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Development and maturation of mango fruits cv. ‘Ubá’ in Visconde do Rio Branco, Minas Gerais State, Brazil

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ABSTRACT

Several criteria have been used to determine fruit maturity, which are based on the appearance and chemical composition of the produce at harvest time. The objective of this study was to evaluate the physical, chemical and physiological changes that occur during the development of mango cv. ‘Ubá’, aiming to determine the stages of fruit development until complete maturation. The experiment was carried out in an approximately 30-year-old orchard in Visconde do Rio Branco, MG (21º00’37"S, 42º50’26"W and 352 m altitude). Weekly, 25 fruits of 15 hoses were collected from the anthesis to the complete maturation in the plant. Samplings took place from August 2007 to January 2008. The characteristics evaluated were length, smaller and larger diameter; CO_2 production; color parameters L*, a*, and b* of skin and pulp; fresh and dry mass (fruit, skin, pulp, and seed); solute leakage; pulp firmness; soluble solids (SS); titratable acidity (TA); SS/TA ratio; Vitamin C; carotenoids, starch, and soluble sugars. The development of mango fruit cv. ‘Ubá’ took 23 weeks. The developmental pattern fit a simple sigmoidal model. Fruits attached to the plant reached the respiratory climacteric stage between 20 and 21 weeks after anthesis.

Keywords: *Mangifera indica* L; Growth curve; harvest point.

RESUMO

Desenvolvimento e maturidade de frutos de mangueira ‘Ubá’ em Visconde do Rio Branco, Minas Gerais

Vários critérios têm sido utilizados na determinação da maturidade de frutos, baseados na aparência e na composição química do produto na época da colheita. Objetivou-se avaliar as mudanças físicas, químicas e fisiológicas ocorridas durante o desenvolvimento da manga ‘Ubá’, visando estabelecer as fases de desenvolvimento do fruto para o completo amadurecimento. O experimento foi desenvolvido em pomar com cerca de 30 anos de idade em Visconde do Rio Branco, MG (21º00’37"S, 42º50’26"O e altitude de 352 m). Semanalmente, desde a antese até o completo amadurecimento na planta, foram coletados 25 frutos de 15 mangueiras. As amostragens ocorreram de agosto de 2007 a janeiro de 2008. As características avaliadas foram: comprimento, menor e maior diâmetro; produção de CO_2; parâmetros de cor L*, a* e b* da casca e da polpa; massa fresca e seca (fruto, casca, polpa e semente); extravasamento de solutos; consistência da polpa; sólidos solúveis (SS); acidez titulável (AT); ratio (razão SS/AT); vitamina C; carotenoides, amido e açúcares solúveis. O desenvolvimento da manga ‘Ubá’ estendeu-se por 23 semanas. O padrão de desenvolvimento ajustou-se a um modelo sigmoidal simples. O climatérico respiratório dos frutos ligados à planta foi atingido entre a 20ª e a 21ª semana após a antese.

Palavras-chave: *Mangifera indica* L; curva de crescimento; ponto de colheita.

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INTRODUCTION

Mango is cultivated in nearly all regions of Brazil, with potential for increase in both the cultivated area and productivity. In Minas Gerais, specifically in the Zona da Mata Region, the cultivar 'Ubá' stands up, growing spontaneously in practically all the municipalities of the region. The fruits of this cultivar are mainly used in industrial processing, but they are accepted for fresh consumption.

The evaluation of the developmental pattern of a fruit from flowering helps in determining maturity and harvest indices (Matarazzo *et al*., 2013). Several indices used during development are based on appearance (shape, diameter, color) and chemical composition (soluble solids, titratable acidity) (Biale & Young, 1964). Filgueiras *et al*. (2000) discussed that the physical indices of mango harvest are mostly based on characteristics of shape and appearance of the fruit, which can be visually perceived without using destructive methods such as: skin color and appearance: dark green color changes to bright green, wax-free; lenticels: close with fruit maturity; apex shape: full and round; beak shape: begins to appear in some cultivars; and shoulder shape: in immature fruit is in line with the stalk insertion, elevating above the stalk attachment in mature fruit.

The stages of fruit development are marked by changes in structure, physiology, and biochemistry of cells, leading to maturity, senescence and ultimately tissue death. Mango ripening is characterized by pulp softening, changes in skin and pulp colors, reduction in astringency, and development of aroma and flavor of fruits (Chitarra & Chitarra 2005).

'Ubá' mango is usually harvested with green skin color, but physiologically mature, that is, in the pre-climacteric stage. If fruit are harvested before this stage, they do not reach good quality for consumption. Therefore, the distinction between a physiologically mature and immature fruit at harvest and the assessment of the green mango quality at harvest is very important for the market (Saranwong *et al*., 2004).

Moraes *et al*. (2000) analyzed the physical and chemical changes in 'Ubá' mango from the 15th week after flowering to full maturity. The respiratory rate of the fruits did not change significantly until the 23rd week, and then a subsequent increase of more than 100% occurred, corresponding to the climacteric peak. Soluble solids accumulation was low until the 23rd week, with average Brix of 7 °, and then a subsequent increase to 20 °, on average, on the 25th week of evaluation. The titratable acidity decreased over the study period, consequently, the soluble solids/titratable acidity ratio increased more rapidly between the 22nd and 24th weeks. From the 15th week after flowering, 'Ubá' mango fruits had already normal maturity capacity, that is, they had already reached physiological maturity (Moraes, 1988).

All aspects of mango development are directly or indirectly influenced by the environment. Thus, understanding plant responses to environmental variations is crucial for management that is suitable to the prevailing conditions, aiming to improve fruit quality and maximize productivity.

No references were found in the literature on the complete development of 'Ubá' mango. Therefore, the objective of this work was to characterize the physical, chemical, and physiological changes during the development of mango (*Mangifera indica* L.) cultivar 'Ubá', from anthesis to complete maturity in the plant.

MATERIAL AND METHODS

The field experimental phase of this study was conducted in a grafted mango orchard of about 30 years old, in Sementeira Farm, belonging to the Universidade Federal de Viçosa, in the municipality of Visconde do Rio Branco, MG (21º00'37"S, 42º50'26"W; 352 m altitude). Weekly, from anthesis (09/08/2007) to complete maturity of the fruit in the plant (10/01/2008), 25 fruits were collected from 15 previously identified 'Ubá' mango trees. The experiment was arranged in a completely randomized design (CRD), with 23 treatments (harvest times) and 5 replicates. The experimental unit consisted of 5 fruits. Samples were collected from August 2007 to January 2008. After harvest, fruits were taken for analyses of the physical, chemical and physiological characteristics to the Laboratory of Fruit Analysis of the Fitotecnia (Plant Science) Department of UFV.

Fruits were evaluated individually for length, smaller and larger diameter (digital caliper and results expressed as mm), skin and pulp color (Minolta CR10 digital colorimeter), and pulp firmness (round-tipped digital penetrometer, 12 mm diameter, results expressed as kPa). Fresh and dry mass (fruit, skin, pulp, and seed), soluble solids content (SS-digital refractometer), titratable acidity (AT-AOAC, 2012), Ratio (soluble solids/titratable acidity ratio), electrolyte leakage (from the 9th week after anthesis-onwards WAA) analysis followed the methodology of Serek *et al*. (1995), with modifications); vitamin C in pulp was determined according to AOAC (2012), carotenoids in pulp was determined according to Lichtenthaler (1987) with modifications, and carbohydrates in pulp was determinied according to Salomão (1995).

Fruit CO_2 production was determined by gas chromatography from the 1st WAA. For this purpose, the fruits were packed in airtight glass jars. Sixty minutes later, 1.0 mL aliquots of jar atmosphere were withdrawn with a syringe and injected into a Gow Mac Series 550P gas chromatograph equipped with a thermal conductivity detector and an aluminum column filled with Porapak Q.

Experimental data as a function of time were analyzed by ANOVA and regression analysis. For some characteristics, non-linear sigmoid regression models with three and four parameters were used to explain physiologically the fruit development. The non-linear models were chosen based on the coefficient of determination and the potential to explain the biological phenomenon.

The program used to analyze the data was the System of Statistical and Genetic Analysis (SAEG, 2007).

RESULTS AND DISCUSSION

The length measurements fitted to a simple sigmoidal model in response to time variation (Figure 1A). The point of minimum curvature occurred at 3.08th WAA, marking the beginning of significant gains in fruit growth (Figure 1A). The maximum length growth rate was at 7.7th WAA, with weekly gain of 8.89 mm. The point of maximum curvature occurred at 12.3rd WAA, indicating that from that week onwards length began to stabilize.

Alves *et al*., (2012) evaluated the development of sweet passion fruit in Viçosa, Minas Gerais, and found that the maximum growth rate for fruit length occurred at 12.44 DAA, with daily gain of 2.61 mm.

The point of minimum curvature for ventral and cross diameters occurred at 2.54th and 2.17th WAA, respectively, marking the beginning of expressive gains in fruit size (Figure 1A). The points of maximum curvature for the ventral and cross diameters occurred at 13.86th and 13.3rd WAA, respectively, indicating that from these weeks the size began to stabilize.

The mean ventral and cross diameters fitted to a sigmoidal model in response to time variation (Figure 1B). Lucena (2007), studying the growth curve of mango cv. Tommy Atkins in San Francisco Valley, Petrolina, PE- Brazil, found that longitudinal, ventral and cross diameters had quadratic fit as a function of time variation. Fruits increased in size up to the 10th WAA, when the length was assessed, and up to the 11th WAA, when ventral and cross diameters were assessed. After these times, these characteristics remained practically constant.

Although not all fruits change color during ripening, this is one of the characteristics most associated to harvesting point and maturity for consumption (Tucker, 1993). This statement is particularly true for mango harvesting, especially in relation to the color of the skin. Figure 1C shows that the difference in skin color (ÄE) of 'Ubá' mango increased 9.9 times from the 9th WAA (ÄE = 2.7) and underwent deeper changes from the 21st WAA, with color difference of 12.6 in the 23rd WAA.

The difference in pulp color doubled from the 9th to the 14th WAA, from 4.0 to 8.6, and from there, there was a high increase, reaching 34.2 on the 23rd WAA (Figure 1 C).

Mango skin hue angle fitted to a sigmoidal model (Figure 1D). The point of minimum curvature occurred at the 21.8th WAA (h = 102.8°), marking the beginning of the transition from green to yellow. On the 23rd WAA, the skin was deep yellow (h = 82.9°). The point of maximum curvature was estimated at 26.1st, indicating lack of stabilization during the experimental period. Fruit color varies markedly with intensity and amount of sunlight exposure (Morais *et al*., 2004). Therefore, the position in the plant and the season influence significantly color development, which can be the likely reason for the high standard deviation of the observed means.

Similar results were found by Moraes *et al*. (2000) studying the development of 'Ubá' mango fruit in Visconde do Rio Branco – MG. The authors found that from the 21st week after flowering (WAA), using the Munsell color system, the skin color changed from hue 5GY (green-yellow) to hue 5Y (yellow), and finally reached hue 10YR (orange) between the 23rd and 24th WAA.

Degradation of chlorophyll in the pericarp and the synthesis and/or manifestation of carotenoid pigments take place gradually, and the green color disappears with the fruit development (Medeiros *et al*., 2011).

According to O'Hare (1995), the beginning of the climacteric in mango shows intense chlorophyll degradation in the skin (Figure 3D), as on the 21.8th WAA, a rapid change of green into yellow began practically coinciding with the climacteric peak (Figure 4C).

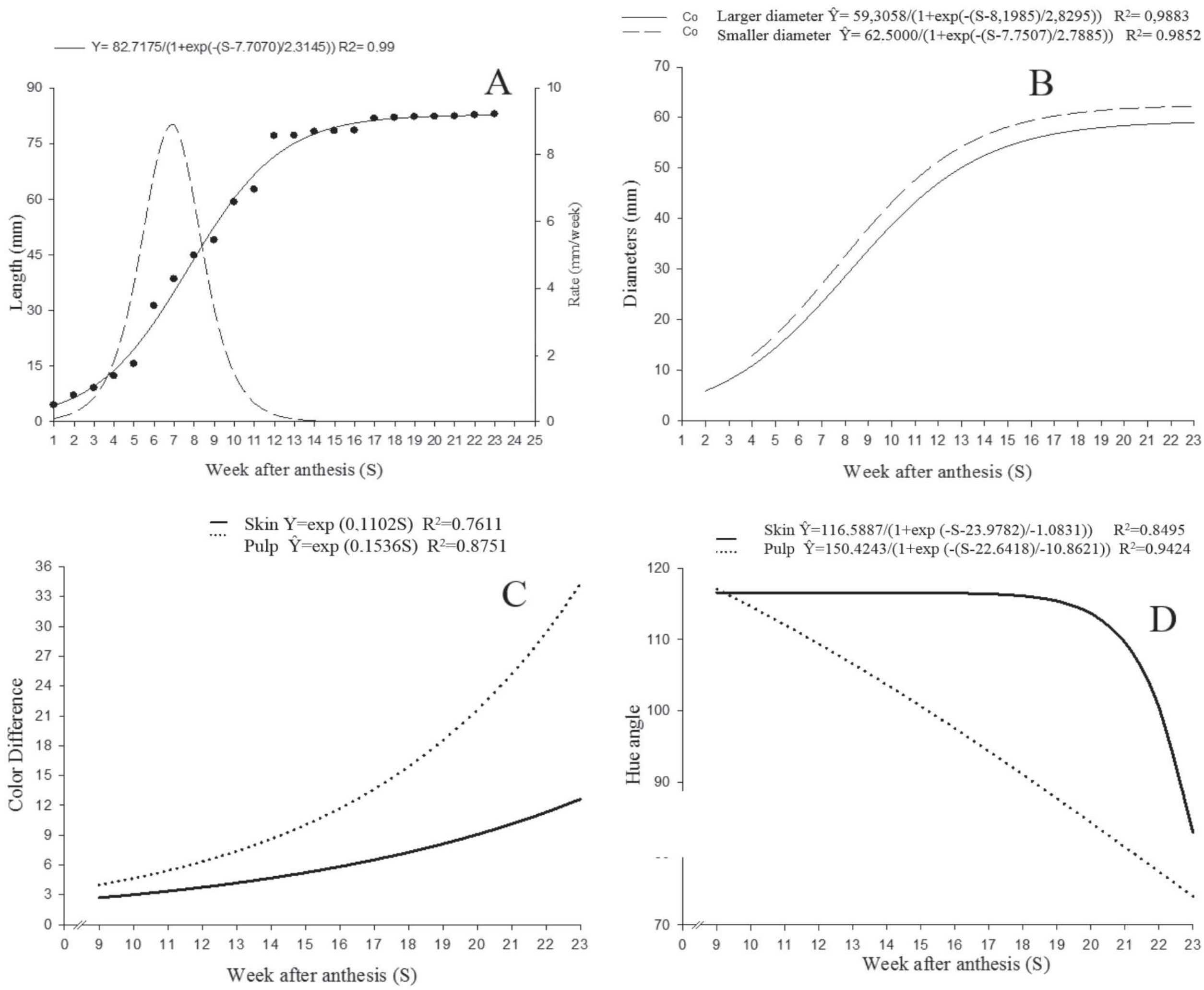
The hue angle of the pulp (Figure 1D) fitted to a sigmoidal model. The yellowish-green color of the pulp was reached on the 15th WAA (h = 100.6°). The yellow color of the pulp (h = 90°) was reached on the 18.3rd WAA. At 23rd WAA, the color of the pulp was 73.9°, indicating a yellow-orange color.

The points of minimum (PC min) and maximum (PC max) curvature were estimated as occurring on the 44.4th WAA and 0.9th WAA, respectively, beyond the experimental period and indicating absence of stable phase in pulp color change. Similar to size, accumulation of fresh mass of fruit, pulp, skin, and seed fitted to a simple sigmoidal development pattern (Figure 2A).

The point of minimum curvature occurred at 7.4th WAA, marking the beginning of expressive gains in the accumulation of fruit fresh mass (Figure 2A). The derivative of the adjustment equation showed that the highest accumulation rate of fresh mass occurred on the 11.4th WAA, with weekly gain of 19.87 g. The point of maximum curvature was on the 15.4th WAA, indicating that from that week on the accumulation of fresh mass began to stabilize, corresponding to 88% of the maximum accumulation. These results are similar to those reported by Moraes *et al*. (2000) for development of ‘Ubá’ mango in the Zona da Mata Region. The authors found that from the 15th week after flowering, accumulation of fruit fresh mass stabilized.

Silva *et al*. (2013) studied the growth curve and respiratory pattern of peach genotypes in a subtropical region. They reported that the fruit fresh mass increased slowly at the beginning of the cycle and, between 60 and 75 days after anthesis (DAA), doubled from 13.31 ± 1.43 g to 26.14 ± 3.71 g. These results are lower than those found in the present study, where the point of minimum curvature occurred on average 51.8 DAA, indicating the beginning of expressive gains in the fruit fresh mass accumulation.

Figure 2A shows the point of minimum curvature of the fresh mass on 6.86th, 5.59th, and 9.73th WAA for pulp,



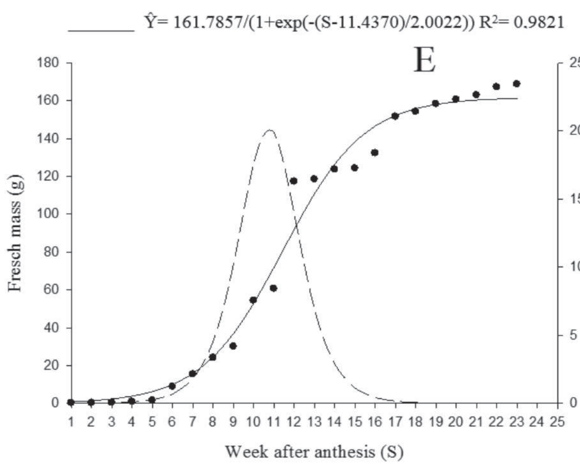


Figure 1: Observed and estimated length increases (A), ventral and cross diameters (B), increase in fresh mass accumulation (C); estimate of color difference, C: skin and pulp (ÄE); D: Hue angle of skin and pulp E: fruit fresh mass over development of ‘Ubá’ mango as a function of time (S).

skin, and seed, respectively, and the point of maximum curvature, that is, the beginning of stabilization of fresh mass accumulation occurring only on 15.19th, 20.25th, and 13.8th WAA, respectively. The maximum values of mass accumulation reached by pulp, ski, and seed were 101.13, 34.75, and 29.09 g, respectively.

From the ninth week on, when it was possible to separate the fruit parts, the pulp already stood out over the other components, reaching up to 62.49% of the total fruit mass.

On the 17th WAA, when the fruit reached physiological maturity, we found that the yield of pulp, skin, and seed was 63.47; 17.35, and 19.18%, respectively. These results confirm those reported by Rocha (2009) for several accessions of 'Ubá' mango with pulp, skin, and seed yields of 65.28, 20.03, and 15.76%, respectively. Folegatti *et al*. (2002) pointed out that the minimum acceptable pulp yield to select a cultivar for industry is 60%, and the fruit analyzed in this study yielded above these requirements.

Figure 2B shows the point of minimum curvature of fruit dry mass on the 8.78th WAA, indicating the beginning of expressive gains in accumulation. The point of maximum curvature was on the 22.58th WAA, showing that from that week the accumulation of dry matter began to stabilize. This initial stabilization occurred near the 23rd WAA, when the fruits could be considered mature, as opposed to the accumulation of fresh mass that stabilized from the 15.4th WAA (Figure 2A).

It is clear that pulp was the component accounting for the greatest amount of dry mass in the fully developed fruit (Figure 2B), as well as observed for jabuticaba fruit (Magalhães, 1991). Untill near the 11th WAA, the skin of 'Ubá' mango accumulated more dry mass than the seed, then, from there on, the seed surpassed the skin mass until the harvest period.

The point of minimum curvature occurred on 9.14th, 5.3th, and 10.26th WAA for pulp, skin, and seed, respectively (Figure 2B). On the other hand, the point of maximum curvature occurred on 22.55th and 20.29th WAA for skin and seed, respectively. The pulp dry mass showed the maximum point of curvature on the 31.32th WAA, indicating no stabilization during the experimental period.

Solute leakage was adjusted to the linear model as a function of time (Figure 2D), being directly proportional to the development of the fruit, that is, there is greater solute leakage as fruit develops. This is possibly caused by cell expansion during fruit development.

Cell expansion, as well as maturity, causes significant changes in membrane structure and cell wall, leading to the increase in solute leakage. For Kader (1999), one of the most remarkable changes that occur during ripening and subsequent senescence of fruits is solute leakage, which confirms the findings of this work.

Pulp firmness reduced gradually until the 14th WAA (Figure 2E). From the 15th WAA onwards, there was increase in the rate of firmness loss, as shown by the increase in the curve slope.

Filgueiras *et al*. (2000) recommended harvest of 'Tommy Atkins' mango with firmness of 129.36 N, while Medlicott & Reynolds (1988) recommend the range of 107.84-127.45 N, and Alves *et al*. (2002) recommended firmness of 129.41 N. As we previously mentioned, the harvest of 'Ubá' mango can be done from the 17th WAA (physiological maturity). During this period, the estimated pulp firmness was 2015.6 kPa (Figure 2E).

At the end of fruit development, the sharp loss of firmness in 'Ubá' mango may be due to maturation and degradation of the cell wall and middle lamella.

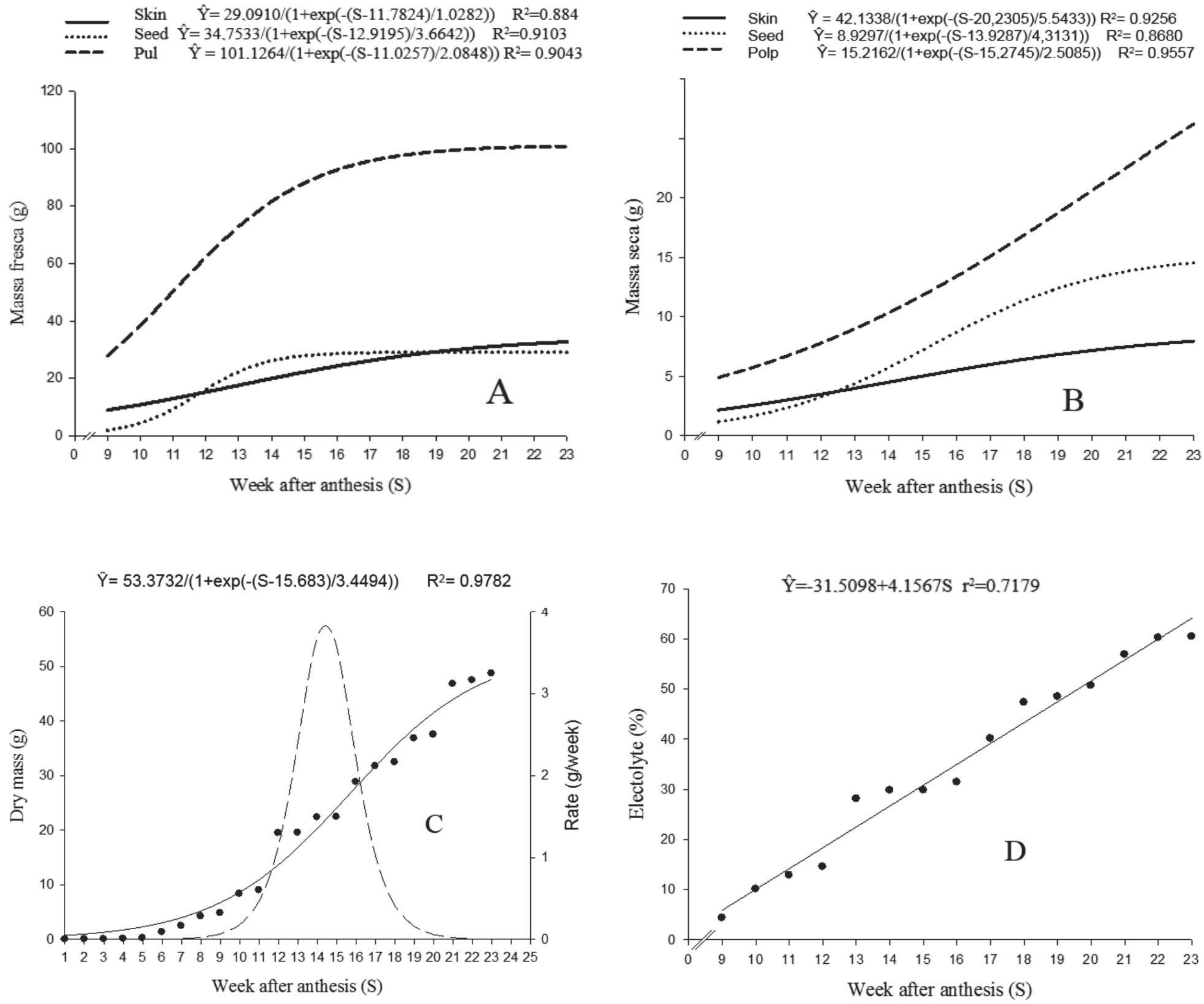
Soluble solids increased slowly up to the 17th WAA and rapidly thereafter (Figure 3A), from 9th to 17th WAA, the soluble solids content increased from 6.5 to 8.0 °Brix, reaching the maximum content of 24.32 ºBrix on the 23rd WAA. Chitarra & Chitarra (2005) attributed the increase in SS content during maturation mainly to the hydrolysis of reserve carbohydrates, accumulated during the fruit growth in the plant.

As it was expected, there was a reduction in titratable acidity with mango fruit development (Figure 3B). The citric acid content decreased from 3.49% on the 9th WAA to 2.33% on the 17th WAA, when the fruit reached physiological maturity, and to 0.83% in the fully mature fruit. According to Kader (1999), after harvest and during storage, the concentration of organic acids usually declines because they are used as substrate in respiration or they are transformed into sugars. This transformation is important for flavor (acidity) and aroma, since some of these compounds are volatile.

In fruits of several species, the soluble solids/titratable acidity ratio indicates the stage of physiological maturity (Chitarra & Chitarra, 2005). This ratio went from 2.57 on the 9th WAA to 2.86 io the 17th WAA, (Figure 3C), a period characterized by low content of soluble solids and high titratable acidity. As development advanced, the acidity decreased and soluble solids content increased and, consequently, after the 17th WAA there was a rapid increase between the 21st and 23rd WAA, reaching 42.63.

Vitamin C decreased over the weeks after anthesis according to a quadratic model (Figure 3D). Kader (1999) observes that ascorbic acid is structurally one of the simplest vitamin components found in plants. It is an acidic sugar lactone that is synthesized in plants from glucose or other simple carbohydrates. For 'Ubá' mango, the contents of vitamin C in mature fruits are nearly double the values found for other cultivars, as on the 23rd WAA, the vitamin C content was 73.67 mg/100g of fresh pulp mass, which highlights the high nutritional value of cultivar 'Ubá'. Similar results were found by Ribeiro (2006), working with ‘Ubá’ mango at maturity for consumption, with 77.71 mg 100 g of vit C per fresh pulp mass, whereas values of 15.69, 9.79, and 10.54 mg/100 g fresh pulp mass were found for the cultivars Haden, Tommy Atkins, and Palmer, respectively.

Vitamin C contents described in this study are very close to those reported by Subramanyam (1975) for ‘Alphonso’ mango, with average concentrations of 175 and 87.5 mg/100 g of pulp fresh mass obtained for 35 and 112 days after anthesis, respectively. Franco (2003) reported that the mature ‘Common’ mango has 43 mg/100 g of vitamin C per fresh pulp mass. On the other hand, Salunke & Desai (1984) detected only 13.9 mg/100 g of vitamin C per fresh pulp mass in ‘Keitt’ mango. The differences between the contents found by these studies and our findings can be attributed to different cultivars, orchards located in



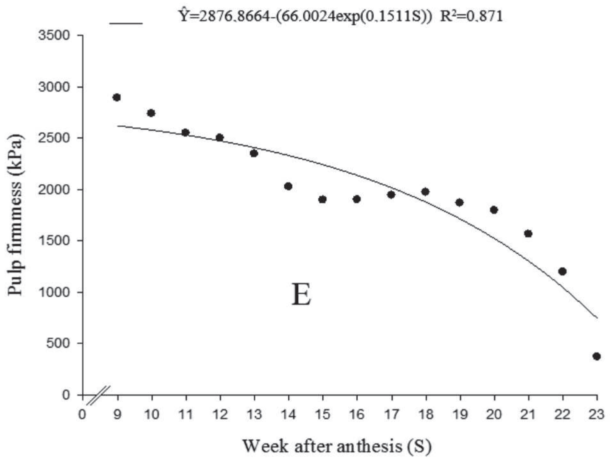
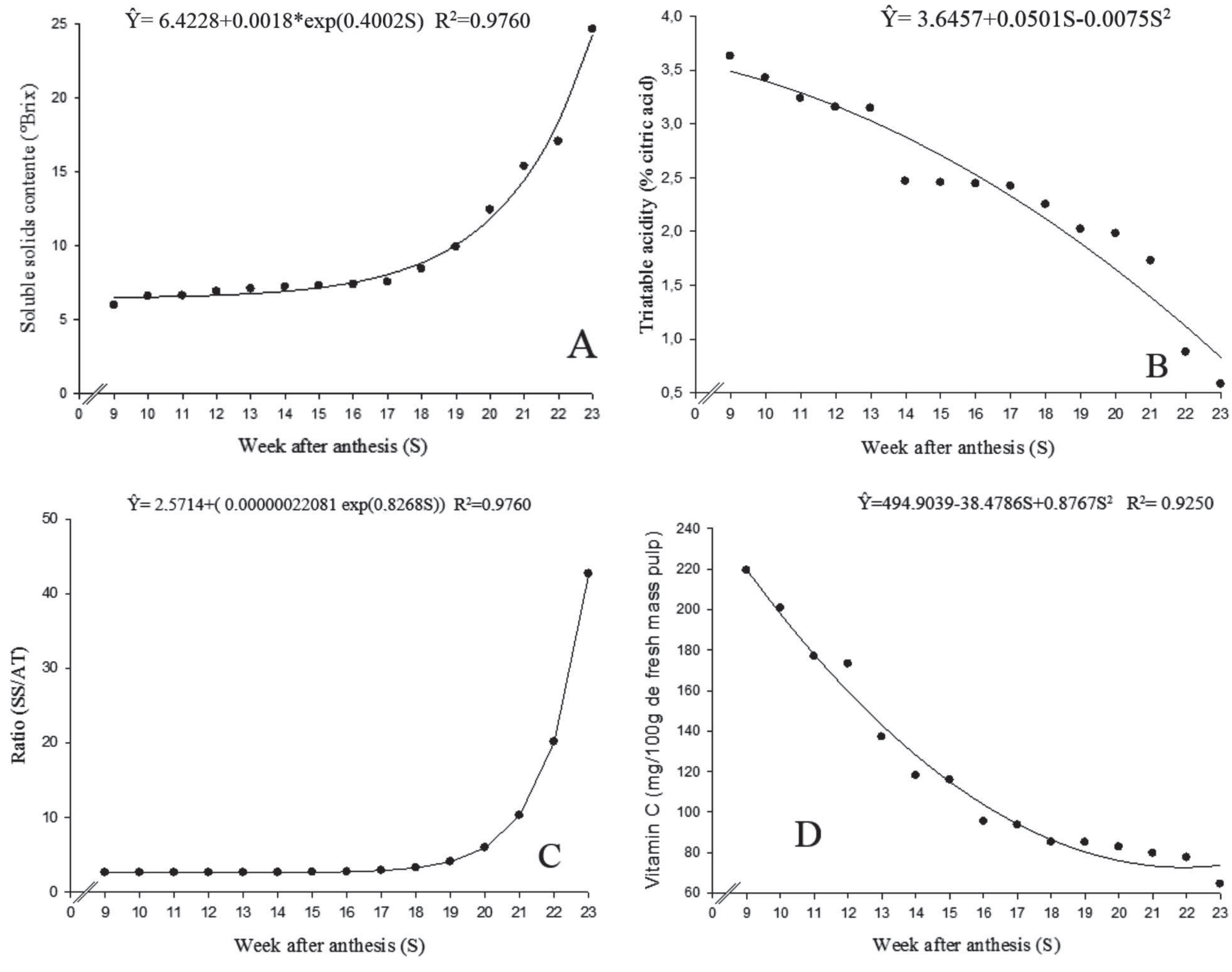


Figure 2: Estimates of fresh mass (A), dry mass (B) of pulp, skin, and seed; observed and estimated values of dry mass accumulation of fruit (C); (D) and pulp firmness (E) during the development of ‘Ubá’ mango as a function of time (S).

different climates and regions, different cultural practices, soil characteristics, and use of irrigation.

The means of carotenoids content in response to time variation fitted a quadratic model (Figure 3E). Carotenoids content increased from 0.3 mg/100 g of the fresh pulp mass on the 9th WAA to 2.5 mg/100 g on the 23th WAA. These results corroborate the work of Ribeiro (2006), who assessed mango cultivars and found total carotenoid contents of 2.41 mg/100g in 'Ubá' mango purchased locally at maturity for consumption, whereas cultivars Haden, Tommy Atkins, and Palmer had carotenoid contents of 1.91, 2.53, and 2.63 mg/100g of pulp, respectively (Ribeiro, 2006).

Medlicott & Reynolds (1988) found total carotenoid values higher than 0.5 mg/100 g of fresh pulp mass for 'Tommy Atkins' mango. Salunke & Desai (1984), among several cultivars of ripened mangoes, found variation in total carotenoid content from 0.9 to 9.2 mg/100 g of fresh pulp mass. Matarazzo *et al*. (2013) point out that the levels



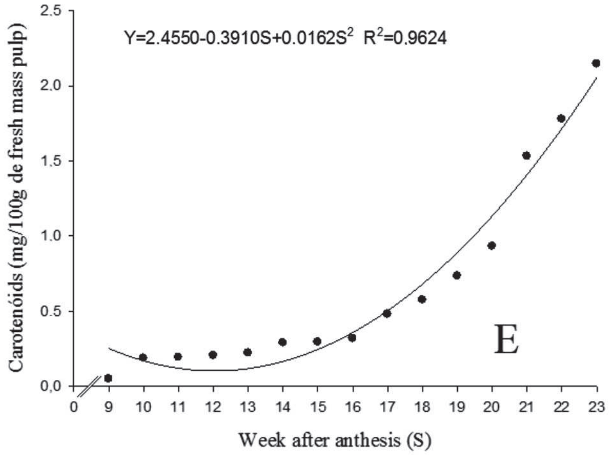


Figure 3: Observed and estimated values of soluble solids content (A), titratable acidity (B), Ratio (C), vitamin C (D), and carotenoids (E) of pulp during development of 'Ubá' mango as a function of time (S).

of these pigments can be influenced by the season, geographical location, harvest conditions, and other factors.

Subbarayan & Cama (1970) working with 'Alphonso' mango in the stages immature, partially mature, and mature, found carotenoid contents of 0.041, 3.36, and 8.92 mg/100 g of the fresh pulp mass, respectively.

Starch content fitted a quadratic model (Figure 4A). On the 9th WAA, starch was estimated to be 7.32%; during fruit development there was expressive accumulation of starch up to the 17th WAA (11.87%), then decreased from that time to complete ripening in the plant. The decrease in starch content from the 17th WAA indicates conversion to sugar (Figure 4A). Subramanyam *et al*. (1975), studying 'Tommy Atkins' mango development in the plant, observed that starch accumulation is the main activity in the pulp tissues, increasing from 1.5% after fruit setting to 13% at full development. However, starch is fully hydrolyzed after harvest and synthesis of total sugars occurs within 8 days. These values may vary with the cultivar, harvest period, cultivation site, and cultivation conditions (Lucena, 2007).

Starch is described as the main carbon reserve used in post-harvest synthesis of sucrose (sugar predominant in mature mango) (Fucks *et al*., 1980; Subramanyam *et al*., 1975). However, there is no consensus, since Hubbard *et al*. (1991) and Castrillo *et al*. (1992), for example, concluded that the starch content found in the freshly harvested mango was insufficient to provide more than 7% increase in pulp sugar content for the production of accumulated sucrose during ripening after harvest.

The content of soluble sugars (Figure 4B), the main constituent of soluble solids, followed the same upward trend of SS. Then, similar to soluble solids content (Figure 3A), the soluble sugar content remained nearly constant until the 7th WAA (2.02%). Thereafter, the sugar content increased and, from the 22nd to the 23rd WAA, this increase amounted to 18.5%, with content rising from 5.84 to 6.92%. These results agree with reports by Chitarra & Chitarra (2005), who found average sugar content varying from 5 to 10% in ripe climacteric fruit such as mango.

The total carbohydrate content (sugars + starch) on the 23rd WAA was 14.40%. This result corroborates the findings of Ribeiro (2006) in the characterization and evaluation of the antioxidant potential of mango, who reported that the total carbohydrate content in mature 'Ubá' mango was 15.87%.

Data from literature are conflicting with regard to the content of soluble sugars during the development stages and the mature fruit. As noted by Subramanyam *et al*. (1975) and Awad (1993), there is a predominance of hexoses at the beginning of ripening (3 to 6%) and sucrose (10 to 12%) in the mature fruit. This result was different from that found by Medlicott & Reynolds (1988), where sucrose was the predominant sugar throughout the ripening of cv. Keitt, accounting for about 57% of the total sugars content in the ripe fruit. There are also reports of an increase in sugars content during fruit growth and reports of these sugars remaining throughout their development (Hubbard *et al*., 1991).

To sum up, there is evidence that ripening and accumulation of soluble sugars in mangos start before

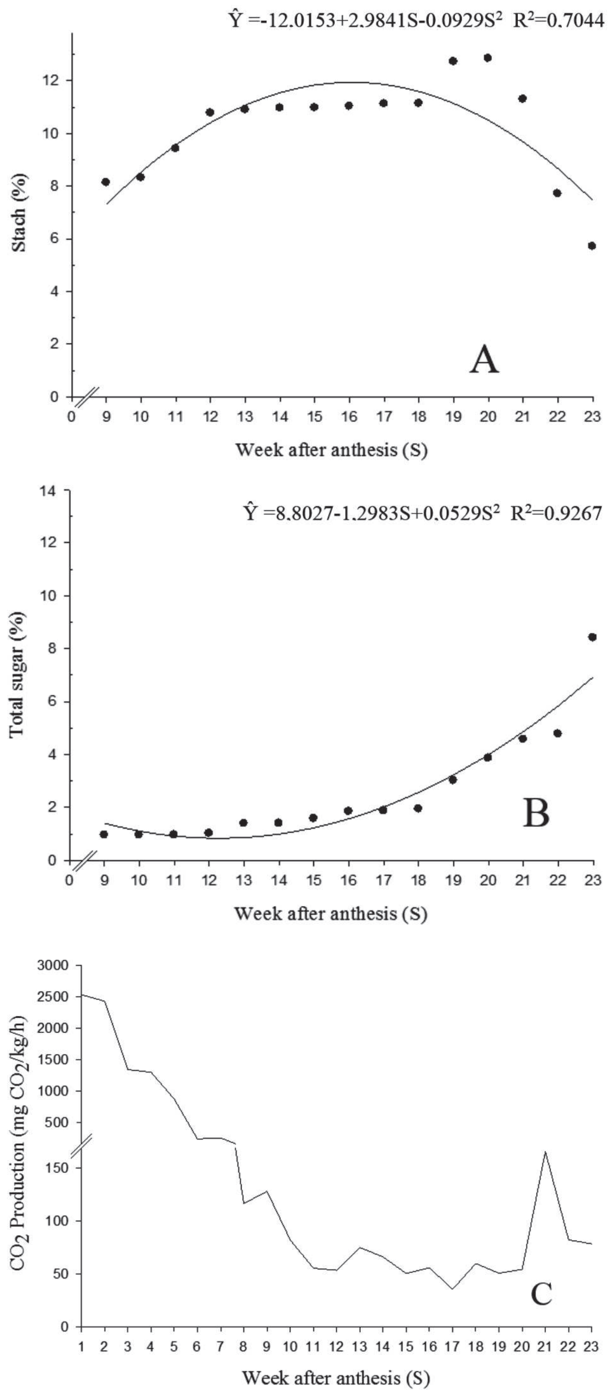


Figure 4: Observed and estimated values of starch content (A), total sugars (B) in fresh pulp mass, and observed values for CO_2 (C) production during development of 'Ubá' mango as a function of time (S).

harvesting and, although starch contents at this time may be considered insufficient, a substantial part of the sugars that compete for the sweetening of ripe fruit is accumulated after harvest. The apparent discrepancy between the data can be due to the studied cultivars, methodologies of analysis, and the maturation stage of the fruit harvested.

In the present work, it is clear that starch synthesis occurs in significant amounts during the fruit formation phase, which explains all the sugar accumulated in the mature fruit, although it takes long time between starch degradation and synthesis of sugar. It is likely that the sweetening of the mango begins with the fruit still attached to the tree and continues after harvesting. Bernardes-Silva *et al*. (2003) pointed out that it is still unclear what source of carbon is used for the post-harvest synthesis of sucrose.

The CO_2 production decreased until around the 11^{th} WAA (Figure 4C). High rates of CO_2 were produced from the first to the fifth WAA, decreasing from 2,533.00 mg CO_2kg/h to 879.21 mg CO_2kg/h. Taiz & Zeiger (2017) argue that high production of CO_2 at the beginning of development has no relation to the climacteric or non-climacteric pattern of the fruit and may be related to cell division and radial cell growth.

From the 6^{th} to the 11^{th} WAA, CO_2 production continued to fall, but smoothly, from 245.26 mg CO_2kg/h to 55.32 mg CO_2kg/h. From the 12^{th} WAA to the 20^{th} WAA, the CO_2 production stabilized, with average of 55.60 mg CO_2kg/h in the period and, on the 21^{th} WAA, the climateric peak occurred, with production of 165.93 mg CO_2kg/h.

These results are similar to the findings of Moraes *et al*. (2000) for the development of 'Ubá' mango in Visconde do Rio Branco, MG. They observed climacteric peak (91 mg CO_2kg/h) of fruits on the 23^{rd} week after flowering.

CONCLUSIONS

The process of development of mango cv. 'Ubá' in Visconde do Rio Branco took 23 weeks.

The developmental pattern fitted a simple sigmoidal model, with three stages of growth, from 1^{st} to 5^{th} WAA; 6^{th} to 15^{th} WAA; and 16^{th} to 23^{rd} WAA.

Fruits attached to the plant reached respiratory climacteric on the 21^{st} week after the anthesis.

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