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Scientific Article

Physiology and quality during maturation of fruits of umbuzeiro genotypes

Fisiologia e qualidade durante a maturação de frutos de genótipos do umbuzeiro

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ABSTRACT – *Spondias tuberosa* fruits are extractively exploited and its use viability is dependent on factors such as occurrence, ripening, and maturity at harvest, which influence quality and contribute to increased perishability. This study evaluates the physiology and quality changes during maturation of fruits of umbuzeiro genotypes from the states of Paraiba and Pernambuco. Fruits from 16 umbuzeiro genotypes were harvested at three maturity stages in the municipalities of Casserengue–PB and Brejo da Madre de Deus-PE. The experiment was conducted using a completely randomized design, adopting a 16 × 3 factorial scheme with 16 genotypes, three maturity stages, and four replications per plant. Umbu fruits have a typical climacteric respiratory pattern, with the respiratory peak onset being dependent on the maturity stage at harvest, and fruit firmness being a maturity indicator. PB2, PE11, PE12, PE13, PE14, and PE16 fruits had a more intense peel color. Among these, PE11, PE12, and PE14 fruits were of greater size and fresh mass when ripe, exceeding approximately 50% of the mean values reported in the literature, and PE15 and PE9 had the highest pulp yield. Among the 16 genotypes, nine had lower acidity content, which adds value to fresh consumption when harvested at green yellowish and yellow greenish maturity stages. The soluble solids content of green yellowish and yellow greenish fruits from all genotypes were higher than those set by the Brazilian Identity and Quality Standards, which is 9.0%.

Keywords: *Spondias tuberosa*. Respiratory rate. Maturity evolution. Identity standard. Adding value.

RESUMO – O fruto do umbuzeiro é explorado extrativamente e sua viabilidade de uso depende de ocorrência, amadurecimento e maturidade na colheita, que influenciam a qualidade e contribuem para o aumento da perecibilidade. Nesse contexto, este trabalho teve como objetivo avaliar as alterações fisiológicas e de qualidade durante a maturação de frutos de genótipos de umbuzeiro dos estados da Paraíba e Pernambuco. Frutos de 16 genótipos de umbuzeiro foram colhidos em três estádios de maturação nos municípios de Casserengue - PB e Brejo da Madre de Deus - PE. O experimento foi conduzido em delineamento inteiramente casualizado, em esquema fatorial 16 x 3, com 16 genótipos, três estádios de maturação e 4 repetições/planta. O umbu apresenta padrão respiratório típico de frutos climatéricos, cujo pico respiratório é dependente do estádio de maturação na colheita, com base na firmeza do fruto como indicador de maturidade. Frutos maduros de PB2, PE11, PE12, PE13, PE14, PE16 possuem coloração da casca mais intensa e, dentre estes, os do PE11, PE12 e PE14 foram de maior tamanho e massa fresca, quando maduros, superando em cerca de 50% a média da literatura e PE15 e PE9 apresentam maior rendimento em polpa. Dentre os 16 genótipos avaliados, nove apresentaram teor de acidez mais baixo, que agrega valor para consumo fresco quando colhidos nos estádios de maturação verde amarelado e amarelo esverdeado. Os sólidos solúveis de frutos verde amarelados e amarelo esverdeados de todos os genótipos avaliados foram superiores ao estabelecido pelo Padrão de Identidade e Qualidade, que é 9%.

Palavras chave: *Spondias tuberosa*. Taxa respiratória. Evolução da maturação. Padrão de identidade. Agregação de valor.

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INTRODUCTION

Umbu (*Spondias tuberosa* Arruda Camara) a threatened tree of the Brazilian Caatinga (MERTENS et al., 2017) is a fruit tree endemic to the semiarid region of Brazil that belongs to the Anacardiaceae family (MATOS et al., 2020). Its fruit production even in the extractive form reached approximately 14,200 t in 2022, with harvested areas being scattered throughout the northeast and north of the state of Minas Gerais mainly in Bahia (5,753 t), with Paraiba producing 1,870 t and Pernambuco producing 443 t (IBGE, 2024).

Changes of the biometrics (COSTA et al., 2015) and fruit quality of the *Spondias* genus have been extensively studied (DANTAS JÚNIOR, 2008; DANTAS et al., 2016; MARQUES; FREITAS, 2020). Such studies have focused particularly on the aspect of quality due to the associated high economic potential especially for small-scale farmers. The socioeconomic potential of *Spondias* fruits has been recognized not only with regard to nutrition but also from a functional perspective, as they are rich in bioactive compounds with notable antioxidant properties (CANGUSSU et al., 2021; GUALBERTO et al., 2021; RIBEIRO et al., 2019; NEVES et al., 2015). These bioactive compounds can be considered as functional discriminants that add even more value to these fruits (SOUSA et al., 2021). Moreover, the incipient operating system currently available, and associated with the great variability among plants (SANTOS et al., 2021) constitutes a challenge when it comes to organizing the umbu production chain especially in the states of Pernambuco and Paraiba. Thus, for breeding programs to use promising matrices to develop productive and profitable varieties, are necessary previous studies describing matrices with highlighted quality characteristics.

Much of the umbu production of municipalities of Paraiba and northeast Pernambuco is still lost during the harvest because of inadequate marketing planning, due to the extractive exploitation (XAVIER et al., 2022; PEREIRA et al., 2021) as well as because of high fruit perishability, with fruits lasting only up to three days postharvest at room conditions (MOURA et al., 2013). From the beginning of maturation to full maturity and early senescence on the plants, the ripening process of *Spondias* fruits is very fast (TEODOSIO et al., 2021; DANTAS et al, 2016). Therefore, knowledge on the fruit maturation physiology and postharvest maturation changes is necessary to establish maturity indices applicable to harvest and postharvest conservation techniques, and minimize postharvest losses (YAHIA, 2019). During fruit ripening, physiological changes promote the development of suitable aroma, flavor, and appearance particularly peel color (PAREEK, 2016). Therefore, maturity at harvest is a key feature closely related to the postharvest life of the fruit (TEODOSIO et al., 2021). Although the color of umbuzeiro fruits during ripening is highly variable, not all genotypes turn yellow when ripe (LIMA; SILVA; OLIVEIRA, 2018).

Besides the changes during maturation, the quality characteristics of *Spondias* fruits can be influenced by many other factors, including genetics (SANTOS et al., 2021; SOLORZANO-MORÁN et al., 2015) and plant location (COSTA et al., 2015). The quality attributes of fruits from other *Spondias* species as well as the changes resulting from the maturation process have been extensively evaluated (TEODOSIO et al., 2021; DANTAS et al., 2016; MOURA et al., 2013). However, studies describing the maturation physiology and maturity evolution of umbu fruits are not available in the literature, and consistent data on the quality features are scarce especially when considering the changes of fruits of different genotypes during maturation. Thus, this study evaluates the physiology and quality changes during maturation of fruits of umbuzeiro genotypes.

MATERIAL AND METHODS

A total of 16 umbuzeiro (*Spondias tuberosa* Arruda Camara) genotypes were selected and previously georeferenced, whose ten (PB1, PB2, PB3, PB4, PB5, PB6, PB7, PB8, PB9, PB10) were located at municipality of Casserengue – PB and six (PE11, PE12, PE13, PE14, PE15, PE16) in the municipality of Brejo da Madre de Deus- PE. At harvest, the plants were separated into quadrants (four replications) and the fruits harvested early in the morning from these previously selected genotypes. After harvest, fruits were transported in styrofoam cooler boxes, and in the laboratory were selected for uniformity and quality, and classified in three maturity stages (green, green yellowish, and yellow greenish) (Figure 1).

The experiment was conducted using a completely randomized design, adopting a 16 × 3 factorial scheme with 16 genotypes and three maturity stages. For the physical evaluations, 80 fruits were used for each genotype and maturity stage, with each fruit representing a replicate. For the physicochemical evaluations, four replicates comprising 20 fruits were used.

Respiratory activity was evaluated under room conditions (24 ±2 °C and 72 ±2% RH) 12 h after harvesting the fruits, while conducting four replicates (@250 g/ replication) in 1,450-mL airtight jars. To evaluate the respiratory activity, mean samples of fruits of different genotypes were obtained for each maturity stage based on peel color and mean firmness (29.77 N = green); 18.57 N = green yellowish; 11.29 N = yellow greenish) (Figure 1). The samples were continuously ventilated using a dehumidified and CO_2-free air supply at a flow rate of 10 $mL.min^{-1}$. The system was closed for 1 h to collect CO_2 samples using a syringe and 1.0 mL was injected into a CO_2 analyzer (CA-10; Sable Systems, USA) coupled to an integrator. The CO_2 production ($mL\ CO_2.kg^{-1}.h^{-1}$) was obtained by comparing with the standard of 2.5% CO_2 (DANTAS et al., 2016).

The color parameters were measured in the day of harvest, immediately after classifying fruit ripeness, in parallel with measuring firmness. The evolution of peel color was evaluated through objective evaluation with the Minolta digital calorimeter, which expresses the color parameters: *L* * (corresponding to the light / brightness); *a* * (defines the transition from green (-*a* *) to red (+ *a* *) b * (represents the transition from blue (-*b* *) to yellow (+ *b* *), so that the farther from the center (= 0), the more saturated the color. Subsequently these parameters (*L*, *a* * and *b* *) were used to calculate the color index (CI) which indicates the degree of green variation / yellow of fruit according to the Equation 1 proposed by Motta et al. (2015):

$$IC = 2000 * (a *) / L * (\sqrt{} (a *) 2+ (b *) 2 \qquad (1)$$

It was determined: length and diameter (mm) with the aid of digital caliper measurements obtained in the perpendicular and parallel directions to the central axis of the fruit; fresh fruit weight (g) by weighing individual fruit on a semi-analytical scale; the firmness of the intact fruit (N), using the Magness Taylor Pressure Tester penetrometer, the insertion region of 2/16 inch diameter expressed in Newton; and the pulp and peel percentage, the total fruit weight, weighing each individual portion using a semi-analytical scale, to then calculate total fruit weight using a simple ratio.

The hydrogen-ionic potential (pH), titratable acidity (TA - g citric acid 100 g^{-1} pulp), soluble solids (%) and total soluble sugars, reducing sugars (g glucose $100g^{-1}$), and non-reducing sugars (g 100g $sucrose^{-1}$), was calculated according to the Adolfo Lutz Institute methodology – IAL (2008). The SS / TA ratio was calculated by simple division between soluble solids and titratable acidity.

It was conducted variance analysis (ANOVA) and the Tukey test ($p \geq 0.005$) to compare the maturity stage means and the Scott–Knott test ($p \geq 0.005$) to compare the genotype means using the Sisvar software, version 5.2 (FERREIRA, 2007). Principal component analysis (PCA) was performed to identify the most significant variability characteristics among the genotypes. Cluster analysis was used to group the genotypes with high similarities in relation to the analyzed characteristics. For the analysis, we used the SAS 9.3 software (2011).

RESULTS AND DISCUSSION

Considering the mean samples of fruits from of the evaluated genotypes, based on peel color and mean firmness at harvest, it was shown here for the first time that umbuzeiro (*Spondias tuberosa* Arr. Cam.) fruits present a respiratory pattern typical of climacteric fruits, with the respiratory peak depending on the maturity stage at harvest (Figure 1) and with firmness being as a maturity indicator. Upon reaching the climacteric, the color of the umbu fruits was predominantly yellow, albeit still with strong green traces. The respiratory peak of fruits harvested at the green maturity stage (mean firmness at harvest = 29.77 N) was reached 108 h after harvest and was 35.69 mg CO_2.Kg^{-1}. h^{-1}. At the green yellowish maturity stage (mean firmness = 18.57 N), the respiratory peak was 36.07 mg CO_2.Kg^{-1}. h^{-1} 60 h after harvest. Furthermore, at the first reading at the yellow greenish stage (mean firmness = 11.29 N), taken approximately 12 h after harvesting, the fruits reached the maximum CO_2 production (43.89 mg CO_2.Kg^{-1}·h^{-1}), which then declined in the subsequent hours. This pattern indicates that at this last maturity stage, the climacteric maximum had already been reached probably when the fruits had a mean firmness of approximately 13-14 N. For fruits of other *Spondias* species, Dantas et al. (2016) reported that umbuguela (*Spondias* sp.) also followed a respiratory pattern typical of climacteric fruits.

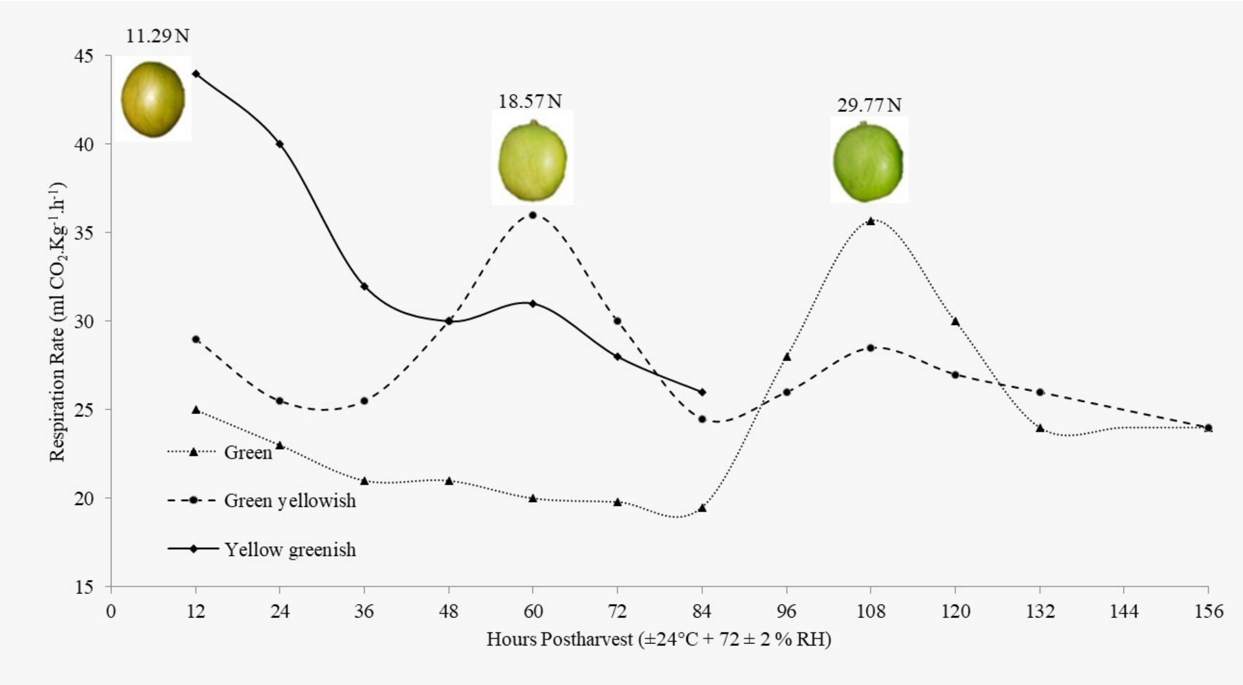


Figure 1. Postharvest respiratory rate (n=4) at room conditions (24 ± 1°C 72 ±2% RH) of a mean sample of umbu fruits (*Spondias tuberosa* Arruda Camara), harvested from different genotypes, at green (mean firmness at harvest = 29.8N), green yellowish (mean firmness = 18.6N), and yellow greenish (mean firmness = 11.3N) maturity stages, respectively. The picture of fruit shows the peel color (maturity stages) with its respective mean firmness at harvest.

The color parameters of the umbuzeiro fruit peel showed marked differences both in terms of the maturation process and among the genotypes. With advancing maturity, the *L** and *b** color parameters of the umbu peel did not change significantly. However, for fruits of the PB5, PB6, PB7, PE11, and PE15 genotypes, *L** decreased as maturity advanced, irrespective of the harvest location. In contrast, the *a** color parameter increased, reaching values close to zero and was positive in the most advanced stage, indicating the loss of green color in the final maturity stages (Table 1).

For the *a** color parameter, the Brejo da Madre de Deus genotypes (PE11, PE12, PE13, PE14, PE15, and PE16) showed positive values due to fruits with no green color when fully mature (yellow greenish maturity stage), as commonly observed for umbu genotypes. Therefore, these umbuzeiro fruits present a light green (*a** = -2.83 at the green stage) to light yellow (*b** = 35.36 at the yellow greenish stage) color variation, with few changes in peel brightness being evident (see the *L** parameter mean) (Table 1).

For the umbu peel color index (Figure 2), the same color transition trend was observed, exhibiting a variation in color with advancing maturity; this was not the case for the PB9 fruits, which did not lose their green color. Genotypes with ripe (yellow greenish) fruits showing more pronounced changes showed also a more intense yellow color without green traces when ripe (mainly PB2, PE11, PE12, PE14, PE15, and PE16), as characterized by the positive values of the CI-Peel index observed for this maturity stage.

Table 1. Color evolution (green, green yellowish, and yellow greenish) during ripening, expressed through the lightness (*L**), *a**, and *b** color parameters of fruits from umbuzeiro (*Spondias tuberosa* Arruda Camara) genotypes from Paraiba (Casserenge - PB) and Pernambuco (Brejo da Madre de Deus - PE) states.

Genotype	*L**			*a**			*b**		
	Green	Green Yellowish	Yellow Greenish	Green	Green Yellowish	Yellow Greenish	Green	Green Yellowish	Yellow Greenish
PB1	41.46 Ca	41.60 Ca	41.11 Ca	-4.28 Dc	-2.30 Eb	-0.94 Ea	36.72 Ba	35.20 Cb	34.66 Cb
PB2	41.73 Cb	43.46 Ba	41.90 Bb	-1.06 Ab	-0.71 Cb	2.58 Ba	34.99 Cc	39.99 Aa	36.89 Bb
PB3	42.93 Ba	42.20 Ca	42.85 Ba	-2.59 Bc	-1.18 Db	1.07 Ca	36.59 Ba	37.25 Ba	36.53 Ba
PB4	37.69 Eb	40.21 Da	39.83 Da	-3.42 Cb	-0.72 Ca	-0.97 Ea	32.78 Dc	35.67 Cb	38.69 Aa
PB5	39.67 Da	38.14 Eab	37.34 Eb	-3.77 Db	-3.51 Fb	-1.28 Ea	36.34 Ba	33.92 Db	35.35 Ca
PB6	44.54 Aa	42.51 Cb	41.36 Cb	-3.29 Cc	-1.46 Db	1.01 Ca	36.51 Ba	35.75 Ca	35.18 Ca
PB7	44.06 Aa	43.56 Bab	42.26 Bb	-2.98 Cb	-2.82 Fb	-1.20 Ea	36.48 Ba	36.77 Ba	36.36 Ba
PB8	42.45 Bb	43.80 Ba	43.56 Bb	-3.21 Cb	-2.08 Ea	-1.15Ea	39.56 Aa	39.22 Aa	35. 86 Ba
PB9	39.87 Da	39.98 Da	39.24 Da	-2.81 Ca	-2.99 Fa	-2.80 Fa	33.13 Da	32.95 Da	32.72 Da
PB10	41.94 Ca	39.24 Db	40.86 Ca	-2.98 Cb	-2.37 Eb	0.17 Da	36.02 Bab	36.87 Ba	34.97 Cb
PE11	45.27 Aa	42.76 Cb	42.76 Bb	-0.99 Ac	2.32 Ab	3.69 Aa	34.75 Cb	36.29 Ca	34.89 Cb
PE12	42.93 Ba	42.04 Ca	42.53 Ba	-2.58 Bc	-0.70 Cb	1.74 Ca	34.23 Ca	33.50 Dab	32.55 Db
PE13	41.54 Cb	43.89 Ba	43.95 Ba	-4.63 Db	-2.42 Ea	0.18 Da	39.20 Aa	35.66 Cb	38.69 Aa
PE14	44.94 Aa	45.20 Aa	45.25 Aa	-2.27 Bc	-0.57 Cb	2.72 Ba	35.76 Ba	35.99 Ca	35.92 Ba
PE15	41.52 Ca	37.36 Eb	35.91 Eb	-2.52 Bc	0.61 Bb	2.80 Ba	36.78 Ba	34.87 Cb	33.21 Dc
PE16	42.54 Ba	42.71 Ca	42.18 Ba	-1.94 Bc	0.82 Bb	4.01 Aa	36.53 Ba	37.60 Ba	37.15 Ba
Mean	42.19 a	41.79 a	41.10 a	-2.83 c	-1.25 b	0.90 a	36.02 a	36.09 a	35.36 a
Minimum	33.15	27.40	31.00	-7.95	-6.35	-6.90	25.95	24.70	24.50
Maximum	54.20	58.40	47.55	3.90	7.05	25.60	46.25	44.60	44.70
CV%	6.10	6.45	5.64	28.80	21.37	22.54	5.76	6.40	7.04

Means followed by the same letter, lowercase in the row and upper case in the column, do not differ by the Tukey and Scott-Knott test, respectively, at the 5% probability level. n=80.

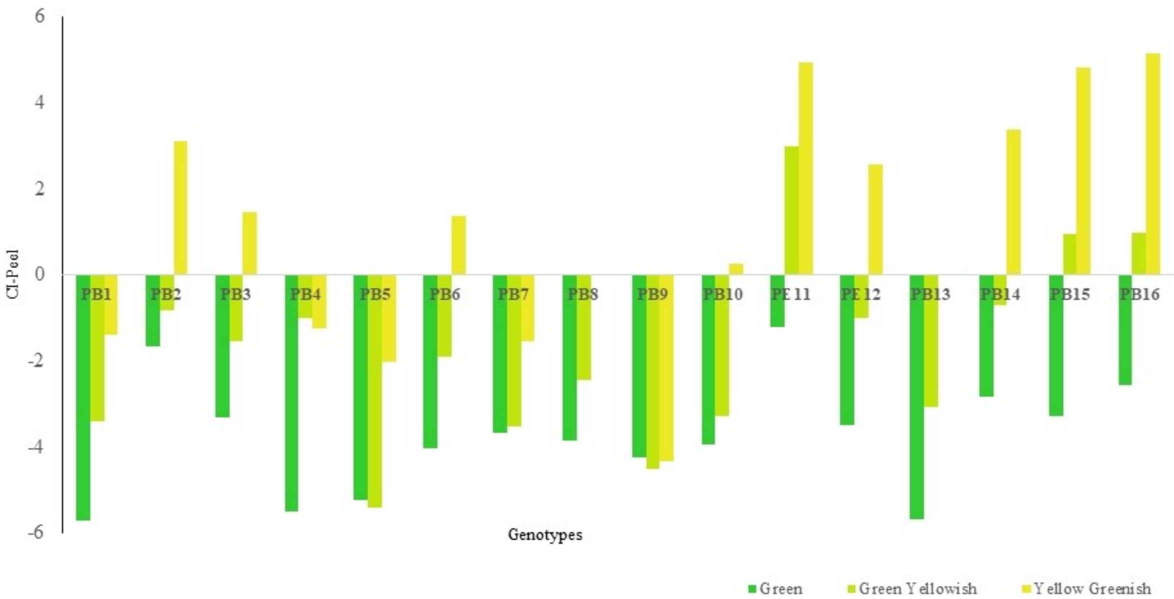


Figure 2. Peel Color Index (CI) at different maturity stages of fruits of umbuzeiro (*Spondias tuberosa* Arruda Camara) genotypes from Paraiba (Casserenge - PB) and Pernambuco (Brejo da Madre de Deus - PE) states. n=80.

Moura et al. (2013) reported that mature umbu fruits are less bright ($L*$ - lightness) than those at earlier maturity stages, as observed for fruits of some of the genotypes in this study. They also reported $a*$ values that were close to negative in mature umbu fruits, indicating that, in general, even mature umbu fruits still have green lines (LIMA; SILVA; OLIVEIRA, 2018). This can be explained by the wide genetic diversity reported for fruits of the umbuzeiro genotypes distributed across several states of the semiarid region of Brazil (COSTA et al., 2015; SANTOS et al., 2021). The development of a green to yellow greenish color occurs because of chlorophyll degradation via the action of chlorophyllase and carotenoid biosynthesis as well as the unmasking of compounds that were previously synthesized (PAREEK, 2016).

Umbu fruits in the green stage (i.e., harvested before ripening for fresh consumption) were smaller, which is generally characteristic of climacteric fruits. In this respect, umbu fruits at the green yellowish maturity stage (i.e., intermediate maturity) of most of the evaluated genotypes were larger in size. However, the fruits of the PB2 genotype were characterized by shorter lengths (28.95 mm) and smaller diameters (27.45 mm) at the yellow greenish maturity stage, whereas the highest values were those of the PE11 genotype that was still green, measuring 55.15 mm in length and 47.39 mm in diameter. In general, fruits from different umbuzeiro genotypes slightly decreased in size as maturity advanced (Table 2). When *Spondias* fruits reach full maturity on the plant, with probable early abscission of the fruit from the plant, there is usually no increase in fruit size. This behavior has been observed in umbuguelas (*Spondias* sp.) (DANTAS et al., 2016). Other genotypes with fruits of larger sizes that stood out were PB4, PB8, PE12, PE14, and PE16, because their dimensions were increased compared to those of the mean of the 16 genotypes. Therefore, along with PE11, these are promising genotypes for propagation and breeding programs, because fruit size is an appealing factor for marketing, as consumers prefer larger fruits.

Table 2. Length and diameter of fruits of umbuzeiro (*Spondias tuberosa* Arruda Camara) genotypes, harvested at different maturity stages from Paraiba (Casserenge - PB) and Pernambuco (Brejo da Madre de Deus - PE) states.

Genotype	Length (mm)			Diameter (mm)		
	Green	Green Yellowish	Yellow Greenish	Green	Green Yellowish	Yellow Greenish
PB1	38.24 Da	32.97 Fb	35.27 Fc	33.65 Da	29.40 Ea	28.71 Ia
PB2	32.71 Fa	32.27 Fa	28.95 Hb	31.37 Ea	30.71 Ea	27.45 Ia
PB3	38.10 Da	37.61 Ea	36.83 Ea	33.51 Da	34.45 Da	33.04 Ea
PB4	41.01 Cb	45.59 Aa	41.89 Cb	34.47 Da	37.26 Ca	33.52 Ea
PB5	37.54 Da	38.45 Ea	37.61 Ea	35.97 Ca	36.62 Ca	36.92 Ba
PB6	33.13 Ea	33.70 Fa	33.81 Ga	28.42 Fa	29.23 Ea	29.51 Ha
PB7	35.57 Eb	41.00 Ca	34.35 Gb	31.69 Ea	37.14 Ca	31.11 Ga
PB8	40.99 Cb	43.94 Ba	41.89 Cb	37.45 Ca	40.22 Ba	37.59 Bb
PB9	34.77 Eb	38.06 Ea	38.04 Ea	30.91 Ea	34.28 Da	34.34 Da
PB10	35.65 Ec	46.04 Aa	39.36 Db	31.22 Ea	42.37 Aa	35.84 Ca
PE11	55.15 Aa	47.39 Ab	48.31 Ab	47.39 Aa	39.44 Ba	42.65 Aa
PE12	40.88 Cb	41.93 Cb	44.70 Ba	36.67 Cb	38.78 Bb	41.72 Aa
PE13	36.27 Da	37.30 Ea	36.80 Ea	32.34 Da	33.73 Da	33.04 Ea
PE14	42.44 Cab	44.12 Ba	41.49 Cb	38.07 Bb	40.35 Ba	37.59 Bb
PE15	34.33 Eb	36.34 Ea	35.78 Fab	30.73 Eb	33.42 Da	32.29 Eab
PE16	44.47 Ba	39.87 Db	38.82 Db	39.74 Ba	35.74 Cb	34.57 Db
Mean	38.83 a	39.79 a	38.23 a	34.60 a	35.82 a	43.39 a
Minimum	29.33	27.87	26.00	20.42	26.00	20.00
Maximum	68.56	74.17	53.37	91.38	64.37	47.83
CV%	8.31	8.81	6.93	12.38	9.66	7.54

Means followed by equal letters, lower case in the row and upper case in the column, do not differ, respectively, by the Tukey and Sott-Knott test at the 5% probability level; n = 80.

Fresh fruit mass is closely linked to fruit size. The PE11 genotype exhibited the greatest mass (42.04, 45.54, and 44.78 g in the green, green yellowish, and yellow greenish stages, respectively), followed by those of the PE14 and PE12 genotypes (Table 3). The mean fresh masses of the fruits in this study were greater than those reported for umbu fruits (PEREIRA et al., 2021) and umbu-cajazeira fruits (GONDIM et al., 2013) - both from Paraíba.

Regarding firmness, there was a progressive decrease with advancing maturity, and the PB7 genotype exhibited the firmest fruits, with their firmness decreasing from 41.79 N in the green stage to 19.74 N when they reached the yellow greenish color (Table 3). The progressive loss of fruit firmness, which causes pulp softening, is due to the breakdown of cell wall components and the disaggregation of polymers, such as cellulose, hemicellulose, and pectin (YAHIA, 2019).

Firmness is one of the main quality and acceptability attributes of fresh fruits especially umbu as peel color does not always reflect the ripening process (LIMA; SILVA; OLIVEIRA, 2018), as confirmed here for fruits of different genotypes. Thus, it is essential to determine the degree of fruit firmness at harvest to select an ideal market. This is because firmer fruits can be transported to longer destinations with less quality loss, whereas softer fruits need to be marketed faster or harvested close to processing plants to minimize losses (PAREEK, 2016).

Table 3. Fresh mass and firmness of fruits of umbuzeiro (*Spondias tuberosa* Arruda Camara) genotypes harvested at different maturity stages from Paraiba (Casserenge - PB) and Pernambuco (Brejo da Madre de Deus - PE) states.

Genotype	Fresh mass (g)			Firmness (N)		
	Green	Green Yellowish	Yellow Greenish	Green	Green Yellowish	Yellow Greenish
PB1	18.06 Fb	20.29 Ha	19.62 Fab	34.02 Ba	12.66 Fb	9.10 Cc
PB2	18.70 Fa	18.08 Ia	18.22 Ha	26.24 Da	9.54 Gb	7.96 Cb
PB3	25.17 Da	24.47 Fab	22.85 Db	28.53 Da	22.95 Cb	10.30 Cb
PB4	25.23 Da	24.00 Fa	24.51 Da	27.26 Da	11.10 Gb	9.75 Cb
PB5	25.96 Db	27.98 Da	27.68 Cab	29.18 Ca	17.15 Eb	9.77 Cc
PB6	15.37 Ga	17.29 Ia	17.07 Ha	31.06 Ca	16.94 Eb	7.06 Cc
PB7	20.21 Eb	23.93 Fa	24.72 Da	41.79 Aa	36.59 Ab	19.74 Ac
PB8	17.57 Fa	18.07 Ia	17.92 Ha	32.94 Ba	27.43 Bb	13.24 Bc
PB9	19.83 Ec	24.77 Fb	27.01 Ca	27.36 Da	19.27 Db	10.91 Cc
PB10	20.19 Eb	22.33 Ga	21.84 Eab	26.46 Da	14.00 Fb	9.74 Cc
PE11	42.04 Ab	45.54 Aa	44.78 Aa	27.28 Da	15.23 Eb	7.98 Cc
PE12	29.82 Cb	35.82 Ca	34.51 Ba	27.92 Da	17.03 Eb	8.63 Cc
PE13	24.23 Db	26.11 Ea	26.05 Ca	30.79 Ca	19.51 Db	11.12 Cc
PE14	35.61 Bc	41.59 Bb	43.65 Aa	31.18 Ca	26.64 Bb	14.04 Bc
PE15	18.35 Fb	24.08 Fa	23.02 Da	27.31 Da	16.16 Eb	14.56 Bb
PE16	23.95 Db	26.10 Ea	26.03 Ca	26.95 Da	14.94 Eb	8.46 Cc
Mean	23.77 b	26.28 a	26.82 a	29.77 a	18.57 b	11.29 c
Minimum	12.29	12.04	12.49	17.98	6.73	2.15
Maximum	54.32	52.42	55.57	56.45	47.58	37.83
CV%	13.50	12.20	12.98	23.71	26.74	32.48

Means followed by equal letters, lowercase in the row and upper case in the column, do not differ, respectively, by the Tukey and Scott-Knott test at the 5% probability level; n= 80.

The mean yields of the umbuzeiro fruit pulp ranged from 42.25% (PB1) to 65.99% (PE11) in the green stage, 44.64% (PB1) to 69.30% (PE15) in the green yellowish stage, and 50.42% (PB1) to 68.97% (PE15) in the yellow greenish stage, with higher values occurring in the last stage. The PE15 and PE9 genotypes, followed by the PB7, PB10, PE11, and PE14 genotypes, showed the highest pulp yields (> 62%) during maturation (Table 4), which confirms that these are promising candidates for breeding programs based on this criterion. Thus, fruits in the advanced maturity stage (i.e., yellow greenish) are the most suitable for both fresh consumption and processing, as they provide more pulp. The mature umbu pulp yield (yellow greenish) values in this study are similar to those reported by Dantas Júnior (2008) for different umbu genotypes and for umbu-cajá (GONDIM et al., 2013).

Regarding peel percentage, the PB1, PB2, PB4, and PB7 genotypes exhibited the highest values. In particular, PB7 (green stage) exhibited the highest peel percentage (41.11%), whereas PB9 (yellow greenish stage) exhibited the lowest (18.43%). The mean peel percentage value (23,49%) for yellow greenish fruits here is in the range reported by Dantas Júnior (2008) for mature umbu fruits, with a minimum percentage of 8.14% and a maximum of 27.30%, and by Gondim et al. (2013) for umbu-cajá, with a minimum percentage of 14.84% and a maximum of 30.71%. Overall, the lowest peel percentage was observed in fruits with higher pulp yields. Moreover, with the advancement of maturity, peel percentage decreased, whereas pulp percentage increased, likely because of peel becoming thinner at the end of maturation.

Table 4. Pulp yield and peel percentage of fruits of umbuzeiro (*Spondias tuberosa* Arruda Camara) genotypes, harvested at different maturity stages from Paraiba (Casserenge - PB) and Pernambuco (Brejo da Madre de Deus - PE) states.

Genotype	Pulp (%)			Peel (%)		
	Green	Green Yellowish	Yellow Greenish	Green	Green Yellowish	Yellow Greenish
PB1	42.25 Db	44.64 Fb	50.42 Ea	39.17 Aa	36.89 Aa	33.04 Aa
PB2	46.20 Db	54.88 Da	51.77 Ea	36.59 Aa	27.39 Cb	29.00 Bb
PB3	63.59 Aa	58.42 Cb	57.25 Db	20.58 Db	24.09 Da	24.67 Ca
PB4	45.59 Db	47.72 Eb	61.65 Ca	39.89 Aa	37.60 Aa	24.47 Cb
PB5	61.16 Bb	67.99 Aa	60.83 Cb	25.15 Ca	19.03 Eb	24.27 Ca
PB6	57.30 Bb	61.63 Ba	60.99 Cab	25.04 Ca	20.63 Eb	21.18 Db
PB7	45.60 Dc	50.28 Eb	62.79 Ba	41.11 Aa	37.37 Ab	22.94 Cc
PB8	63.21 Aa	53.95 Dc	58.96 Cb	20.09 Db	30.47 Ba	22.71 Cb
PB9	58.05 Bb	61.19 Bb	68.97 Aa	27.49 Ca	26.57 Ca	18.43 Eb
PB10	52.76 Cb	62.96 Ba	63.14 Ba	31.70 Ba	20.55 Eb	20.64 Eb
PE11	65.99 Aa	62.93 Ba	64.25 Ba	20.22 Da	22.02 Ea	20.70 Ea
PE12	58.72 Ba	59.21 Ca	60.17 Ca	26.09 Ca	24.63 Dab	22.66 Cb
PE13	65.55 Aa	59.17 Cb	51.72 Ec	20.35 Db	25.04 Da	24.27 Ca
PE14	59.91 Ba	54.41 Db	62.43 Ba	25.78 Cb	30.69 Ba	22.71 Cb
PE15	64.17 Ab	69.30 Aa	66.86 Ab	23.14 Da	19.07 Eb	20.35 Eb
PE16	57.78 Ba	59.46 Ca	58.96 Ca	27.66 Ca	23.93 Db	23.83 Cb
Mean	56.74 a	58.01 a	60.75 a	28.13 a	26.62 a	23.49 b
Minimum	10.00	4.63	3.32	11.91	12.52	13.15
Maximum	76.93	74.37	76.05	75.22	80.94	51.33
CV%	13.94	10.78	8.51	13.64	14.93	12.85

Means followed by equal letters, lowercase in the row and upper case in the column, do not differ, respectively, by the Tukey and Scott-Knott test at the 5% probability level; n=4.

Soluble solids (SS) increased during maturation, especially for the fruits of the PB5 genotype, for which SS increased from 11.17% at the green stage to 13.75% at the yellow greenish stage. However, titratable acidity decreased, resulting in an increase in the SS/TS ratio (Table 5).

According to Normative Instruction No. 19 of June 19, 2013, the SS contents of fruits of the umbuzeiro genotypes evaluated in this study were higher than the minimum required by the Identity and Quality Standard (i.e., PIQ) for umbu pulp (9%) (BRASIL, 2013). This indicates that these fruits have a high level of sweetness, and therefore their SS contents are superior to those reported by Dantas Júnior (2008) (i.e., 10.30%) for fully mature fruits. The SS contents in this study were similar to those of umbu-cajá (*Spondias* sp.) fruits, i.e., average of 11.86% (GONDIM et al., 2013). However, compared to the SS contents of umbugueleira (*Spondias* sp.) fruits, i.e., mean value of 20%, these values were 50% lower (DANTAS et al., 2016).

The green yellowish stages of the PB4, PB8, PB10, PE15, and PE16 genotypes and the yellow greenish stages of the PB3, PB5, PB10, and PE14 genotypes exhibited equal to or less than 1.1% citric acid, featuring fruits of lower acidity.

Regarding the SS/TA ratio, the PB5 genotype showed the most significant increase, i.e., from 9.39 in the green stage to 16.90 in the yellow greenish stage. In general, the SS/TA ratio in the green stage ranged from 6.91 (PE13) to 12.24 (PB10), that in the yellow greenish stage ranged from 9.03 (PB6) to 13.86 (PE15), and that in the yellow greenish stage ranged from 9.09 (PB7) to 16.90 (PB5). This high amplitude of the SS/TA ratio among genotypes was also observed by Dantas Júnior (2008), who evaluated 32 mature umbu genotypes ranging from 4.89 to 11.89. The SS/TA ratios of umbu genotypes in this study were intermediate to those of cajá (SILVA et al., 2013). These large variations in the SS/TA ratio at the same maturity stage among genotypes may be due to factors such as the genetics of the materials (SANTOS et al., 2021), climate, soil, precipitation conditions during fruit growth (YAHIA, 2019), and seed dispersal by animals (PEREIRA et al., 2021). Furthermore, the variability of the maturity stage itself can also be considered when harvesting fruits from each genotype, as can be seen from the differences in firmness at the same maturity stage among these genotypes.

These observed changes in the sugar and acid contents during the ripening of fruits are irreversible. They stem from coordinated events of a physiological and biochemical nature stimulated mainly by the action of ethylene, leading to the formation of a product with the desired quality attributes (PAREEK, 2016).

Table 5. Soluble solids (SS), titratable acidity (TA), and SS/TS ratio of fruits from umbuzeiro (*Spondias tuberosa* Arruda Camara) genotypes, harvested at different maturity stages from Paraiba (Casserenge - PB) and Pernambuco (Brejo da Madre de Deus - PE) states.

Genotype	SS (%)			AT (g 100 g^{-1})			SS/AT		
	Green	Green Yellowish	Yellow Greenish	Green	Green Yellowish	Yellow Greenish	Green	Green Yellowish	Yellow greenish
PB1	11.25 Ca	12.75 Aa	12.50 Ba	1.44 Ba	1.16 Bb	1.13 Bb	7.98 Bb	11.01 Aa	11.14 Ca
PB2	12.42 Ba	11.58 Aa	11.67 Ca	1.02 Da	1.11 Ba	1.11 Ba	12.20 Aa	10.54 Bb	10.52 Cb
PB3	13.08 Aa	13.42 Aa	12.75 Ba	1.33 Ba	1.19 Ba	0.97 Cb	10.01 Ab	11.41 Aab	13.17 Ba
PB4	10.67 Ca	10.52 Aa	11.33 Ca	0.94 Da	0.95 Ca	1.11 Ba	11.44 Aa	11.05 Aab	10.22 Cb
PB5	11.17 Cb	12.25 Aab	13.75 Aa	1.20 Ca	1.03 Ca	0.82 Db	9.39 Bc	11.97 Ab	16.90 Aa
PB6	10.92 Ca	12.42 Aa	11.08 Ca	1.28 Bab	1.38 Aa	1.18 Bb	8.52 Ba	9.03 Ba	9.44 Ca
PB7	11.08 Ca	11.50 Aa	11.75 Ca	1.14 Cab	1.11 Bb	1.31 Aaa	9.98 Aa	10.39 Ba	9.09 Cb
PB8	11.92 Bb	10.92 Ab	13.25 Aa	1.14 Ca	0.83 Dc	0.97 Cb	10.47 Ab	13.22 Aa	13.66Ba
PB9	10.58 Ca	11.33 Aa	12.33 Ba	1.32 Ba	1.20 Cab	1.13 Bb	8.06 Bb	9.41 Bab	10.90 Ca
PB10	11.42 Ca	11.25 Aa	10.58 Ca	0.93 Da	0.93 Ca	0.87 Da	12.24 Aa	12.19 Aa	12.31 Ba
PE11	11.17 Ca	12.58 Aa	10.58 Ca	1.30 Ba	1.02 Cb	1.05 Bb	8.63 Bb	12.37 Aa	10.16 Cab
PE12	11.58 Ca	8.67 Ab	11.83 Ca	1.63 Aa	1.16 Bb	1.09 Bb	7.16 Bb	7.37 Bb	10.88 Ca
PE13	10.75 Cb	11.58 Aa	12.33 Ba	1.56 Aa	1.18 Bb	1.09 Bab	6.91 Bc	9.87 Bb	11.31Ca
PE14	10.33 Cab	10.00 Ab	12.17 Ba	1.36 Ba	1.11 Bb	0.99 Cb	7.63 Bc	9.06 Bb	12.40 Ba
PE15	12.83 Aa	13.67 Aa	13.25 Aa	1.19 Ca	0.99 Cb	1.06 Bab	10.88 Ab	13.86 Aa	12.58 Ba
PE16	10.83 Ca	10.00 Aa	11.08 Ca	1.22 Ca	1.00 Cb	1.09 Bab	8.94 Ba	10.02 Ba	10.14 Ca
Mean	11.38 a	11.53 a	11.90 a	1.25 a	1.080 b	1.06 b	9.40 b	10.80 ab	11.42 a
Minimum	9.75	9.50	10.50	0.87	0.80	0.76	6.11	8.84	8.01
Maximum	9.75	9.50	10.50	0.87	0.80	0.76	13.84	14.20	19.08
CV%	4.06	14.39	5.17	10.21	6.74	7.14	7.12	9.14	6.27

Means followed by equal letters, lowercase in the row and upper case in the column, do not differ, respectively, by the Tukey and Scott-Knott test at the 5% probability level; n=4.

Regarding reducing sugars (RS), among the 16 evaluated genotypes, for all maturity stages, the PB3 and PB9 genotypes had the highest contents, and the PE16 genotype had the lowest. Regarding non-reducing sugars (NRS), the highest content was observed for the fruits of the PB2 genotypes at the green stage and for those of PB1 at the green yellowish and yellow greenish stages. Regarding the total soluble sugars (TS), the fruits of the PE16 genotype had lower contents during ripening, and the fruits of the PB3 and PB1 genotypes in the green, green yellowish, and yellow greenish stages had the highest contents (Table 6).

The fruits of the PE12 genotype showed the highest TS value in the green stage, i.e., 1.63 g·(100 g)$^{-1}$, decreasing to 1.09 g·(100 g)$^{-1}$ in the yellow greenish stage. The lowest TS value was observed for fruit of the PB8 genotype at the green yellowish maturity stage (0.83 g·(100 g)$^{-1}$). These results are close to the mean values reported for green yellowish fruits of 32 genotypes harvested from the Umbuzeiro Active Germplasm Bank and Umbuzeiro Experimental Field of Origins and Progenies, both from Embrapa Semiárido (DANTAS JÚNIOR, 2008), and for mature umbu-cajá (GONDIM et al., 2013); however, they are much lower than those reported for umbuguelas (DANTAS et al., 2016).

The contents of RS and TS in umbu (yellow greenish stage) observed in this study were below the maximum values observed for 32 umbu genotypes of Petrolina reported by Dantas Júnior (2008).

Notably, sugar development in umbus during maturation is less clear than that in other *Spondias*, such as the cajá, as the contents of TS and RS increased to approximately six times those in the green stage of maturation (SILVA et al., 2013), whereas for umbu, this increase was less than 1-fold.

Considering the differences resulting from maturation and among genotypes, the correlation analysis showed for the first time for umbu that firmness was significantly correlated with other variables (Table 7). A moderately positive correlation with lightness (L^*) was observed, indicating that firmer fruits had more intense brightness, as indicated by the higher L^* values at the onset of maturation (Table 1). However, with the a^* color parameter, there was a moderate negative correlation, whereas the b^* color parameter was low and positive, indicating a loss of firmness with ripening, which is related to the characteristic light changes in fruit color. This confirms that coloration is not the most appropriate attribute for describing the evolution of umbu maturity. However, this suggests the loss of green coloration and onset of yellowing as umbu firmness declines. These changes in color with reduced firmness were also noted, along with a negative correlation with the color index. Overall, these results indicate that firmness is a suitable maturity indicator for umbu.

Firmness decreases with increasing maturity. This is also evidenced by the positive correlation with titratable acidity and the negative correlation with the SS/TA ratio Consequently, firmer fruits (onset of ripening) are more acidic and less sweet, with a decline in firmness (i.e., advancement of maturity) increasing sweetness and reducing acidity.

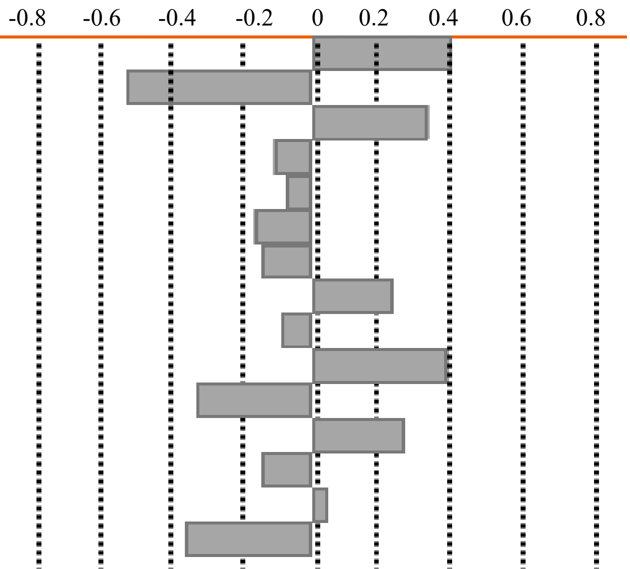
Table 6. Reducing (RS), non-reducing (NRS), and total sugars (TS) of fruits of umbuzeiro (*Spondias tuberosa* Arruda Camara) genotypes, harvested at different maturity stages from Paraiba (Casserenge - PB) and Pernambuco (Brejo da Madre de Deus - PE) states.

Genotype	RS			NRS			TS		
	Green	Green Yellowish	Yellow Greenish	Green	Green Yellowish	Yellow Greenish	Green	Green Yellowish	Yellow Greenish
PB1	2.99 Cc	3.57 Db	4.18 Ba	1.95 Bb	3.78 Aa	3.64 Aa	5.04 Bb	7.56 Aa	8.01 Aa
PB2	3.47 Ba	3.64 Da	3.69 Ca	2.79 Aab	3.39 Aa	2.51 Bb	6.41 Aab	7.21 Aa	6.32 Cb
PB3	4.11 Ab	4.79 Aa	4.62 Aa	2.38 Aa	2.39 Ba	2.50 Ba	6.61 Aa	7.30 Aa	7.25 Ba
PB4	3.42 Bb	3.57 Db	4.16 Ba	1.98 Ba	1.97 Ba	1.99 Ca	5.51 Aa	5.64 Ca	6.25 Ca
BP5	3.99 Ab	4.23 Bb	4.81 Aa	1.49 Cb	2.31 Ba	2.45 Ba	5.55 Ab	6.66 Ba	7.38 Ba
PB6	4.06 Aa	3.78 Ca	4.08 Ba	1.76 Ba	2.20 Ba	1.93 Ca	5.91 Aa	6.10 Ba	6.11 Ca
PB7	4.24 Ab	4.71 Aa	4.23 Bb	1.79 Bab	2.39 Ba	1.54 Cb	6.12 Ab	7.22 Aa	5.85 Cb
PB8	4.29 Aa	4.38 Ba	4.91 Aa	1.67 Bb	2.45 Ba	2.30 Ba	6.04 Ab	6.96 Aa	7.21 Ba
PB9	3.85 Ab	4.56 Aa	4.64 Aa	1.17 Ca	1.42 Ca	1.02 Da	5.08 Bb	6.05 Ba	5.71 Dab
PB10	3.30 Bb	3.98 Ca	3.67 Cab	2.22 Aa	0.99 Cb	1.56 Cab	5.64 Aa	5.03 Ca	5.32 Da
PE11	3.79 Aa	3.77 Cab	3.34 Db	1.38 Ca	1.63 Ca	1.81 Ca	5.24 Ba	5.49 Ca	5.25 Da
PE12	3.99 Aa	4.03 Ca	3.37 Db	1.82 Ba	2.01 Ba	1.87 Ca	5.90 Aa	6.14 Ba	5.34 Da
PE13	3.88 Aa	3.93 Ca	3.77 Cab	0.90 Ca	0.85 Ca	1.22 Da	4.83 Ba	4.83 Ca	4.25 Ea
PE14	2.96 Ca	3.29 Da	3.20 Da	0.96 Ca	1.45 Ca	0.99 Da	3.97 Ca	4.82 Ca	4.25 Ea
PE15	3.38 Ba	3.61 Da	3.33 Da	1.13 Cb	2.38 Ba	2.30 Ba	4.58 Bb	6.12 Ba	5.75 Da
PE16	2.92 Ca	2.58 Ea	2.66 Ea	0.95 Ca	1.32 Ca	1.44 Ca	3.92 Ca	3.97 Da	4.17 Ea
Mean	3.67 a	3.90 a	3.86 a	1.65 a	2.06 a	1.97 a	5.40 a	6.07 a	5.93 a
Minimum	2.77	2.51	2.50	0.74	0.65	0.72	3.82	3.78	3.92
Maximum	4.49	5.50	5.20	3.54	3.96	3.75	7.45	8.64	8.39
CV%	5.59	6.19	5.92	21.15	21.79	14.49	8.19	8.32	6.10

Means followed by equal letters, lowercase in the row and upper case in the column, do not differ, respectively, by the Tukey and Scott-Knott test at the 5% probability level; n=4.

Table 7. Pearson correlation between firmness and physical, and physicochemical properties in the stages of ripeness, as green, green yellowish, and yellow greenish of fruits of umbuzeiro (*Spondias tuberosa* Arruda Camara) genotypes.

Variable	by Variables	Correlation	Significance
Firmness	L*	0.4035	0.0054*
	a*	-0.5375	0.0001*
	b*	0.3345	0.0231*
	Length	-0.1129	0.4551
	Diameter	-0.0769	0.6114
	Fresh Weight	-0.1730	0.2502
	Pulp Percentage	-0.1468	0.3303
	Peel Percentage	0.2305	0. 1233
	Soluble Solids (SS)	-0.0917	0.5446
	Titratable Acidity (TA)	0.3915	0.0071*
	SS/TA ratio	-0.3326	0.0239*
	Reducing Sugars	0.2654	0.0747
	Non-reducing Sugars	-0.1434	0.3418
	Total Sugars	0.0408	0.7876
	IC	-0.3737	0.0105*



Based on the principal component analyses (PCA), three components that reached a cumulative variance of 62.39% of the observed variability (Table 8) was necessary. In this respect, the variables that contributed the most to the variability in umbuzeiro fruits were length, diameter, fresh weight, NRS, and TS, resulting in CP1 with 29.72% of variance; lightness, acidity, and SS/TA resulted in CP2 with 17.73% of variance; and firmness, *a** color parameter, and reducing sugars resulted in CP3 with 14.94% of variance.

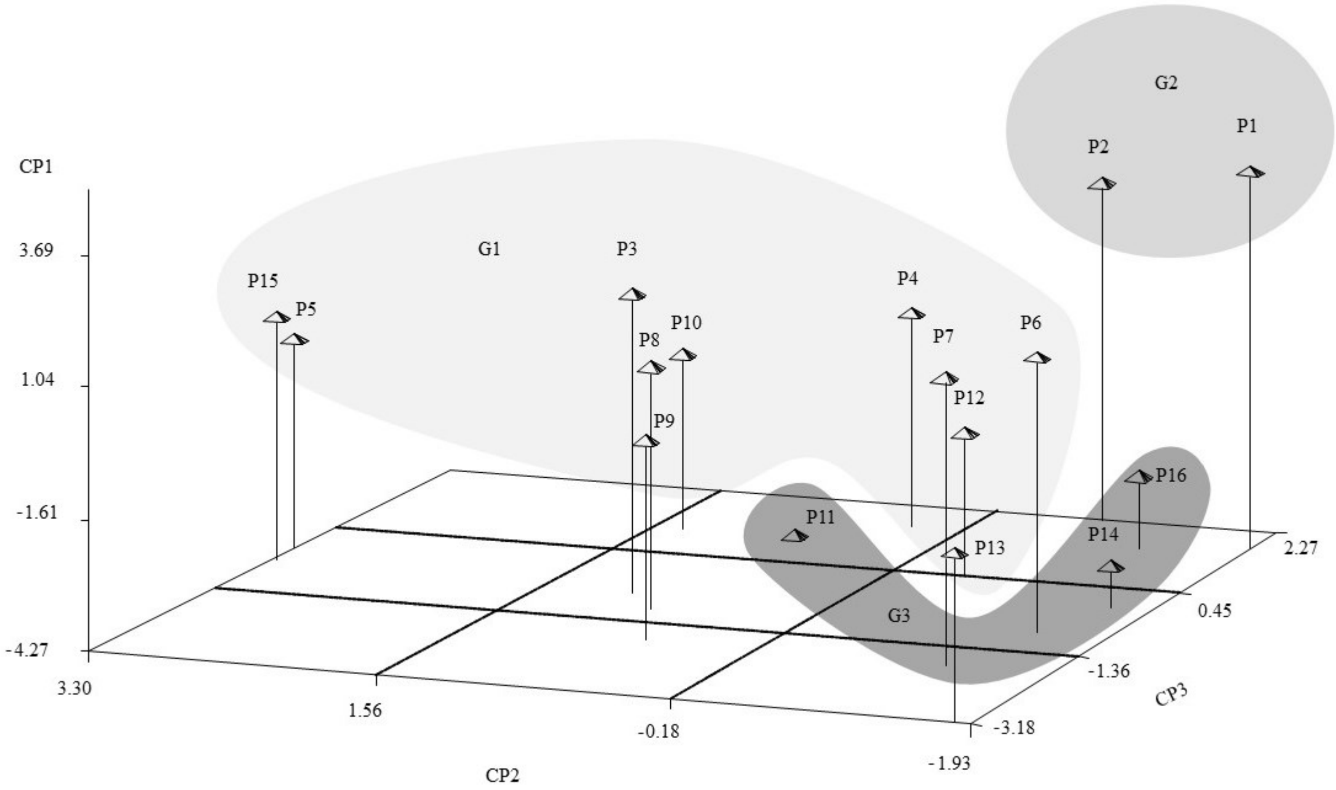
Table 8. Auto vectors and accumulated variance of three main components (CP1, CP2, and CP3), considering the physical and physicochemical characteristics of green, green yellowish, and yellow greenish maturity stages of fruits from 16 umbuzeiro (*Spondias tuberosa* Arruda Camara) genotypes.

Variables	Auto vectors		
	CP 1	CP 2	CP 3
Length	**-0.353289**[N]	0.062799	0.124538
Diameter	**-0.354047**	0.127233	0.080248
Fresh mass	**-0.368477**	-0.003645	0.06138
Pulp Percentage	-0.260462	0.333089	-0.289425
Peel Percentage	0.232118	-0.27726	0.230668
Firmness	0.082897	-0.105024	**-0.481541**
Lightness	-0.136872	**-0.407994**	-0.052396
*a**	-0.221082	0.016828	**0.383365**
*b**	0.077266	-0.116304	-0.035409
Color index	0.15802	-0.258322	0.297403
Soluble solids (SS)	0.223232	0.327508	-0.038249
Titratable acidity (TA)	0.010343	**-0.359519**	-0.290555
SS/TA ratio	0.106944	**0.502001**	0.188835
Reducing Sugars	0.216855	0.166857	**-0.386869**
Non-reducing Sugars	**0.362224**	0.044415	0.307789
Total Sugars	**0.383812**	0.125177	0.008068
High Values	4.75	2.84	2.39
Accumulated Variance (%)	29.72	47.44	62.39

[N]Auto significant vectors above the limit of inclusion of variables (result of multiplying the largest auto vector by 0.7).

However, the percentages of pulp and peel, *b** color parameter, color index, and soluble solid variables were not important in explaining the changes during ripening in the 16 umbuzeiro genotypes in this study. Significant variability in biometric characteristics is reportedly related to the locations of umbu fruits of 58 genotypes in the semiarid region of Brazil (COSTA et al., 2015). For different ecotypes of ciriguelas, genetic factors also contribute to these differences (SOLORZANO-MORÁN et al., 2015).

Considering the similarity among the evaluated fruits of umbuzeiro genotypes, three groups were established irrespective of the ripening stage (Figure 3). Group 1 (G1) comprised fruits of the PB3, PB4, PB5, PB6, PB7, PB8, PB9, PB10, PE12, PE13, and PE15 genotypes, which were grouped together because they had values closest to the mean length, diameter, fresh mass, and NRS, and TS contents. Group 2 (G2) comprised fruits of the PB1 and PB2 genotypes, which were grouped together because of their lower length, diameter, and fresh mass, and higher NRS and TS contents. Group 3 (G3) comprised the other genotypes (i.e., PE11, PE14, and PE16) from Brejo da Madre de Deus–PE; these had higher length, diameter, and fresh mass and lower RS contents and firmness.



*P1 to P10, equivalent to PB1 to PB10 (Casserengue - PB) and P11 to P16, equivalent to PE11 to PE16 (Brejo da Madre de Deus - PE)

Figure 3. Grouping of umbu maturity stages (green, green yellowish, and yellow greenish) of fruits of umbuzeiro (*Spondias tuberosa* Arr. Camara) *genotypes.

CONCLUSIONS

Umbu fruits exhibit a climacteric respiratory pattern, as indicated by clear changes in the respiratory rate and quality attributes (color, firmness, and sugar) during ripening.

Changes in color, a decline in titratable acidity, and an increase in the SS/TA ratio correlated with firmness loss.

The PB4, PB8, PE12, PE11, PE12, PE14, and PE16 genotypes produced fruits of greater size and fresh mass, exceeding by approximately 50% the overall mean values reported in the literature. The PE15 and PE9 genotypes exhibited the highest pulp yield and may therefore be promising for use in breeding programs.

Fruits from umbuzeiro genotypes that have lower acidity levels (PB3, PB5, PB8, PB10, PB11, PB12, PB13, PB14, PB15, and PB16) in the yellow greenish and green yellowish maturity stages are more suitable for fresh consumption.

The soluble solids and SS/TA ratios of fruits from all genotypes were higher than those set by the Identity and Quality Standard for umbu and other *Spondias* fruit pulps intended for the market.

Thus, umbuzeiro fruits from Casserengue–PB (PB3, BB5, PB8, and PB10) and Brejo da Madre de Deus–PE (PE11, PE12, PE13, P14, and PE16) are suitable for both fresh consumption and processing particularly when harvested at the mature (yellow greenish) stage.

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