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Morphology and biochemistry of achacha (*Garcinia humilis* (Clusiaceae) (Vahl) C.D. Adam) fruits harvested at three consumption ripeness stages

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ABSTRACT

Objective: To identify the morphological and biochemical variations of achacha (*Garcinia humilis* (Clusiaceae) (Vahl) C.D. Adam) in three ripeness stages of consumption.

Design/Methodology/Approach: The morphological and biochemical variables of fruits in three ripeness stages were evaluated to identify the preferred stage for consumption. We collected 15 fruits from 10 productive-stage trees (n=150) for each ripeness stage for their subsequent evaluation in the laboratory. The morphological and biochemical variables were evaluated in each one. Each fruit was considered an experimental unit. The morphological and biochemical variables were evaluated for each unit.

Results: Delaying the harvest for a few days increases the weight, length, diameter, and pulp:seed ratio of the fruits and decreases the firmness of the epicarp and the acidity. The °Brix increases and the fruits lose a considerable weight during storage. The pulp of the ripest fruits had light and unsaturated colors.

Study Limitations/Implications: Changes in the conditions of the production systems and the variation in the availability of rainwater throughout the year and from one year to another can cause variation in fruit quality.

Findings/Conclusions: The ripest fruits had outstanding biochemical parameters for its consumption and better morphological characteristics (length, total weight, diameter, and pulp:seed ratio). With adequate training, the results enable the color of the epicarp and the pulp variables to be used as a harvest index.

Keywords: Post-harvest, Harvest Index, consumption ripeness, Total Soluble Solids (TSS).

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INTRODUCTION

The genus Garcinia comprises more than 1,300 species, including achacha (*Garcinia humilis* (Clusiaceae) (Vahl) C.D. Adam), also known as Bolivian bacupari (Lorenzi *et*

al., 2006). During the last decade, the "Select" achacha, also known as achachairú or mangosteen, has shown its potential as a commercial species in various regions of Brazil (Melo *et al*., 2017). Cury *et al*. (2016) report that this species has various uses: it has healing, laxative, anti-inflammatory, and digestive properties; likewise, it prevents rheumatism and gastric ulcers. The same authors mention that bioflavonoids, benzophenones, and other substances can be extracted from its leaves and fruits. These substances increase its anticancer, antioxidant, and anti-inflammatory potential. The fruit can be found in the tropical rainforests of Bolivia, Guyana, Panama, and much of the Caribbean. It was also introduced to Australia where it has become a commercial crop (Lim, 2012).

The achacha has been studied and propagated in other parts of the world where commercial plantations have been established for various purposes (medicinal studies and trade). However, despite the recent boom of this fruit tree in in the various places where its plantation are located, the optimal maturity stage for ripeness and consumption —which can affect its organoleptic and biochemical properties— has not been determined. The objective of this work was to identify the morphological and biochemical variation of achacha in three consumption ripeness stages and consequently to guarantee acceptable organoleptic properties that facilitate its commercialization, generating alternatives for fruit diversification in the Soconusco region, in Chiapas, Mexico.

MATERIALS AND METHODS

Productive "Select" achacha trees were identified in an orchard with eight-year-old trees. They had been planted in a 10×10 m square system, in the Santa Cecilia community, Huehuetán, Chiapas, Mexico (15° 03' 12.4" N, 92° 20 ' 60" W, and 311 m.a.s.l.). Ten productive-stage trees were selected and 15 fruits in different ripeness stages (E1, E2, and E3) were collected from each tree to evaluate the corresponding variables. The soil of the orchard has a vegetal cover mainly composed of pampano (*Calathea lutea* (Aubl.) E. Mey. ex Schult.) and kudzu (*Pueraria phaseoloides* (Roxb.) Benth.). It also has *Theobroma cacao* L., *Ananas comosus* (L.) Merr., and *Cedrela odorata* L. intercrops. The dominant soil group is Acrisol, with a clay loam texture, 6.12 pH (1:2 water), 3.4% OM, 3.16% NO_3^- (mg kg^{-1}), 1.72% P (mg kg^{-1} Bray), 22.9% Fe_2^+ (mg kg^{-1}), 13.4% Mn_2^+ (mg kg^{-1}), 0.1% Zn_2^+ (mg kg^{-1}), 0.1% B (mg kg^{-1}), 58.7% K^+ int. (mg kg^{-1}), 39.7 Ca_2^+ (mg kg^{-1}), and 98.3% Mg_2^+ (mg kg^{-1}), 0.07% EC (Dsm^{-1} at 25 °C), and a ≥18% slope. The following data were also recorded: a 63% saturation point, a 33.8% field capacity, a 20.1% permanent wilting point, a 0.90 cm h^{-1} hydraulic conductivity, and a 1.03 apparent density. The climate belongs to the Am(w")ig type, with 3,000 to 3,500 mm of rainfall and minimum, average, and maximum temperatures of 19, 27, and 35 °C, respectively, according to García (1973).

Variables

A digital scale (OHAUS® USA) was used to determine the total weight (g) and weight loss (g) of the fruits. Fifteen fruits were selected and the weight loss was recorded every 72 h. To determine the pulp:seed ratio, each part of the fruit was weighed separately using a digital scale. A FOY analog vernier (USA) was used to determine the polar and equatorial diameter of the fruits. The CIE (International Commission on Illumination) system was used to evaluate the color of the epicarp and the pulp of the fruits in the L*C*h° colour space where L* is lightness, C* is chroma, and h° is hue angle, which are measured with an X-Rite® brand colorimeter. Once the color of the epicarp was measured, it was removed to measure the color of the pulp.

The firmness of the epicarp was determined with an FDV-30 manual texture analyzer (Brand Chatillon, USA), measuring the force (N) required to penetrate it. The Total Soluble Solids (TSS, expressed as °Brix), the pH, and the titratable acidity were calculated through destructive samplings, weighing 10 g of pulp, adjusted to 50 mL with distilled water. The °Brix were determined with a digital refractometer (SPER SCIENTIFIC, model 300034), following the AOAC methodology (1990), while the pH was determined with a 230[a] potentiometer (Thermo Orion, USA). The titratable acidity was calculated following the volumetric method of the AOAC (1990): 10 g of liquefied pulp were poured into 50 mL of distilled water; subsequently, a 20-mL aliquot was titrated with NaOH (0.1 N) and four phenolphthalein drops were added as indicator. The following formula was used to make the conversion to citric acid: (Volume spent*N*Meq*Total volume/Sample weight*mL used)*100. °Brix were divided by acidity (°Brix/acidity) to calculate the flavor index. The resulting data was processed with the SAS software ver. 9.0 (SAS Institute, 2009). An analysis of variance (ANOVA) was performed to establish the statistical difference between the three ripeness. Any differences were subjected to a Tukey's mean comparison ($\rho \leq 0.05$).

RESULTS AND DISCUSSION

Three different stages were determined depending on the color of the fruit at harvest time (according to the producer's experience): ripeness stage 1 (E1), fruits with green epicarp; ripeness stage 2 (E2), yellow fruits; and ripeness stage 3 (E3), reddish-orange fruits (Figure 2). The weight of the achacha fruits differed depending on the degree of ripeness at which they were harvested; the average weight per ripeness stage was 28.9 g (E1), 32.5 g (E2), and 40.6 g (E3). Since the fruits harvested in E3 are on average larger, E3 recorded the highest weight and was higher than E1 (28.6%) and E2 (19.90%). Weight is lost over

Figure 1. Achacha (*Garcinia humilis* Vahl) fruits: oval-shaped berries with a yellow to reddish-orange color at the stage of physiological maturity. They almost always have one normal seed and one rudimentary seed.

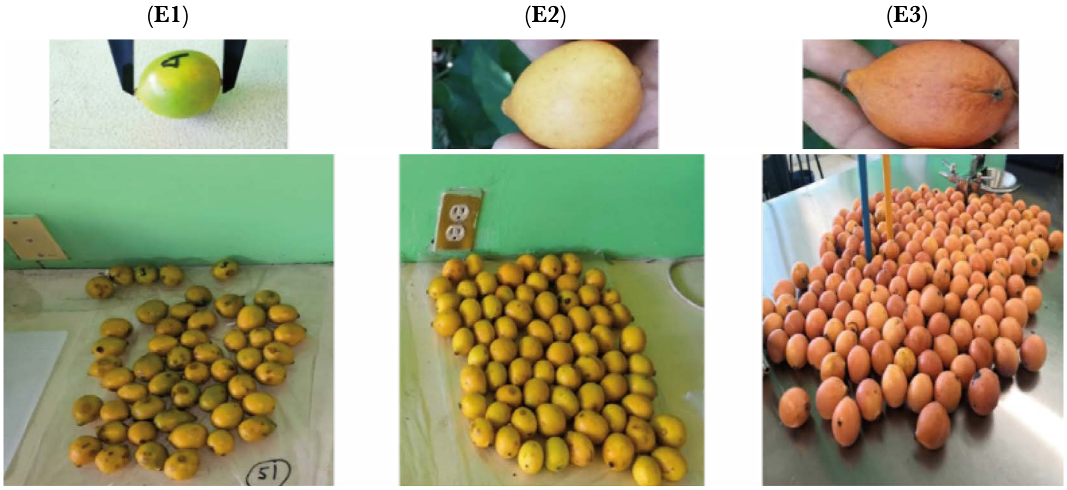

Figure 2. Ripeness stages of achacha fruits at harvest time.

storage time, because of transpiration; the E3 fruits lost less weight. The values obtained in this work are like the results of Cotty-More *et al.* (2019), who reported a daily weight loss of 0.71 to 1.1 g, as well as a reduction in diameter and in pulp weight, as a result of dehydration (Table 1). Water loss is the main cause of fruit deterioration, since it has a quantitative impact on weight loss and, consequently, on appearance (Kader, 1992).

The amount of pulp increased significantly in the riper fruits (E3) (Table 1, Figure 3). Melo *et al.* (2017) recorded averages ranging from 7.21 to 8.50 g of pulp, in achacha fruits collected from three parts of the crowns in Brazilian plantations. These results are higher than those obtained in the present work. The pulp:seed ratio of the "Select" type achacha is three times higher and reaches a ≈3 proportion (CIAT, 2004). The E3 value was close to 2.5 (Table 1).

The E1 has heavier (11.56%) and its peel was thicker (12.51%) than E2 and E3. The epicarp of the same fruits also was firmer, showing a statistical difference —this phenomenon can be attributed to the lower ripeness degree, which directly impacts the morphological characteristics of the fruit (Castedo, 1999). Regarding their length and diameter, the E3 fruits recorded the highest average with 48.34 and 35.87 mm, respectively; they were

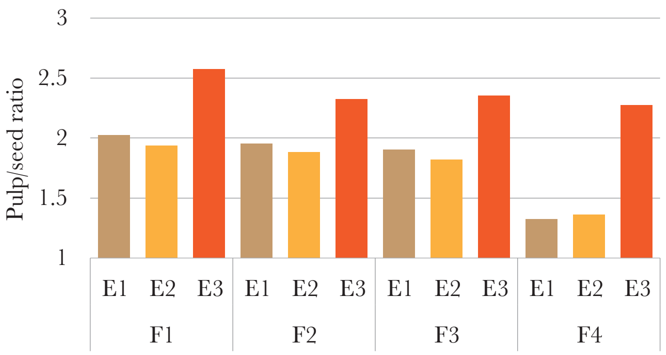

Figure 3. Achacha pulp weight:seed weight ratio.

Table 1. Characterization of achacha fruits in three ripeness stages.

Variable	Maturity 1	Maturity 2	Maturity 3	VC %
Fruit morphology				
Total weight (g)	28.99 c	32.55 b	40.64 a	9.05
Pulp/seed ratio	2.02 b	1.93 b	2.57 a	19.03
Firmness (N)	23.18 a	20.28 b	20.53 b	8.14
Longitude (mm)	45.89 b	45.89 b	48.34 a	4.51
Diameter (mm)	34.69 b	35.28 ab	35.87 a	2.84
Weight loss	28.01 a	25.69 b	28.47 a	5.44
Shape index				
Peel colour				
Brightness (L*)	61.95 b	66.07 a	57.86 c	3.91
Chroma (C*)	51.80 b	57.25 a	46.80 c	3.96
Hue (°h)	81.69 a	83.43 a	67.62 b	4.11
Pulp Colour				
Brightness (L*)	22.75 c	37.97 b	55.25 a	13.34
Chroma (C*)	3.05 c	5.92 b	10.00 a	23.78
Hue (°h)	84.14 a	116.37 a	76.37 b	12.78
Biochemistry fruit				
Acidity	2.39 a	3.08 a	2.15 a	42.32
pH	2.86 ab	2.64 b	2.93 a	8.64
°Brix	13.19 a	12.18 a	10.71 b	10.58
Ratio °Brix/Acidity	5.78 ab	3.79 b	7.48 a	57.4

* Values with the same letter within each factor and row are equal, according to Tukey's test ($P \leq 0.05$).
** CV: Coefficient of Variation.

statistically superior to the fruits with E1 and E2 ripeness. Lim (2012) reported achacha fruits with a length of 55 to 60 mm and a diameter of 44 to 55 mm in an orchard with commercial agronomic management, while the achacha trees in this study are planted with an intercropping system.

Along with the fruits of E2 (°Hue 83.43), the color of the fruits of E1 was closer to yellow (°Hue 91.69), while the fruits in E3 showed a tendency towards red and were statistically different from the fruits in E1 and E2 (Figure 2 and Table 1). Regarding the lightness (L*) and chroma (C*) results, the values of E3 stand out: the fruits had less lightness and less shade, along with a slight tendency towards red and their tone was firmly closer to orange. With respect to pulp color, the results indicate that E3 had similar (L*) values (*i.e.*, a light-coloured pulp). For their part, Santos and Pereira (2012) determined that the color of the epicarp in mango cultivars changed in a green-yellow-orange-red-purple gradation during the ripening process; likewise, they mention that the hue angle (h°) adequately describes the coloring change of the epicarp and it is a sign of the optimum fruit ripeness.

Regarding the total soluble solids, E3 had higher results than E1 and E2 (Table 1). They have a 10.71-13.19 range and are slightly lower than the results reported by Melo *et al.* (2017), who found a 14.08-16.36% °Brix range in an achacha plantation in Brazil. The pH value of the fruits does not show a trend towards the ripeness degree, although it has statistical differences. Unlike the case of °Brix, the pH results obtained with E1 and E2 were similar to those reported by Melo *et al.* (2017), who recorded 2.66-2.80 pH values; however, the averages of the E3 fruits were higher than the results reported by those authors (Table 1). Melo *et al.* (2017) also mention that the values indicate that the fruit is very acid and it is therefore recommended for the manufacture of juices and other industrialized products. The percentage of citric acid ranged from 2.1 to 3.0 in the three ripeness stages, without significant differences (Table 1). These results are lower than the values reported by Chávez *et al.* (2012), who recorded an average of 13.2% citric acid in achacha; however, they are higher than those reported by Melo *et al.* (2017) and CIAT (2004), both of whom recorded <1.90% citric acid values.

CONCLUSIONS

We recommend E3 for harvest, given its outstanding biochemical parameters for consumption purposes and because it has better morphological characteristics. The color of the epicarp and pulp are likely a determining factor to decide the optimal ripeness stage (when the harvest should be carried out); therefore, the reddish-orange color can be considered a harvest index. The fruits in E3 should be evaluated during post-harvest to calculate the potential commercialization of the fruit in other markets.

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