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REVIEW

Relationships Between Physical–Chemical Parameters and Physiological Maturation Stages of Formosa Papaya Growing in a Tropical Semiarid Climate

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Abstract The objective of this study was to evaluate the physicochemical characteristics of 'Tainung 01' papaya fruit, identify its maturation stage, and recommend its commercial harvest point in a tropical semiarid climate. Fruits in different stages of development were harvested throughout the 4.5 months to evaluate their growth. After harvesting, the fruits were evaluated for their physicochemical characteristics. The experimental design used for the growth studies of the fruit was completely randomized, with five replicates, each repetition being composed of three fruits. It was verified that physiological maturity was reached at 130 days after effective fruiting (DAEF), with values of soluble solids > 11°Brix, which is considered ideal for fruit commercialization by the 'Formosa' cultivar. At 123 DAEF, the physical–chemical parameters indicated that the fruits had reached physiological maturity, but they remained green and shriveled when stored at room temperature.

Keywords *Carica papaya* L. · Fruit · Commercial maturation · Quality

Introduction

Papaya (*Carica papaya* L.) is a fruit species that originates in tropical America and is currently distributed and consumed worldwide. Brazil is the fourth largest producer of papaya in the world, with a production of 1,107,761 tons and an export volume of 39,834.61 tons in 2022 [5]. The fruit is consumed fresh, and it has excellent flavor and high nutritional value. Papaya is also a valuable source of antioxidants (vitamin C, carotenes, and flavonoids) that contribute to the reduction of cardiovascular diseases and some cancers, as well as an excellent source of minerals (calcium, potassium, and magnesium) and fibers [14, 17].

During fruit development, several biochemical processes occur that result in changes in the intrinsic properties of fruits, such as color, texture, taste, and aroma, along with changes in their external appearance (size, color, and shape) and nutritional value [20]. These properties strongly influence the production of commercially acceptable fruits [16] as well as their shelf life. In addition, a fruit with higher nutritional quality and an ideal harvest stage [1] guarantees greater food security, a critical global issue, and has a significant impact on reducing postharvest losses.

The timing of the harvest is one of the main parameters that determine the quality of fruits, both for local consumption and fruit export. The harvesting time should be determined using appropriate maturation indices, which include physical and chemical attributes that change during fruit

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Significance statement: This manuscript highlighted the main alterations of qualities parameters such as physical and chemical under semiarid conditions of 'Tainung 01" papaya during development, physiological maturation of fruit.

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maturation. When fruits are harvested at the correct time, the maximum nutritional quality is obtained, and the fruits are more tolerant to handling at harvest [9]. On the other hand, fruits harvested early or later have no good sensory or commercial quality.

Papaya is a climacteric fruit and should be harvested when it reaches physiological maturity [11]. Therefore, several characteristics or combinations (destructive or not) that can be used, such as soluble solid content or skin color, usually indicate the best harvest point for papaya fruits [20]. However, the degree of peel color under field conditions is a subjective estimate that can lead to errors such as harvesting physiologically immature fruit.

One way to avoid errors at the time of harvest is to associate quality indices such as skin background color and maturity indices such as firmness, soluble solid (SS) content, titratable acidity, soluble solids, fruit size, and weight [1]. However, for papaya, the main quality characteristic is the soluble solid content, which does not increase significantly after harvesting the fruit [16], given the low starch accumulation [7]. Furthermore, it is not known how much of the Formosa papaya produced in a semiarid tropical climate is harvested at the ideal maturity according to the postharvest destination and consumer quality requirements. However, it is known that plant growth under abiotic stresses, such as high temperatures in semiarid tropical climates, affects the growth and development of plants [15], which can affect fruit development.

Therefore, it is necessary to investigate the performance of the ’Tainung 01’ papaya under a tropical semiarid climate by assessing its quality parameters and shelf life. Thus, we hypothesize that high temperatures in semiarid environments can accelerate fruit development and can be monitored by the quality parameters of fruits. Hence, to reduce postharvest loss and extend the shelf life of fruits, the objective was to define the physiological maturation (using physicochemical parameters) minimum level that guarantees a satisfactory time for fruit commercialization.

Material and Methods

Plant Material

The experiment was conducted in a commercial orchard of papaya fruit at the company Frutacor in the municipality of Russia, CE (located at 20 m altitude, latitude 04° 56′ 25″ S, and longitude 37° 58′ 33′ W). The average temperature and relative humidity during the experiment were 29 ± 5 °C and 63 ± 5%, respectively. The total measured evaporation was 4.5 mm (My IrriWise-EB 1 total station). Papaya plants of the ’Formosa’ group and hybrid ’Tainung 01’ were five months of age and planted with a spacing of 2 m × 2 m. The field used in the experiment had an area of four hectares (ha) with an east–west orientation. The area was planted on March 19th, 2013, using certified seedlings from the company Top Plant (Mossoró-RN), which were arranged in 94 rows with a plant density of 1410 plants/ha. Before planting, the soil pH was corrected to close to 5.5–6.0 with four tons of dolomitic limestone. Fertigation was performed via a drip irrigation system (micro irrigation) with two drippers per plant spaced 40 cm apart at a flow rate of 1.5 L/ha. After five months of planting, 160 plants were chosen and randomized in the experimental area, and each plant, three hermaphrodite fertilized flowers with diameters varying from 1 to 1.5 cm (0 days after effective fructification), were marked for identification. In each leaf insert, one flower was selected, allowing one fruit at each leaf insertion. The marked fruits were harvested over the next 4.5 months for evaluation of their development.

The interval between fruit harvesting was weekly up to 28 days after effective fructification (DAEF). After 28 DAEF, fruit samples were collected every 15 days. Harvesting was carried out in the morning (7:00 a.m. to 8:00 a.m.), and after harvest, the fruits were packed in a monoblock coated with wet newspaper and transported to the laboratory for analysis (Fig. 1).

Fruit Size

The longitudinal and transverse lengths were measured using a digital caliper (Fowler Sylvac) with an accuracy ranging from 0.02 to 0.03 mm. The longitudinal length was measured from the insertion of the peduncle to the stigma scar. The transverse length was measured in the equatorial region. Both the thickness of the pulp and the diameter of the ovarian cavity were measured from a cross section performed in the middle region of the fruit. The average thickness of the pulp was determined by the average between the highest and lowest thicknesses of the pulp. The diameter of the ovarian cavity comprised the measurement of the line drawn between two points of the star.

Fresh Matter and Dry Matter

A semianalytical balance was used to obtain a total of 110 fresh matter samples from each fruit. Longitudinal cross sections of the fruits were cut to separate the seeds from the pulp. After this process, the rest of the fruit was dried in an oven at 70 °C until a constant weight was reached, after which the dry matter content of the fruit was determined.

Pulp Firmness

A Stable Micro Systems digital texturometer, model TA. XT2i with a 2 mm tip (for up to 28 days) and a 6 mm tip for

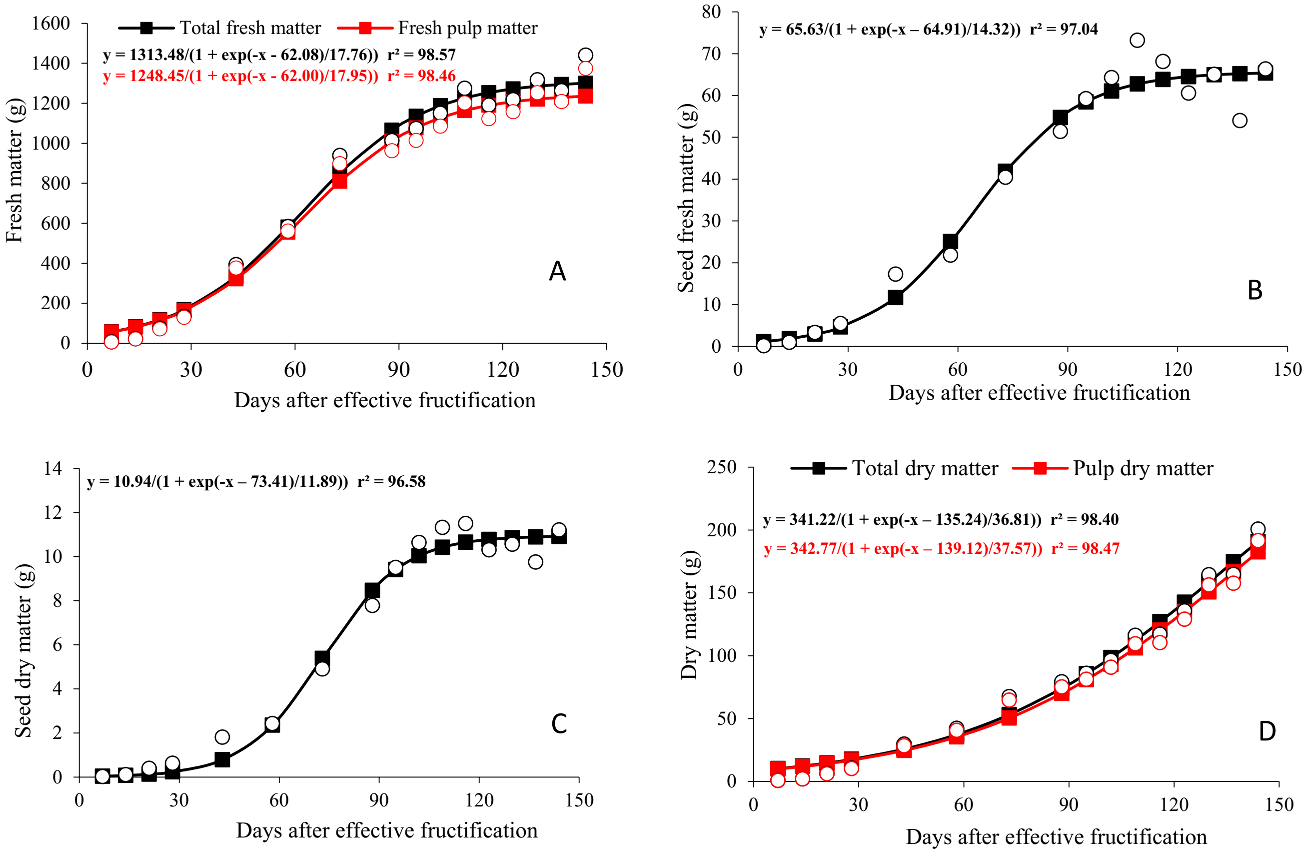


Fig. 1 Total fresh matter and pulp (**A**), seed fresh matter (**B**), seed dry matter (**C**), total dry matter and pulp (**D**) during the development of the papaya 'Tainung 01'

the other evaluations were used to determine the firmness of the pulp. The pulp was removed with a peeler at two distinct points in the region of greatest diameter. Considering that the pressure causing the rupture of the pulp is equivalent to the relation between the force applied on the tip and the area of the pulp, calculations were made to standardize the results obtained due to the use of different tips. The data are expressed in Kgf cm^{-2}, considering the average of the two readings.

Color Analyses

The color of the peel and pulp was determined by reflectometry using a CR-300 colorimeter (Konica Minolta®, Japan) calibrated on a white porcelain surface under lighting conditions. The readings were expressed in modules L, c, and h, which, according to the International Commission of L'Eclaraige (CIE), define the color: L, corresponding to brightness (0 = dark/opaque and 100 = White); C, chroma (0 = impure color and 60 = pure color); and h°, the hue angle (hue, 0° = red, 90° = yellow, 180° = green, 270° = blue). The measurements were performed at two equidistant points. The results are expressed as the hue angle (h°), considering the average of the two measurements.

After the physical evaluations, the edible pulp was extracted using a domestic centrifuge (RI model 6720 Philips-Wallita). Part of the extract was used for the immediate analysis of soluble solids; another part was 135 packed into film cups and stored in an Ultra1 freezer at −70 °C for further determination of total sugars and acidity. The peel and pulp wrapped in aluminum foil were also stored for determination of chlorophyll and carotenoids.

To evaluate the amount of chlorophyll in the peel, 1.0 g of peel was removed at several points equally distributed on the surface of the fruit. The tissue was macerated in a dark room in 7.0 mL of 80% acetone with washed sand. The extract was filtered on 'J Prolab' paper, with a porosity of 14 L s^{-1} m^{-2} 141 and diameter of 11.5 cm, protected against lightness, by wrapping the volumetric flasks with foil. The filter was washed twice with 7.0 mL of 80% acetone, and the volume was adjusted to 25 mL. The absorbances of the extracts were read in a spectrophotometer (Spectronic® GenesysTM 2) at wavelengths of 646.8 and 663.2 nm using quartz cuvettes. The contents of chlorophyll a (Ca), b (Cb), and total chlorophyll were determined according to the equations proposed by Lichtenthaler [13].

$$\text{chlorophyll } a\left(\text{ug.mL}^{-1}\right) = 12.25xA_{663.2} - 2.79xA_{646.8} \quad (1)$$

$$\text{chlorophyll } b\left(\text{ug.mL}^{-1}\right) = 21.5xA_{646.8} - 5.10xA_{663.2} \quad (2)$$

$$\text{Total chlorophyll } \left(\text{ug.mL}^{-1}\right) = 7.15xA_{663.2} - 18.71xA_{646.8} \quad (3)$$

$\text{Abs}_{663.2}$ and $\text{Abs}_{646.8}$: absorbances at their respective wavelengths.

For the transformation of the measured values in µg. mL^{-1} to µg. g^{-1}, this result was multiplied by 25 mL (volume of the flask) divided by the weight of the sample. The carotenoids in the peel were evaluated with the same extract and procedure, but the absorbance was measured at wavelengths of 646.8, 663.2, and 470 nm using the equation proposed by Lichtenthaler [13].

$$\text{Total carotenoids } \left(\text{ug.mL}^{-1}\right) = \left[1000xAbs_{470} - (1.82Ca - 85.02xCb)\right]/198 \quad (4)$$

For carotenoid determination in the pulp, the procedure was the same as that described for the peel, with approximately 3.0 g of pulp removed at several points in the middle region of the fruit.

Chemical Analyses

To determine soluble solids, a sample of the pulp of each repetition was processed in a centrifuge (model RI-6720 brand Philips-Walita). The juice was filtered on filter paper and evaluated in a digital refractometer model PR-101 pallet (Attago Co., Ltd., Japan) with a scale ranging from 0 to 45% and automatic temperature compensation. The results are expressed as percentages (%).

The titratable total acidity was determined in duplicate using an aliquot of juice (1 g), to which 50 mL of distilled water and three drops of alcoholic phenolphthalein (1%) were titrated using 0.1 N NaOH until it reached the turning point, characterized by the appearance of a pink color. The results are expressed as the percentage (%) of citric acid. For the determination of the rate of acidity, the following formula was used:

$$\text{Tritatable acidity}(\%) = 10xF_{\text{acid}}xF_{\text{NaOH}}xV_{\text{NaOH}}(\text{mL})/M(g) \quad (5)$$

F_{acid} = Correction factor obtained in the standardization of citric acid.

F_{NaOH} = Correction factor obtained in NaOH standardization.

V_{NaOH} = Volume spent on sample titration (ml).

M = pulp mass (g).

The total soluble sugars were determined using the Antrone reagent according to Yemn & Willis [28]. The extract was homogenized using 1 g of pulp and 50 ml of distilled water. This extract was filtered through filter paper into a volumetric flask, and the volume was adjusted to 250 ml with distilled water. From this solution, 500 µl (papaya for up to 21 days), 250 µl (papaya for between 28 and 73 days), 200 µl (papaya for 88 days), 150 µl (papaya for 95 days), 100 µl (papaya for between 102 and 123 days), and 50 µl (papaya for 130 days) were removed and deposited in screw-threaded test tubes, and 500, 750, 800, 850, 900, and 950 µl of distilled water were added to obtain a final volume of 1 ml. The tubes were placed in an ice bath to which 2 ml of anthrone was added, vortexed, and again placed in an ice bath and then in a water bath at 100 °C for 5 min. After the withdrawal of the water bath, the test tubes were returned to the ice bath to cool. The samples were read in a spectrophotometer at 620 nm. Calculations to obtain the total soluble sugar content were performed based on the following formulas:

$$\text{Result} = \frac{\text{weigh (g)}x\text{ aliquot (mL)}x\,1{,}000{,}000}{\text{Dilution (mL)}} \quad (6)$$

$$\%\text{sugar} = \frac{\text{concentration average } \times 100}{\text{Result}} \quad (7)$$

Postharvest Analysis

At 123 days after effective fruiting (DAEF), six fruits were collected to compose a sample of three replicates, each of which was composed of two fruits. These fruits were stored at room temperature (25 °C ± 2) and 60 ± 2% relative humidity (RH) for later verification of their ripeness. Analyses of pulp firmness, soluble solids, titratable acidity, and total soluble sugars were performed.

Experimental Design

A completely randomized design with five replications was used, with each repetition being composed of three fruits.

Statistical Analysis

The data were subjected to analysis of variance, and all analyses were performed through the SISVAR program [6]. The most appropriate equation was obtained as a function of R^2 (coefficient of determination), which is a function of the significance of the parameters of the equations and the regression deviations. Tukey's test was applied at a 5% probability for qualitative treatment (postharvest).

Results and Discussion

Fresh Matter and Dry Matter

The total fresh matter, pulp, and seeds followed a simple sigmoidal pattern characterized by rapid initial growth up to 88 days after effective fruiting (DAEF), followed by slow growth (Fig. 1A and B). The period of greatest increase in total fresh mass and fruit occurred from 28 to 88 DAEF, during which the total mass increased by 84.7% (Fig. 1A).

The initial rapid growth is the result of the process of expansion and multiplication of cells, which is most intense at the beginning of fruit development. The slower growth at 88 DAEF reflects a decrease in mass accumulation and consequently an increase in the maturation process [19].

The highest accumulation rate of fresh matter in the seeds also occurred from 28 to 88 DAEF, with an increase of 92.6% (Fig. 1B). Unlike pulp, which continued to accumulate mass up to 144 DAEF, the growth rate of the seeds virtually ceased at 123 DAEF (Fig. 1B). This behavior can be attributed to the fact that the seeds reached their maximum physiological development up to this period and thus stabilized the deposition of photoassimilates in their reserve tissues [21]. Generally, the seeds reach maturation more rapidly than other organs of the fruit.

Seed dry matter also followed a simple sigmoidal pattern, similar to that of fresh matter. However, the greatest accumulation occurred between 43 and 102 DAEF. At 102 DAEF, the seeds did not accumulate more dry matter (Fig. 1C). The mean values for weight, ranging from 1285 to 1300 g, were verified when the fruits reached physiological maturity at 130 DAEF. These values are considered satisfactory for the commercialization of the papaya cultivar "Formosa" [4].

The total and pulp dry matter also showed a sigmoidal growth pattern (Fig. 1D). For these variables, 50% of the total and pulp dry matter reached 102 DAEF. The other 50% of the accumulated total and pulp dry matter was formed between 109 and 144 DAEF. This increase in initial accumulation, with a decrease to the final stages of maturation, can be explained by the fruit ripening process, which is characterized by the depolymerization of complex carbohydrates (insoluble fiber) and an increase in sucrose and soluble sugar concentrations. First, fruits drain high amounts of insoluble photoassimilates, increasing their weight rapidly. After this process, the maturation process involves the conversion of insoluble carbohydrates to soluble sugars without high rates of mass accumulation [26].

Although fresh matter reaches good values for the market at 88 DAEF, the dry matter accumulation of fruits is very low at this time (approximately 54 g). Thus, periods less than 88 DAEF are not recommended for the harvesting of the papaya cultivar "Formosa," as during this period, the fruits are likely to have a high water content and low carbohydrate content.

Fruit Dimensions

The fruits showed a high growth rate in length (transversal and longitudinal) up to approximately 73 DAEF, followed by a slow growth phase between 73° and 102° (Fig. 2A). After these phases, the increase in length stabilized, indicating that the final size of the fruit was reached at 102° DAEF (Fig. 2A). A greater increase was observed for transverse length (Fig. 2A). This growth behavior allows the elongated shape of the papaya fruit, which is commonly preferred by the consumer market. Therefore, for fruit shape, the most important period is between 0 and 102 DAEF, and it is necessary to adopt practices that avoid any biotic or abiotic stress that affects papaya growth.

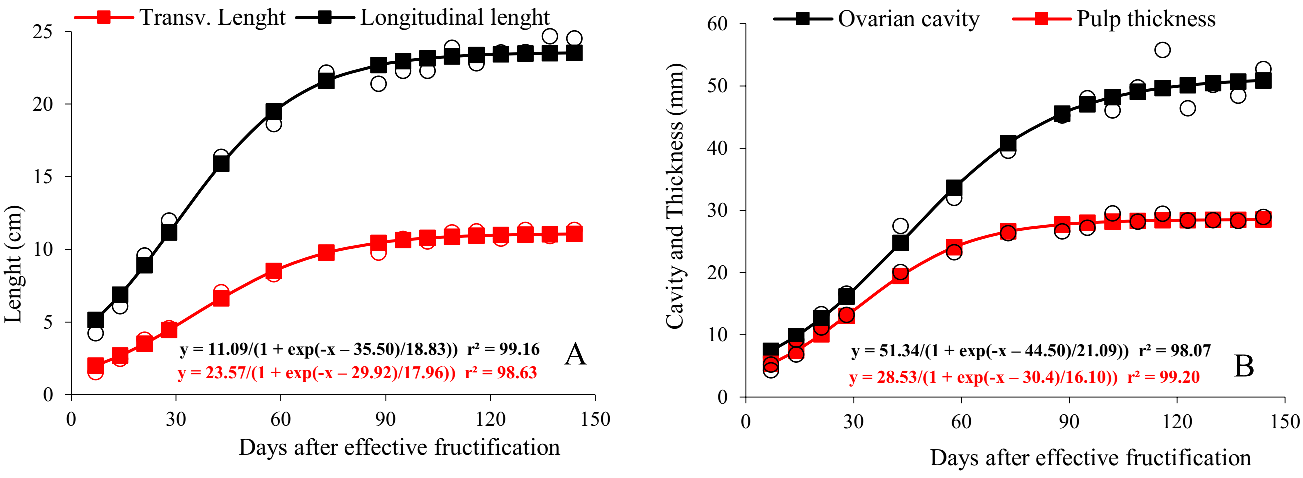


Fig. 2 Transverse and longitudinal length (**A**), ovarian cavity and thickness of pulp (**B**) during the development of the papaya 'Tainung 01'

The longitudinal and transverse lengths (23.56 and 11.06 cm, respectively) observed in this study are approximately 25.60 cm and 10.95 cm greater than those found in the ’Tainung 01’ papaya by Júnior et al. [12]. Berilli et al. [2] reported that higher temperatures in the growing environment favor the development of more long and smaller-diameter papaya fruits. These conditions are characteristic of semiarid regions; similar to those measured in this experiment, these conditions may have contributed to the optimal values observed for the papaya cultivar ’Tainung 01’.

An increase in the stability of the ovarian cavity (45.25 mm) and pulp thickness (27.74 mm), such as transversal and longitudinal lengths, was observed at 102 DAEF (Fig. 2B). These parameters are associated with the inner shape of the papaya, so it is possible to assume that until 102 DAEF, papaya harvesting should not be carried out due to incomplete formation of the fruit shape.

Pulp Firmness

The pulp firmness decreased by 68.7% after 144 DAEF (Fig. 3). There was an accentuated reduction in the pulp firmness of papaya fruit until 85 DAEF, after which the variations in softening were less pronounced in the pulp tissues. According to Yao et al. [27], the loss of firmness in papaya fruits is associated with the high activity of enzymes such as cellulase, pectin methylesterase, and polygalacturonases, which degrade polysaccharides of the cell wall, such as cellulose, hemicellulose, and pectin. Furthermore, for enzymatic degradation of the cell wall, loss of firmness in papaya is associated with respiratory activity [17], synthesis, and ethylene action. The lower reduction after 85 DAEF may be caused by the lower substrate concentrations required for the enzymatic reactions [27]. The change in pulp firmness during the ripening of papaya is the main factor used to indicate fruit maturation; however, it is necessary to associate pulp firmness with other fruit properties to ensure the quality of the product at the moment of harvesting [16].

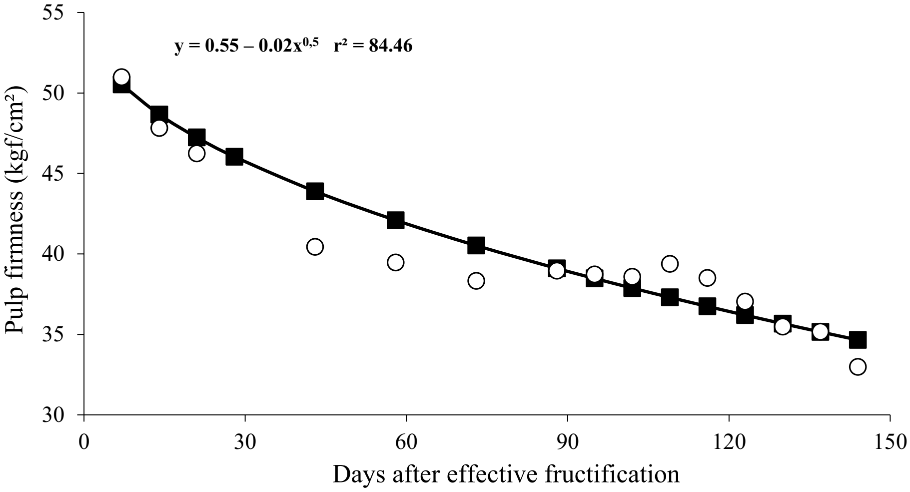
Color and Pigments of the Peel and Pulp

The intensification of the green color in the fruit peel, measured by hue (°h), was accompanied by an increase in the amount of chlorophyll and carotenoids in the peel for up to 88 days (Fig. 4A and B). The coloration of fruits at 88 days after effective fruiting presented a mean hue angle of 128°, corresponding to a dark green color in the peel (Fig. 4A). The chlorophylls and carotenoids of the peel also showed a slight initial increase, reaching the maximum concentration at 88 days, with values of 451.14 and 212.33 µg g^{-1}, respectively (Fig. 4A and B). However, from this period, there was a change from dark to light green, as indicated by a reduction in hue angle (Fig. 4A).

The green color of the papaya peels is caused by an increase in the chlorophyll concentration in the fruits. This pigment is mainly responsible for the green color of different plant organs. Generally, tissues that are green in color are photosynthetically active. The increase in the chlorophyll content of the peel until it reached a dark green color may be related to the synthesis of the photoassimilates necessary for the initial days of fruit development. This tissue of fruit can produce carbohydrates and transport them to pulp cells, providing the primary energy resource for the initial growth of cells [18]. The deposition of photoassimilates from the peel may decrease as soon as other organs, such as leaves, provide the necessary sugars for the final growth and development of the papaya fruits.

The change in the peel color from dark to light green after 88 DAEF was due to the reduction in chlorophyll and carotenoid concentrations in the peel. This is caused by the degradation of chlorophyll and synthesis of lycopene [24], a

Fig. 3 Pulp firmness during the development of the papaya ’Tainung 01’



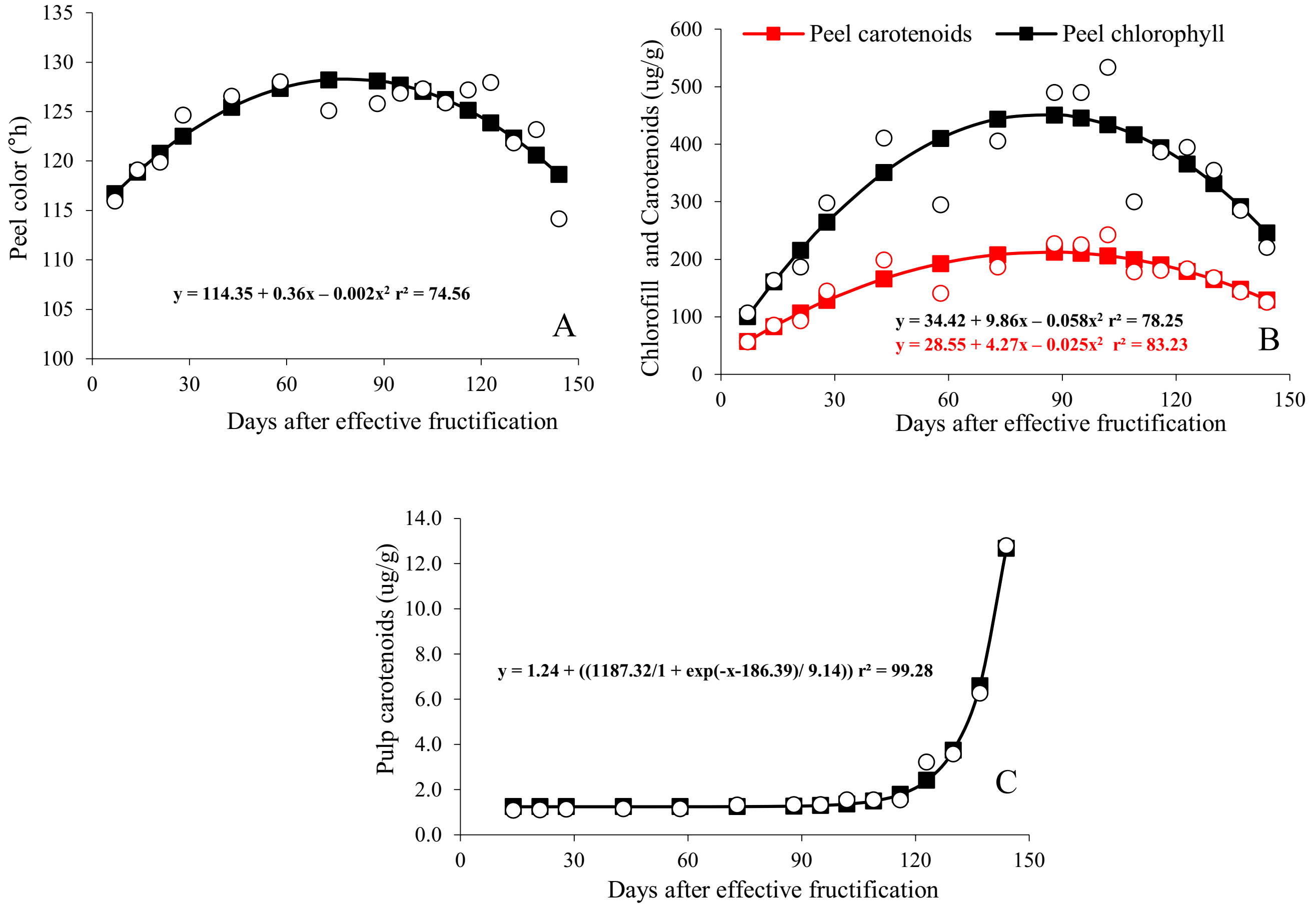


Fig. 4 Peel color (**A**), chlorophyll and carotenoids in the peel (**B**), carotenoids in the pulp (**C**) during the development of the papaya ’Tainung 01’

phenomenon that has been observed in several fruits, which changes the color of the peel from green to red. Chlorophyll degradation can occur due to three factors, either individually or concomitantly, and is associated with the oxidation of chlorophyll [29]. Changes in pH (organic acid leakage of vacuoles), oxidative systems, and chlorophylls are processes in fruits that promote the conversion of chlorophyll to lycopene or other red–yellow pigments [8]. These mechanisms increase in intensity as the process of breathing and maturation progresses at 88 DAEF for the papaya ’Tainung 01.’

At 130 DAEF, the fruit presented a hue angle of 122° (Fig. 4A), which corresponds to the aspect of the fruit most used as a harvesting point for commercialization, thus indicating physiological maturity. Barragán-Iglesias et al. [1] reported that the harvest period begins when the first fruits reach physiological maturity or exhibit color breakage of the epicarp. This phase for papaya ’Tainung 01’ cultivated in the semiarid region of Northeast Brazil started at 130 DAEF, with a chlorophyll concentration close to 331.4 µg/g.

The pulp pigments increased significantly after 109 DAEF (Fig. 4C). The increase in the carotenoid content at 144 DAEF was 8.45 times greater than that at 109 DAEF and 10.22 times greater than that at 14 DAEF, showing that there was no carotenoid synthesis between 14 and 109 days. The increase in the carotenoid content of the pulp coincided with the development of yellow coloration of the peel at 130 days (Fig. 4A), representing approximately 29.4% of the total accumulated carotenoids, which was 12.68 µg/g at 144 DAEF. From 109 DAEF, the pulp began to acquire pink coloration at the periphery of the fruit cavity, and this coloration intensified from then on. At 130 days, the hue angle decreased by almost 50%, reaching 56°, corresponding to yellow-orange coloration. Schweiggert et al. [24] reported a color change of 50° in the pulp during the intermediate stage of maturation, with areas of green and yellow color. This marked increase after 130 days indicates the possibility of physiological maturity.

The increase in the carotenoid content of pulp from 109 DAEF may be a result of the synthesis and accumulation of carotenoids throughout the stage of fruit development.

According to Chan-León et al. [3], the pulp of papaya fruits becomes more reddish during ripening, mainly due to the accumulation of the carotenoids lycopene and β-cryptoxanthin. According to Tripathi et al. [25], the variability at the point of maturation may contribute to a wide range of differences in vitamin A (or carotenoid) levels in papaya fruits. Martins et al. [14], evaluating different papaya cultivars, reported that total carotenoid levels increased from 3.52 to 14.74 µg/g in cv. 'Sunrise Solo' and from 5.11 to 14.59 µg/g in cv. 'Golden,' corresponds to stage 1 (up to 10% yellow peel) and stage 7 (75% to 100% yellow peel), respectively.

A high concentration of carotenoids in papaya fruits is of special interest because they have been reported to have potent health-protective benefits, ensuring certain functional properties of this food for human health. Carotenoids are powerful antioxidants capable of preventing many types of cell damage caused by reactive oxygen species (ROS) [23]. Therefore, the harvest of papaya fruits with relatively high concentrations of carotenoids is important for guaranteeing the benefits of the fruit in the human diet. The 'Tainung 01' papaya cultivated under abiotic stress (in a tropical semiarid climate) exhibited increased biosynthesis and accumulation of carotenoids in the pulp, mainly from 109 to 130 DAEF.

Soluble Solids, Total Soluble Sugars, and Titratable Acidity

The percentage of soluble solids (SS) was constant (5.1%) until 109 DAEF (Fig. 5A). After this period, an exponential increase was observed, reaching 11.24% at 130 DAEF (Fig. 5A). The Papaya Technical Regulation establishes a minimum value of 11° Brix for papaya harvesting (Brazil, 2010). The total soluble sugars in the papaya fruits increased

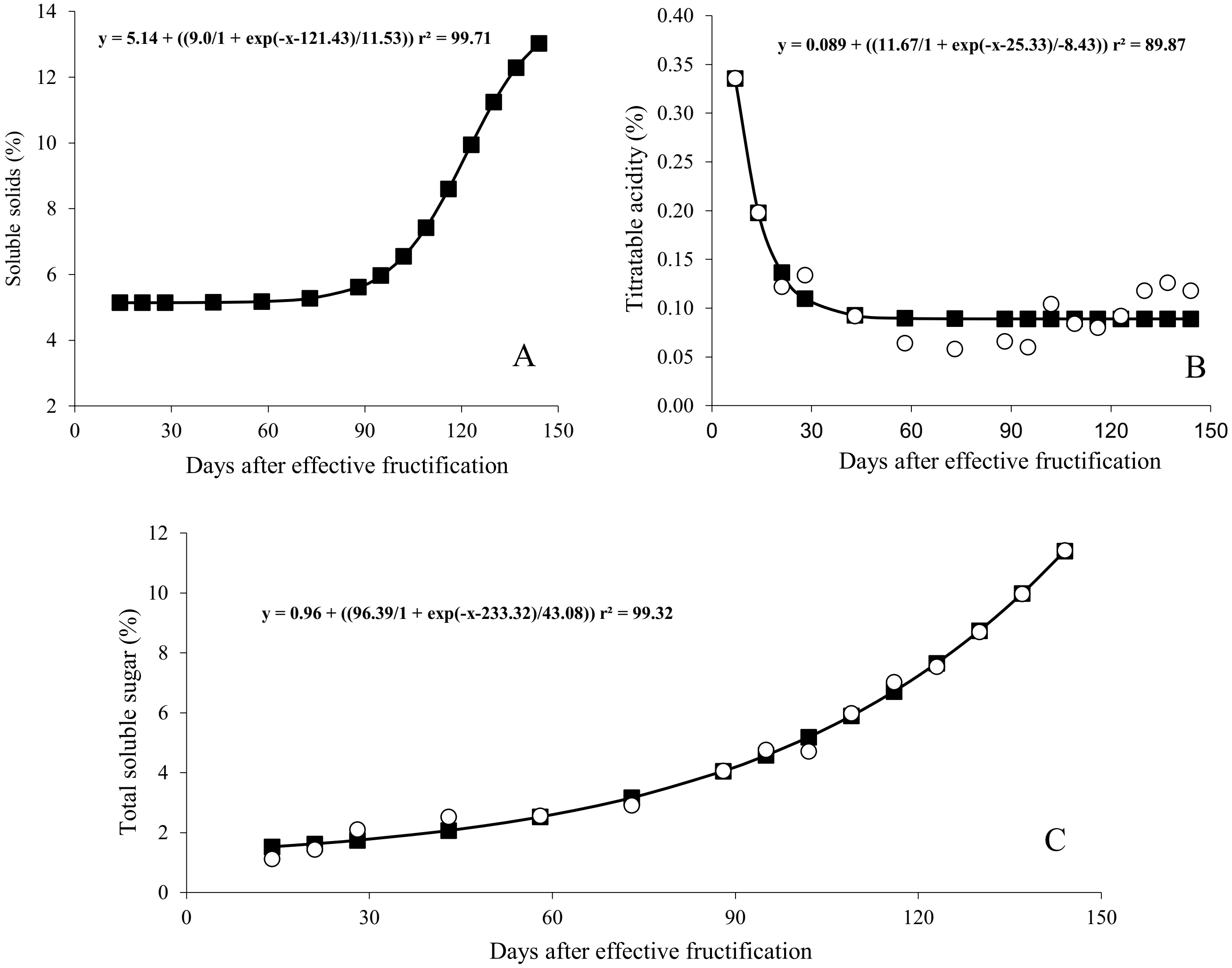


Fig. 5 Percent (%) soluble solids (**A**), total soluble solids (**B**), and titratable acidity (**C**) of the pulp during the development of the papaya 'Tainung 01'

from 14 (1.12%) to 144 (11.42%) DAEF (Fig. 5B). At 130 DAEF, the total sugar content of fruits (8.7%) corresponded to 77.4% of the soluble solids (11.2%), and 76.3% of the total soluble sugars accumulated at 144 DAEF (11.4%) (Fig. 5B). The titratable acidity decreased from 7 to 73 DAEF, representing a value of 0.089% (Fig. 5C). After 73 DAEF, the acidity remained constant until maturation at 130 DAEF (Fig. 5C).

The reduction in the titratable acidity of the pulp up to 73 DAEF may be associated with two factors: the conversion of these organic acids, mainly citric, malic, and fumaric acids, to sugar and other derivatives and the use of these acids as respiratory substrates [17]. Although organic acids are transformed into soluble sugars in some fruits, for the papaya to cultivate ’Tainung 01,’ the process of converting acids into sugars does not occur simultaneously. It is possible that the organic acids in papaya fruits cultivated in ’Tainung 01’ may initially contribute to the respiratory reactions that over time will affect the degradation of structural polysaccharides, thus increasing the levels of soluble solids in the fruit [10].

The taste of papaya fruit is characterized by a balance between soluble solids and acidity, and those with high sugar content and low acidity are preferred by the consumer market [1]. This characteristic of the fruit varies according to cultivar, climatic and soil conditions, and agricultural management practices [22]. Therefore, for the conditions of this semiarid region of the Brazilian Northeast Region, these characteristics only occurred in the fruits harvested at 130 DAEF. The time of greatest accumulation of soluble solids and lower acidity coincided with the time when the color of the peel reached the yellowish hue commonly used to indicate the harvest point.

Storage of Fruits

The firmness of the pulp at 130 DAEF was greater than that at 144 DAEF when the fruits were stored for seven days at 25 ± 2 °C and 60 ± 2% RH (Table 1). On the other hand, the soluble solids and titratable acidity were lower at 130 DAEF than at 144 DAEF (Table 1). There was no difference in the total soluble sugar content in the stored fruits (Table 1). Thus, fruits stored at temperatures of 25 ± 2 °C and 60 ± 2% RH from 130 DAEF presented optimal consumption characteristics, such as pulp firmness, soluble solids, titratable acidity, and total soluble sugars. At seven days of storage, more than 75% of all fruits had yellow pulp. Fruits stored for periods before 130 DAEF did not ripen, remaining green and shriveling due to the loss of water from fruit tissues. This finding is consistent with the results obtained for the analyzed variables, which showed that physiological maturity, or the ideal harvest point, occurred only 130 days after effective fructification.

Table 1 Firmness of pulp (FP), soluble solids (SS), titratable acidity (AT), and total soluble sugars (TSS) of Formosa papaya ’Tainung 01’ as a function of the harvest period after seven days of storage at room temperature (25 ± 2 °C) and 60 ± 2% RH

Days until harvest	Average FP ($kgf.mm^{-2}$)	SS (%)	TA (%)	TSS (%)
130*	0.065a[1]	12.67a	0.11a	9.74a
137	0.046ab	13.67ab	0.13ab	11.09a
144	0.034b	14.33b	0.16b	11.55a

*After the indicated days, the fruits remained at room temperature (25 ± 2 °C) and 60 ± 2% RH for seven days

[1] Means followed by the same letter in the column do not differ according to the Tukey test at the 5% probability level

Conclusions

The physical and physicochemical properties are influenced during fruit development. At 88 DAEF, the fresh matter and the transverse and longitudinal length of the papaya already had weight and shape, respectively. Furthermore, it was verified that color and firmness could determine the ideal harvest point at which ‘Tainung 01’ papaya produces relatively high concentrations of carotenoids, soluble solids, and total soluble sugars. These nutritional characteristics of papaya ’Tainung 01’ grown in a semiarid tropical climate are optimal at 130 DAEF, when physiological maturity is reached, and the peel becomes yellowish (56°) and has a firmness equivalent to 0.37 kgf/mm^2.

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Declarations

Conflict of interest There is no conflict of interest.

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