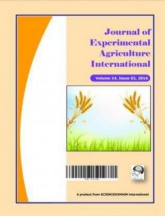

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Geometric, Physical and Mechanical Properties of the Fruit-rachilla of the Macauba Palm (*Acrocomia aculeata*) Considering Different Sampling Sites in the State of Minas Gerais in Brazil

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Authors' contributions

This work was carried out in collaboration among all authors. Author JPR designed the study, performed the statistical analysis, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Authors DMQ and FLS managed the analyses of the study. Authors FACP and DSMV corrected aspects of the research. All authors read and approved the final manuscript.

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ABSTRACT

This study aimed to determine the geometric, physical and mechanical properties of the fruit-rachilla system of the macauba palm (*Acrocomia aculeata*) from three different locations in the state of Minas Gerais. Three different sampling site wee assemble in the mature and green maturation stages. The replicates of the experiment were established, use 20 samples from four different plants for each sampling site, at different stages of maturation. For the experiment, the dimensions in three directions were determined, the mass, volume and density of the fruits and the rachilla. The modulus od elasticity and Poisson's ratio were determined using a universal test machine. The

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mean values of the diameter and density for the fruits were 40 mm and 1.20 g cm^{-3}, approximately. The mean valeus of the density of the rachillae obtained of 0.55 g cm^{-3}. The dimensions and the density of the fruits and the rachillae presented significant in relation to the study of the interaction of the factors. The values of modulus of elasticity green maturation stage are higher than values for mature maturation stage in two sampling sites studied. The values of the Poisson's ratio of the rachillae were 0.37 m m^{-1} and were not different with respect to none of the factors studied.

Keywords: Modulus of elasticity; Poisson's ratio; exotic fruits; fruit oil.

1. INTRODUCTION

The increasing prices of energy matrices, reduction of the fossil fuel offer and the consequent increase in fuel prices worldwide have fomented the search for alternative energy sources. Among such sources, biofuels, in particular, have been gaining considerable attention [1].

Following the trends observed in the USA and in European countries, biofuel production in Brazil has increased markedly over the last years [2]. This increase in Brazilian production can be attributed mainly to law project no. 11,097 of 2005, which proposed the creation of more production incentives and the regulation of biodiesel use in the energy matrix of the country. Since March 2016, after publication of law no. 13,263, the percentage of obligatory addition of biodiesel to diesel fuel has been raised to 8% [3].

The significant increase in biodiesel production in Brazil over the last years has stimulated research on high-yield oil-producing species, aiming to meet market demands in the country. In that context, the macauba palm [Acrocomia aculeata (Jacq.) Lodd. ex Mart.] has been highlighted for its particular relevance due to its high-yield potential [4].

The macauba is the most widely distributed palm species in Brazilian territory, occurring mostly in Cerrado regions of the country [5]. The species yields ca. 5000 kg oil per hectare [6].

However, fruit maturation in the macauba is not uniform. As its production system is based on extractivism, fruit harvest is usually made by cutting bunches or by directly collecting the fruits that detach naturally from the parental plant. Such harvesting mode results not only in lower oil yields but also in lower quality of the extracted oil, because contamination of the pulp occurs under the action of the microbial flora or enzymes (lipases), favored by environmental conditions, promoting the increase of the acidity of the oil [7].

Therefore, in order to increase yield and product quality of cultivated macauba palms, the use of technology from production to the postharvest stage is highly necessary. A viable alternative to improve fruit harvest may be the use of mechanized systems. However, in order for mechanization to be effectively employed, an adequate knowledge on diverse properties of the crop is still needed.

Thus, it was aimed to determine and evaluate the geometric, physical and mechanical properties of the macauba fruit-rachilla system as well as to assess the influence of fruit maturation stages and plant sampling sites on those properties.

2. MATERIALS AND METHODS

Samples (macauba bunches) were obtained from the germplasm bank of the Federal University of Viçosa (UFV), located at the university experimental farm at Araponga municipality, Minas Gerais state, southeastern Brazil. The study was conducted at the Laboratory of Machinery Projecting and Artificial Vision (PROVISAGRO, Portuguese acronym) of the Department of Agricultural Engineering of UFV, from September 2016 through January 2017, which is the period related to fruit maturation in the macauba palm – September: green fruits; January: ripe fruits.

Bunches were collected from plants of different sampling sites: BD27 – Abaeté municipality, Minas Gerais (MG) state; BD45 – Unaí municipality, MG; and BGP29 – Prudente de Morais and Matozinhos municipalities, MG. All assays were performed using 20 samples randomly obtained from four different palms of the same sampling site, at both fruit maturation stages: green and ripe fruit. Each palm constituted one replicate. The experimental design was completely randomized in a factorial

scheme, with two factors: fruit maturation stage and plant sampling site.

Rachilla diameter was determined on samples from bunches having ca. 15 cm in length. Diameter measurements were taken from the lower, middle and upper thirds of each bunch, from which the mean rachilla diameter was calculated. Mean fruit diameter was determined based on the average of three distinct fruit directions. Both the rachilla and the fruit were measured with a Mitutoyo digital caliper of 0.02 mm precision.

Mean mass of the fruit-rachilla system was determined on both maturation stages and from all three sampling sites. For that, was used a digital precision balance with a 0.001 g resolution. Mean volume of fruit and rachilla samples at each maturation stage were measured by the water column displacement method, using a 10 mL graduated test tube, with a 0.1 mL precision. Volumes were measured by immerging each sample separately in water. The mean density of fruit and rachilla samples was determined using the mass and volume values obtained experimentally.

The modulus of elasticity was determined by tension tests, in an Instron universal testing machine (model 3365) with a 5 kN load capacity. Rachilla samples were obtained at both maturation stages and were standardized to a 15 cm length, through cutting. These samples were then subjected to a 2 N pre-load with strain at a constant speed of 3 mm min^{-1}. The test sequence that determined and controlled the stresses and strains applied to samples was created using software Bluehill 3 version 3.61 (Instron). In the software, samples were deemed having a cylindrical geometry with constant area.

The test was performed by mounting samples on the extremities of the testing machine and applying the test sequence to them until their rupture. That enabled us to obtain values of maximum and rupture loads, modulus of elasticity, and specific strains – considering the elastic deformation region of the stress-strain curve.

Poisson's ratio of rachillae at the different maturation stages were determined by measuring longitudinal and transverse geometric variables, considering isotropic material samples, using Equation [8].

$$\nu = (-\Delta d)/\Delta l$$

Where, ν is the Poisson's ratio (m m^{-1}), Δd is transverse strain (m) and Δl is longitudinal strain (m).

The longitudinal and transverse strain values were measured by applying the same test sequence created to assess the modulus of elasticity. Then, with the pre-set longitudinal strain of rachilla samples (15 cm long), of ca. 2 mm for all assays, was measured the strains on the longitudinal and transverse directions.

Longitudinal strain was measured using a Mitutoyo digital caliper (model 500-784) with a 0.02 mm precision, whereas transverse strain was assessed using a Mitutoyo outside micrometer with a 0.01 mm graduation and a ± 0.002 mm precision. These measurements were taken from the lower, middle and upper thirds of samples. Longitudinal strains were measured taking into account the distance between the grips of the testing machine before and after the assay.

3. RESULTS AND DISCUSSION

Fruit dimension (mean diameter) differed significantly in the study of the interaction. Regarding the green and ripe fruit maturation stages, in sampling sites BD27 and BGP29 was observed an increase and a decrease in mean fruit diameter, respectively, along fruit maturation (Table 1). Velloso et al., [9] evaluated solely the different fruit maturation stages and obtained diameter values that did not differ significantly.

Sampling site BGP29 showed the highest mean fruit diameter values at the green maturation stage, while sampling site BD45 (Unaí) showed the lowest such values. This difference between the values found may be due to intrinsic features of the sampling sites, each of which was collected from a different region of the country, thereby propitiating differential adaptability responses to the Araponga region.

The mean rachilla diameter of sampling site BD27 showed decreasing values along fruit maturation (Table 1). This result may be explained by the crop variability, which is reflected in the differing rachilla size of different plants, even in those from the same sampling site. It was also observed that only green fruits of sampling site BD27 differed significantly in the analysis of the studied sampling sites, which corroborates the aforementioned hypothesis.

Table 1. Mean diameters of fruits and rachillae of the macauba palm for each fruit maturation stage and plant sampling site

Sampling site	Fruit maturation stage	Mean diameter of fruit (mm)	Mean diameter of rachilla (mm)
BD27	Green	38.93^{bB}	3.99^{aA}
	Ripe	41.96^{aA}	3.60^{bA}
BGP29	Green	44.25^{aA}	3.39^{aB}
	Ripe	43.13^{bA}	3.59^{aA}
BD45	Green	39.71^{aB}	3.44^{aB}
	Ripe	39.31^{aB}	3.36^{aA}

Means followed by at least one upper case letter (sampling site) or at least one lower case letter (maturation stage) do not differ significantly by Tukey's test at 5% probability. BD27 – sampling site collected at Abaeté municipality, Minas Gerais (MG) state; BGP29 – sampling site collected at Prudente de Morais and Matozinhos municipalities, MG; BD45 – sampling site collected at Unaí municipality, MG

Table 2. Mean density of fruits and rachillae of the macauba palm for each fruit maturation stage and plant sampling site

Sampling site	Fruit maturation stage	Density of fruit (g cm^{-3})	Density of rachilla (g cm^{-3})
BD27	Green	1.17^{bA}	0.60^{aA}
	Ripe	1.24^{aA}	0.57^{aB}
BGP29	Green	1.17^{aA}	0.54^{bB}
	Ripe	1.21^{aAB}	0.66^{aA}
BD45	Green	1.21^{aA}	0.47^{aC}
	Ripe	1.17^{bB}	0.46^{aC}

Means followed by at least one upper case letter (sampling site) or at least one lower case letter (maturation stage) do not differ significantly by Tukey's test at 5% probability. BD27 – sampling site collected at Abaeté municipality, Minas Gerais (MG) state; BGP29 – sampling site collected at Prudente de Morais and Matozinhos municipalities, MG; BD45 – sampling site collected at Unaí municipality, MG

Table 3. Mean modulus of rachillae of the macauba palm for each fruit maturation stage and plant sampling site

Sampling site	Fruit maturation stage	Modulus of elasticity of rachilla (MPa)
BD27	Green	269^{aA}
	Ripe	189^{bB}
BGP29	Green	319^{aA}
	Ripe	275^{bA}
BD45	Green	194^{aB}
	Ripe	183^{aB}

Means followed by at least one upper case letter (sampling site) or at least one lower case letter (maturation stage) do not differ significantly by Tukey's test at 5% probability. BD27 – sampling site collected at Abaeté municipality, Minas Gerais (MG) state; BGP29 – sampling site collected at Prudente de Morais and Matozinhos municipalities, MG; BD45 – sampling site collected at Unaí municipality, MG

In the interaction of factors fruit maturation stage and plant sampling site, was observed an increase in mean fruit density of sampling site BD27 and a decrease in such values of sampling site BD45 along fruit maturation (Table 2). The density of green fruits from the different sampling sites did not differ significantly.

Souza and Pereira [10] found decreasing density values of the macauba nut oil with advancing fruit maturation stages. Those values are therefore different from the ones found in this study, which thus reinforces the need for and the importance of specific studies on different sampling sites of the species.

The mean density value of rachillae from sampling site BD45 showed the lowest value in the analysis of all studied sampling sites, considering both maturation stages (Table 2).

The mean values of modulus of elasticity found in this study were 100 fold higher than those obtained by Villar et al., [11]. The factorial analysis revealed decreasing values of the modulus of elasticity along fruit maturation in sampling sites BD27 and BGP29 (Table 3). Other crops, like coffee, have also showed such a reduction in the modulus of elasticity of fruits and peduncles [12]. It was also observed that the modulus of elasticity of green rachillae from sampling site BD45 differed statistically from that of the other sampling sites, showing the lowest values of that variable.

No significant difference was detected in the statistical analysis of Poisson's ratio of the studied rachillae. The mean value found in this study was 0.37 with a 22.80% coefficient of variation. Villar et al., [11] have also found a 0.37 mean Poisson's ratio in green bunches of macauba plants collected from different municipalities at Minas Gerais state: Ibiá/Araxá; Sítio Paraíso/Belo Horizonte; Três Marias; and São João Del Rei.

4. CONCLUSION

The data in this study highlight the importance of studying the specific features of the macauba fruit-rachilla system from different plant sampling sites and at different fruit maturation stages, since, with the single exception of Poisson's ratio analysis, the values found in all the other experiments showed significantly different results regarding the statistical analysis of factor interaction.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Silva ASB, Guimarães CMM, Lordêlo FS, Porto CM. The importance of the use of renewable energies for the construction of sustainable economic development for Brazil and for Bahia. Dialogues and Science. 2011;27:1-14. Brazil.
2. Energy Information Administration (EIA). Use of Biodiesel; 2015.
3. Brazil. Civil couple. Law No. 13,263. It provides for the percentage of biodiesel added to the diesel oil marketed in the national territory; 2016.
   (Accessed on: 15 June. 2019)
   Available:
   http://www.planalto.gov.br/ccivil_03/_Ato2015- 2018/2016 / Lei / L13263.htm. Brazil
4. Evaristo AB, Grossi JAS, Carneiro ACO, Pimentel LD, Motoike SY, Kui KN. Actual and putative potential of macauba palm as feedstock for solid biofuel production from residues. Biomass and Bioenergy. 2016;85:18-24.
5. Ciconini G, Favaro SP, Roscoe R, Miranda CHB, Tapeti CF, Miyahira MAM, et al. Biometry and oil content of *Acrocomia aculeata* fruits from the Cerrados and Pantanal biomes in Mato Grosso do Sul, Brazil. Industrial Crops and Products (Print). 2013;45:208-214.
6. Pimentel L, Manfio C, Motoike SY, Paes J, Bruckner C. Coeficientes técnicos e custos de produção do cultivo da macauba. In. Macauba: potencial e sustentabilidade para o biodiesel. Belo Horizonte. 2011;32:20-30. Brazil.
7. Cavalcanti-Oliveira ED, Silva PR, Rosa TS, Moura NML, Santos BCP, Carvalho DB. Sousa JS, Carvalhinho MTJE, Castro AM, Freire, DMG. Methods to prevent acidification of Macaúba (*Acrocomia aculeata*) fruit pulp oil: A promising oil for producing biodiesel. Industrial Crops and Products. 2015;77:703-707.
8. Callister Jr. WD. Materials science and engineering. 7th ed. New York: John Wiley & Sons, Inc; 2007.
9. Velloso NS, Santos FL, Pinto FAC, Villar FM, Valente DSM. Mechanical properties of the macaw palm fruito-rachilla system. Tropical Agriculture Research. 2017;47 (2):218-225.
10. Souza GK, Pereira, NC. Avaliação sazonal da massa específica da amêndoa de macaw (*Acrocomia totai*). I Congresso Brasileiro de Macauba – Consolidação da Cadeia Produtividade; 2013. Patos de Minas. Brazil.

11. Villar FMM, Pinto FAC, Santos FL, Grossi JAS, Velloso NS. Elasticity modulus and damping ratio of macaw palm rachillas. Rural Science. 2016;47(2):1-8.
12. Coelho ALF, Santos FL, Pinto FAC, Queiroz DM. Determinação das propriedades geométricas, físicas e mecânicas do sistema fruto-pedúnculo-ramo do cafeeiro. Revista Brasileira de Engenharia Agrícola e Ambiental. 2015;19(3):286-292. Brazil.

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