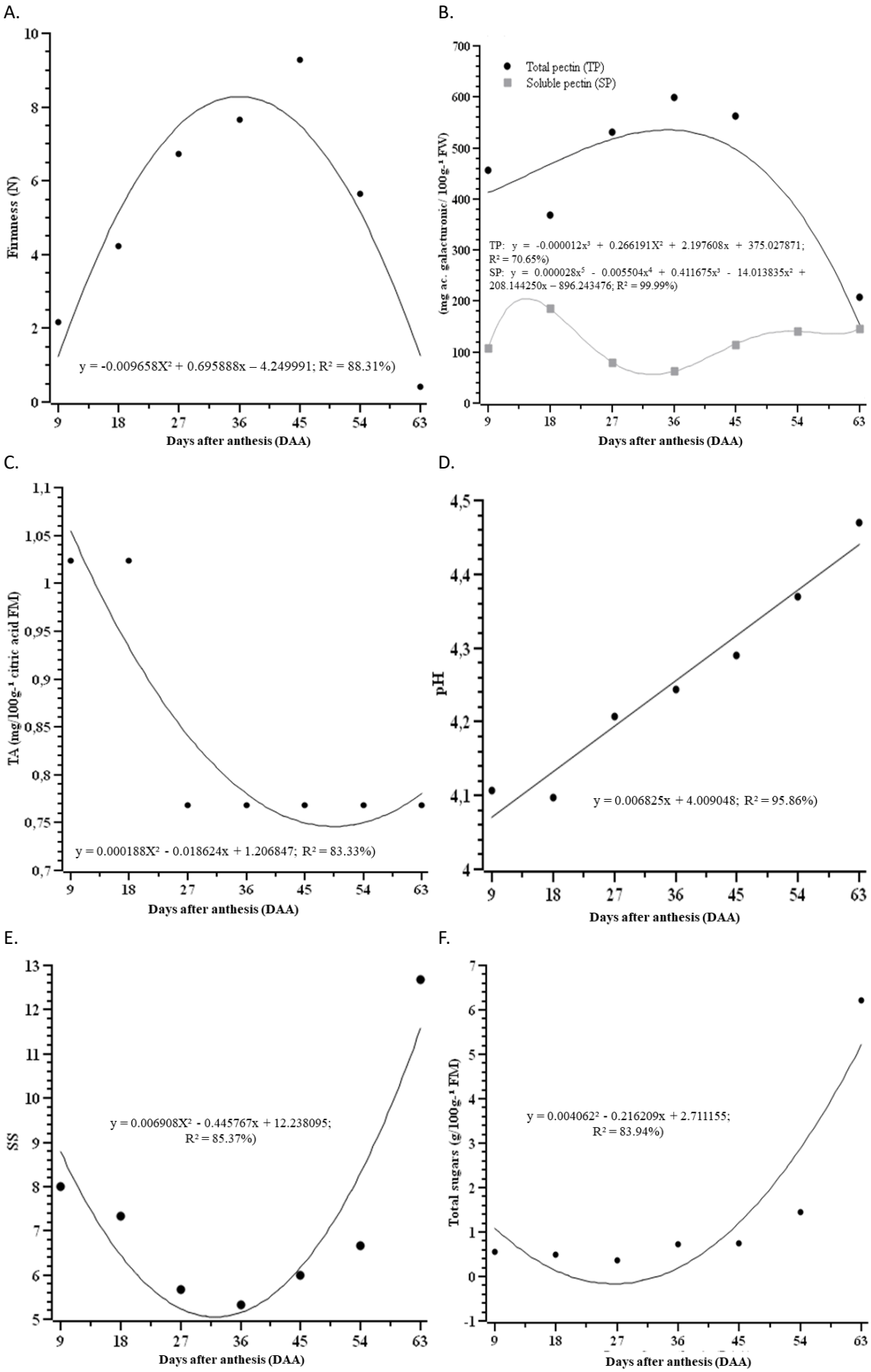

Figure 4. Changes in (A) firmness, (B) soluble and total pectin, (C) titratable acidity, (D) pH, (E) soluble solids, and (F) total sugars in gabiroba fruit during the development.

the quantity of hydrogen ions provided by organic acids, which are consumed in the respiratory process, especially during fruit ripening (Barragán-Iglesias et al., 2018; Batista-Silva et al., 2018; Khodabakhshian & Khojastehpour, 2021). The observed changes in titratable acidity and pH during gabiroba development are similar to those reported by Lima et al. (2016) for fruits of the same species, as well as for fruits of other species of the same family (*Myrtaceae*), such as arrayan (*Luma apiculata*), camu-camu [*Myrciaria dubia (H.B.K) McVaugh*], jabuticaba 'Sabará' (*Myrciaria jaboticaba* (Vell.) O. Berg), murta (*Eugenia gracillina Kiaersk*), and guava (*Psidium guajava*) (Araújo et al., 2015; Becker et al., 2015; Neves et al., 2015; Araújo et al., 2016; Fuentes et al., 2016).

Soluble solids and total sugars showed a quadratic behavior throughout development, marked by a reduction from 9 to 27 days, followed by an increase until full ripening at 63 days (Figure 4E and F). Sugars typically account for the majority fraction of soluble solids, which also comprise organic acids, pectins, among other water-soluble compounds. Therefore, the similarity between the behaviors of sugars and soluble solids was expected. Since sugars are the main sources of energy used by fruits, their reduction can be associated with the demand generated by growth. Conversely, the increase in sugars and, consequently, soluble solids was observed during ripening, a phase of lower growth rate, hence lower energy demand, compared to the initial stages of growth.

Considering that the accumulation of sugars occurred while the fruits were still attached to the mother plant, it is suggested that this is due to both the translocation of photoassimilates from the leaves to the fruits and the possible hydrolysis of carbohydrates of higher molecular weight, such as starch and constituents of the fiber fraction. The increase in sugars and soluble solids during ripening is responsible for sweetening the fruits, making them attractive to seed dispersal agents, which are essential for the perpetuation of the species. The increase in soluble solids coinciding with the climacteric of gabiroba is consistent with what was observed by Silva et al. (2009).

Overall, the pH and the levels of soluble solids, sugars, and titratable acidity reported in this study fall within a range of values reported for fruits of the *Campomanesia genus* (Silva et al., 2009; Morzelle et al., 2015; Santos et al., 2015; Bianchini et al., 2016; Azevedo et al., 2016; Lima et al., 2016; Emer et al., 2018; Souza et al., 2018; Souza et al., 2019;Abreu et al., 2020; Verruck et al., 2020). These variables are influenced by *Campomanesia* species, environmental factors, and stages of maturity (Goldini et al., 2019), which justifies the reported data.

Artificial Neural Network combined with Kohonen Self-Organizing Maps (ANN/KSOM)

The data obtained from the analyses of gabiroba at different developmental stages was used to obtain the Kohonen Self-Organizing Map (ANN/KSOM), a type of Artificial Neural Network (Figure 5). Thus, maps with different dimensions were generated aiming to achieve the best cluster validation indices and the lowest measurement errors (quantification, topographic, and combined), contributing to a better visual identification of the variables studied concerning the fruit's developmental stages.

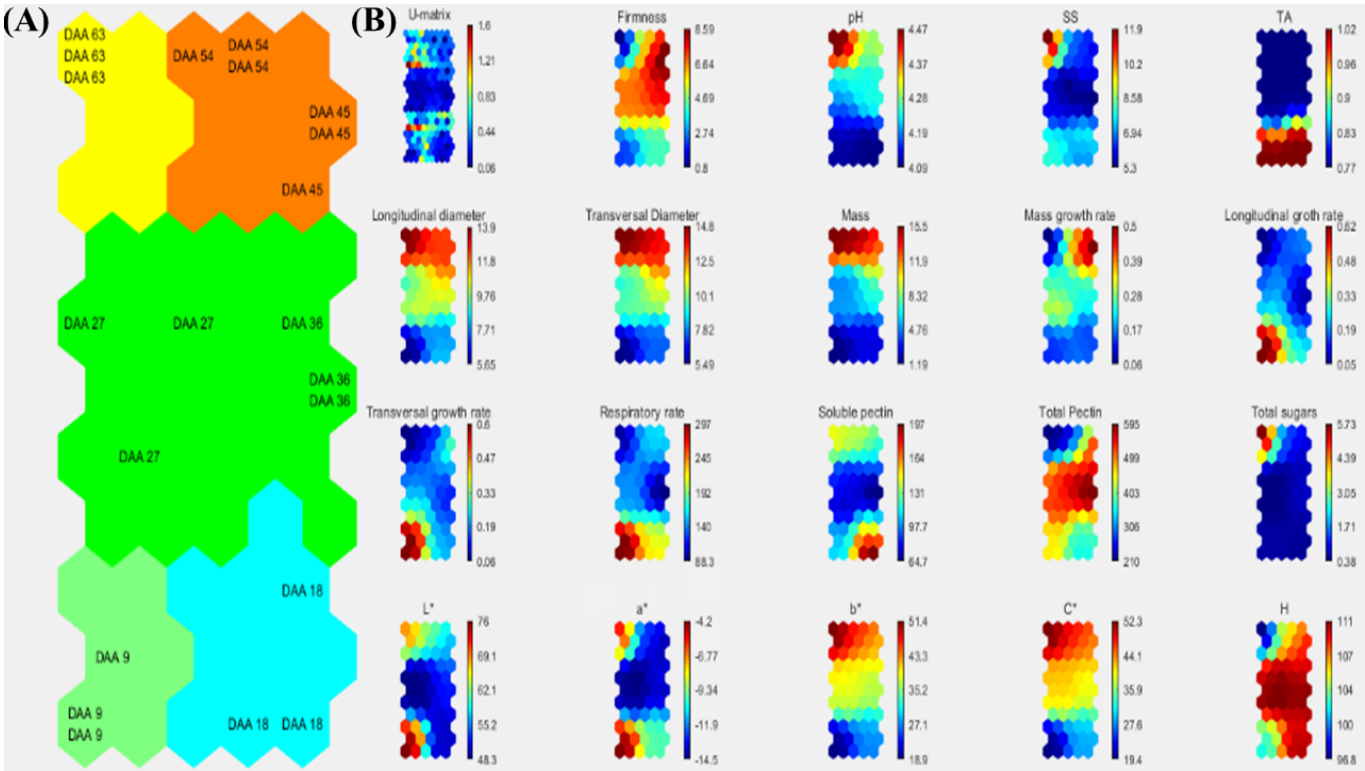

Figure 5. Bidimensional neural cluster map of gabiroba fruit during the development (A) and component maps and distance matrix (U matrix) of the analyzed variables.

The Davies-Bouldin (DB) and Silhouette (S) indices are cluster validation indicators, where DB infers the similarity between clusters, regardless of the number of clusters and the partitioning method used. The closer the value is to zero, the better the data partitioning. The S index, on the other hand, assesses the quality of clustering based on the proximity between objects within a cluster and the proximity of these objects to the nearest cluster. The closer the value is to one, the better the clustering. The network chosen in this study was a 5 × 11 hexagonal grid with DB and S values of 0.55145 and 0.73656, respectively. The observed quantization, topographic, and combined errors were 0.14857, 0, and 0.23141, respectively. The lower the value, the better the accuracy and continuity of the network, and thus, this study demonstrated good accuracy and continuity in the network.

The topological map of the network, also known as the two-dimensional neural clustering map, is shown in Figure 5A, while the component maps of each analysis and the U-matrix are displayed in Figure 5B. Additionally, it's worth noting that the distance between adjacent neurons is inferred by the color scale, and the variation in the analytical determinations is represented by the color gradient of the bars located at the bottom of each map, except for the U-matrix.

In the two-dimensional ANN/KSOM neural map, each hexagon represents a neuron, where the studied treatments are grouped according to their similarities. Consequently, the division of the samples into five groups was identified (Figure 5A). Another factor contributing to the formation of the five groups was the U-matrix, indicating a significant distance between neurons and, consequently, between different developmental stages of gabiroba. Additionally, considering that the position occupied by a sample on the neural map (Figure 5A) corresponds to its same position on the component map (Figure 5B), it was possible to identify the main variables responsible for the grouping and separation of the samples.

The Kohonen self-organizing map enabled the distinction of fruits based on age and, consequently, developmental stages. Fruits at 27 and 36 days post-anthesis showed similarities that grouped them together, as did fruits at 45 and 54 days. Fruits at 9, 18, and 63 days post-anthesis were distinct from each other and from the two previous groups. Group 1, located in the lower left (avocado green), contains 6 neurons and corresponds to fruits at 9 DAA. In this group, the highest values for AT, longitudinal and transversal growth rate, respiration, L*, and a*, and low values of pH and total sugars were observed (Figure 5B). Group 2, in blue, located in the lower right, contains 10 neurons, housing fruits harvested at 18 DAA, which are distinguished not only by higher AT and soluble pectin, but also, like in group 1, low values of pH and total sugars. The largest group (3), represented by light green, has 24 neurons, gathering two developmental stages, corresponding to fruits harvested at 27 and 36 DAA, which showed higher levels of total pectin and h°, but still with low sugar content. In the upper right, in orange color, is group 4, represented by fruits harvested at 45 and 54 DAA, which showed higher firmness and mass growth rate. The last group, in yellow, contains 6 neurons, referring to mature fruits harvested at 63 DAA, which showed higher values of pH, SS, longitudinal and transversal size, mass, total sugars, b*, and C*, and lower values of firmness, h°, and minimal growth rate. The neural network data corroborate the data presented in Figures 2, 3, and 4, aiding in the identification of similarities and correlation trends more effectively and intuitively.

Conclusions

Fruits of *Campomanesia pubescens* exhibit cumulative growth until full ripening, which occurs at 63 days post-anthesis of development. They display a simple sigmoidal growth behavior and typical climacteric fruit respiratory activity. These fruits can be grouped, through the Kohonen self-organizing map, based on the developmental stage, using the studied variables, in a more effective and intuitive manner.

Compliance with Ethical Standards

Author contributions: Conceptualization: GGLM, HEAB, CVLN, ABSA, CHMR, EVBVB; Data curation: GGLM; Formal analysis: GGLM, HEAB, CVLN, ABSA, CHMR; Funding acquisition: EVBVB; Investigation: GGLM; Methodology: GGLM; Project administration: EVBVB; Resources: EVBVB; Supervision: EVBVB; Writing – original draft: GGLM; Writing – review & editing: EVBVB.

Conflict of interest: The authors declare no potential conflicts of interest.

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