DETERMINING PHYSICAL PROPERTIES OF *JATROPHA CURCAS* L. GRAINS

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Abstract:
The objective of this study was to determine the physical properties of *Jatropha curcas* grains, such as: size, shape, density and porosity, and to determine the terminal velocity, comparing the results with those calculated from mathematical models available in the literature. To perform the experimental analysis, samples with different moisture contents, between 4 and 25% (wb), were selected. To determine the size and shape of the grains, sphericity and roundness characteristics were used, and it was found that both stay approximately constant, despite different moisture content. For specific weight and porosity, results show that the porosity is directly proportional to the moisture content until the point where interaction between the moisture content and volumetric contraction causes the specific weight to increase again, thus decreasing porosity. It was also found that the equation used for calculating the terminal velocity is in agreement with the results obtained experimentally. Furthermore, the results also show that the terminal velocity for the Jatropha grains is directly proportional to its moisture content.

Index terms: Oilseed, postharvest, terminal velocity.

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INTRODUCTION

For many years, researches on bioenergy have received special attention. Among the main forms of energy obtained from biomass is biodiesel. Besides being clean and renewable, biodiesel also enables a reduction on conventional diesel fuel importation, representing an important opportunity of economic development for many regions (Laviola et al., 2013).

Biodiesel can be extracted from vegetable oil, animal fats and even used frying oil. *Jatropha curcas* presents itself as a promising culture, with a potential productivity three times larger than that of soybean (Holanda, 2004). One of its main advantages is the long productive cycle, that can reach 40 years and keep an average productivity of 2 $ton.ha^{-1}$ (Melo et al., 2006). The oil content in each *Jatropha curcas* seed is between 35 to 37%, which is lower than some other oleaginous plants. However, its resistance to normally inadequate conditions for crops, along with its adaptability to desert, saline, marginal and with extreme pH soils, makes it an ideal plant for biodiesel production in otherwise unproductive areas. For being perennial, it also contributes to soil conservation and reduces the production costs, an important factor for its economic feasibility, especially in familiar agriculture. Another advantage is that it allows cultivation amongst other crops of interest (Padilha et al., 2016). Besides, its presence in areas of strong aridity protects the soil from water and wind erosion, and increases air humidity. One hectare can produce 6 to 8 tons of *Jatropha curcas* seeds, while the same area sown with castor bean produces 3 to 5 tons of seeds. In liters of oil, the *Jatropha curcas* would produce 2100 to 2800 L and the castor bean 1200 to 2000 L per hectare.

The main applications of knowledge of the physical properties of grains relate to the design, construction and operation of equipment for cleaning, drying, classification, storage and industrialization, optimization of equipment operation aiming at higher efficiency, energy savings, pollution control and cost-cutting.

Terminal velocity is determined in order to obtain the maximum speed to be imposed in the air in cleaning equipment, so that grains are not transported with impurities (Teixeira et al., 2003). This property is also used on pneumatic transporting, densimetric selection, cooling, among others (Mohsenin, 1986).

Therefore, this paper's objective is to determine the main physical characteristics of Jatropha grains, such as size, shape, specific weight and porosity, and to experimentally determine the terminal velocity of the air involved in the postharvest processes, making a comparison between the experimental results obtained and those calculated using mathematical models.

MATERIAL AND METHODS

This study was conducted in the Agricultural and Environment Engineering Department and in the Thermosciences Laboratory (Latermo) on the Fluminense Federal University (UFF), Niterói, RJ. *Jatropha curcas* L. grains, with initial moisture content of 25% (wb), manually harvested from the municipal garden of Macaé, RJ, were used.

The initial sample was divided into subsamples of approximately 250g. The first was kept in an airtight bag, in order to preserve its original moisture content. The other subsamples were dried to moisture contents of approximately 4, 8, 9, 11, 13, 15, 18, 20, 24 and 25% (wb). After drying the grains were homogenized, stored in airtight bags and put in refrigeration. Posteriorly the moisture content of each sample was determined.

Moisture content

In order to determine the moisture content of the grains, were realized according to the recommendations of (Brasil, 1992), as it is shown in Equation 1:

$$U = \left(P_i - P_f\right) \cdot \left(P_i\right)^{-1} \cdot 100 \qquad (1)$$

where:
U : moisture content (% wb);
Pi: initial weight of sample (g);
Pf: final weight of sample (g).

For each treatment, 3 samples of approximately 30 grams were used. These were housed at 105±1 °C for a period of 24 hours. After this time, the samples were placed in a desiccator, until ambient temperature was reached for weighting. The difference on initial and final mass represents the mass of water contained in the grains.

Size and shape

For the determination of size and shape, samples of 200 grains were used for each moisture content. The grain size was determined using a digital caliper, measuring the width, length and thickness of each grain, as shown in illustration of grain dimensions (Figure 1).

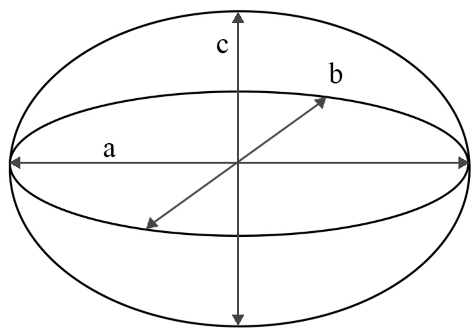

Figure 1: Grain dimensions: Width (a), Thickness (b) and Length (c).

The shape was characterized by calculating the gran circularity and sphericity. Circularity is the measure of how closely the shape of an object approaches that of a mathematically perfect circle. It can be expressed as the ratio of the largest projected area of the object in natural resting position to the area of the smallest circumscribed circle. For the delimitation of the circumscribed and inscribed circles, and the projected area, AutoCad 2008 was used by inserting an image taken from the grain and then delineating the grain and the circles (Figure 2).

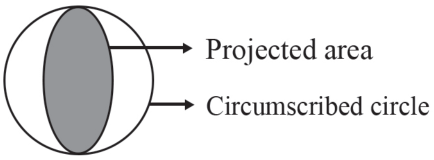

Figure 2: Projected area and circumscribed circle.

Specific weight

The specific weight was determined with 7 repetitions for each sample, using a 1000 mL beaker and a precision scale.

After the scale is balanced with the ambient, the dry beaker is weighted, becoming the curb weight. The grains were deposited in the beaker to the 1000 mL mark and then weighted. The specific weight was then obtained using Equation 2.

$$\gamma = \mathrm{m} \cdot \mathrm{V}^{-1} \qquad (2)$$

where:
γ: specific weight (kg.m^{-3});
m: mass (kg);
V: volume (m^3).

Porosity

Porosity was determined by the direct method, where it is obtained by adding a known liquid in order to complete the spaces of the granular mass (Mohsenin, 1986). Beakers of 500 mL and 100 mL were used, with soybean oil being the chosen liquid.

Experimental terminal velocity

The terminal velocity was determined by using a device made of a fan coupled to a PVC tube with diameter of 100 mm and 1040 mm in length. These dimensions were used in order to obtain a greater uniformity of air distribution in the cross section of the tube, in accordance to Mohsenin (1986). At a distance of 7.5 cm from its upper end, a net was attached to sustain the samples. At the fan inlet, at a distance of 70 cm, a gate valve was used to control the air flow. The air velocity was measured 7.5 cm above the sustaining net, using a digital anemometer. The measurement of the air velocity (which corresponds to the terminal velocity) was performed at the beginning of sample trepidation, to avoid its fluctuation. Figure 3 shows the schematic of the equipment used.

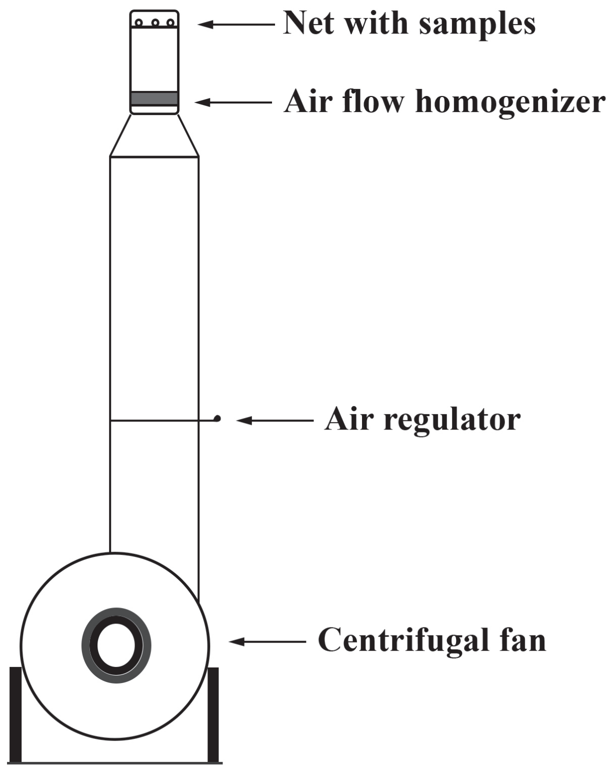

Figure 3: Schematic of the equipment used for measuring the terminal velocity.

The terminal velocity was obtained for 7 samples with different moisture contents. For each sample, 7 grains weighting between 0.7 and 1.0 grams were used.

Calculated terminal velocity

The terminal velocity was calculated for comparison between the experimental results with results obtained from mathematical models. The Equation 3 proposed by Hawk et al. (1966) was used.

$$V_t = \left[\frac{2 \cdot w \cdot (pp - pf)}{C \cdot pp \cdot pf \cdot Ap} \right]^{\frac{1}{2}} \quad (3)$$

where,
Vt = terminal velocity ($m.s^{-1}$);
w = weight of the particles (N);
ρp = specific weight of the particles ($kg.m^{-3}$);
ρt = specific weight of the fluid ($kg.m^{-3}$);
C = drag coefficient, dimensionless;
Ap = projected area of the particles, normal to its movement in relation to the fluid (m^2);
G = gravity acceleration ($m.s^{-2}$).

RESULTS AND DISCUSSION

Table 1 presents the average values for width (a), length (c) and thickness (b), and the moisture content of each sample. It is noted an increase of those values as the moisture content increases. Thickness show less variation, which was expected, as it is the smaller axis.

Table 1: Average values for width, length and thickness, for each moisture content.

Moisture content (% wb)	Width (a) (mm)	Length (c) (mm)	Thickness (b) (mm)
4.3	10.965	17.275	8.400
8.3	11.205	17.555	8.825
13.3	11.215	17.520	8.790
17.8	11.238	17.570	8.870
23.7	11.358	17.793	9.003

On Table 2, the average values for circularity and sphericity of grains for each moisture content are shown. Both circularity and sphericity values remained approximately constant, despite different values of moisture content. As expected, the weight increased with higher moisture contents.

Table 2: Average values for circularity, sphericity and weight of 1000 grains, for each moisture content.

Moisture content (% wb)	Circularity	Sphericity	Weight of 1000 grains (kg)
4.3	0.598	0.570	0.777
8.3	0.595	0.575	0.794
13.3	0.582	0.565	0.825
17.8	0.602	0.571	0.889
23.7	0.604	0.576	0.954

The average values for specific weight and porosity are presented on Table 3. Porosity is directly proportional and specific weight is indirectly proportional to the moisture content up to a certain point (around 14% of moisture content). At this point, the interaction between moisture content and volumetric contraction causes the specific weight to increase again, thus decreasing porosity. This can be explained due to the fact that moisture content has influence on the volume contraction of the grain, making its volume vary.

Table 3: Average values for specific weight and porosity, for each moisture content.

Moisture content (% wb)	Specific weight ($kg.m^{-3}$)	Porosity (%)
4.3	480.47	44.93
8.3	436.66	47.00
13.3	430.40	47.08
17.8	439.34	46.42
23.7	446.72	45.56

The values for specific weight were adjusted in a cubic function. The obtained adjusted function has an R^2 value of 0.997, and is represented by Equation 4.

$$\text{Specific weight}_{\text{calculated}} = -0.0388 \cdot \theta^3 + 1.9833 \cdot \theta^2 - 30.805 \cdot \theta + 579.0 \quad (4)$$

where θ = moisture content (% wb).

The experimental and calculated values of specific weight, for each moisture content are presented on Table 4. The simulated values for the specific weight of the grains adequately represented the variation of this property with the moisture content.

Likewise, porosity can be calculated through the adjusted equation (with R^2 = 0.995), shown in Equation 5:

$$\text{Specific weight}_{\text{calculated}} = -0.0388 \cdot \theta^3 + 1.9833 \cdot \theta^2 - 30.805 \cdot \theta + 579.0 \quad (5)$$

where θ = moisture content (% wb).

The experimental and calculated porosity, for each moisture content are presented on Table 5. The simulated values for the porosity of the grains adequately represented the variation of this property with the moisture content.

Figure 4 below shows the values for experimental and calculated porosity and specific weight as moisture content increases.

On Table 6, obtained values of experimental and calculated terminal velocity for each sample are presented. It was found that terminal velocity is directly proportional to the moisture content. This increase is possibly due to the physical changes on the grain, mostly its weight, area and volume, as moisture content changes.

Table 4: Experimental and calculated values of specific weight, for each moisture content.

Moisture content (% wb)	Experimental (kg.m^{-3})	Calculated (kg.m^{-3})
4.3	480.47	479.93
8.3	436.66	438.30
13.3	430.40	428.32
17.8	439.34	440.40
23.7	446.72	455.51

Table 5: Experimental and calculated porosity.

Moisture content (% wb)	Experimental (%)	Calculated (%)
4.3	44.93	44.95
8.3	47.00	46.91
13.3	47.08	47.21
17.8	46.42	46.34
23.7	45.55	45.01

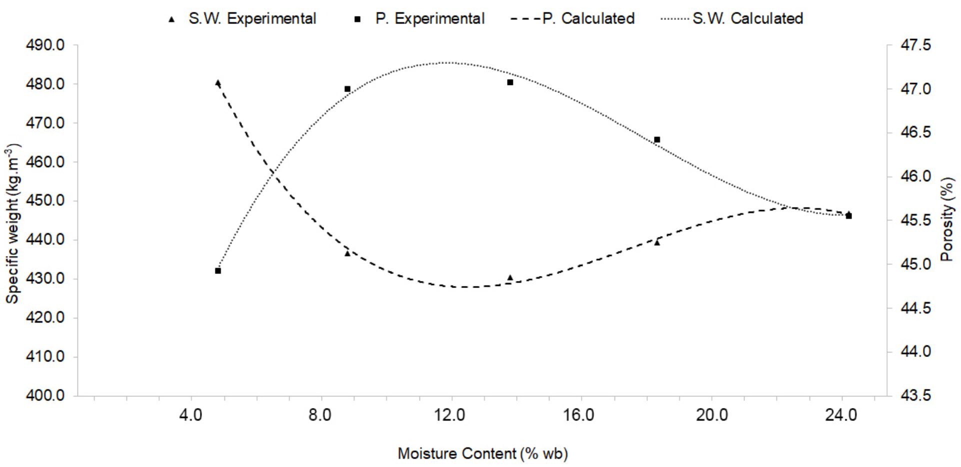

Figure 4: Values for porosity (%): experimental (P. Experimental) and calculated (P. Calculated), and values for specific weight (kg.m^{-3}): experimental (S.W. Experimental) and calculated (S.W. Calculated), for each moisture content (% wb).

Table 6: Obtained results for experimental and calculated Terminal Velocity (m.s^{-1}), for each moisture content.

Moisture content (% wb)	Experimental (m.s^{-1})	Calculated (m.s^{-1})
3.9	7.81	7.79
8.8	7.96	7.95
10.8	8.09	8.03
14.7	8.29	8.20
16.7	8.43	8.30
18.9	8.67	8.42
25.0	8.97	8.81

CONCLUSIONS

Jatropha grain's width, length and thickness increase as its moisture content increases. Circularity and sphericity remain approximately constant, despite different values of moisture content. Porosity increases with the moisture content, but only to up a certain point. Around 14% moisture content, the interaction between moisture content and volumetric contraction causes the specific weight to increase instead of decrease, thus decreasing porosity.

For terminal velocity, the experimental values are in accordance to the ones obtained by using mathematical models. The results also show that terminal velocity is directly proportional to the moisture content of the grain.

The methodology used in this work was adequate to determine the physical properties of *Jatropha curcas*.

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