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MACHINE DESIGN PARAMETERS: RUPTURE FORCE AND DISPLACEMENT OF MACAW PALM ENDOCARP

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Abstract. *This work aimed to evaluate the compressive force required to break the macaw endocarp and the displacement imposed on it, without damage the seed. The endocarp rupture force and the fruit displacement were evaluated as a function of the pulp condition, the direction of application of force) and the fruit diameter class. The experiment was conducted in a completely randomized design in a factorial 2 x 2 x 3, with ten replications. Variance analysis was performed to verify the influence of the above factors on the compression force and displacement of the macaw fruits. The endocarp compression force was influenced by fruit diameter class (DC), pulp condition (PC) and direction of force application (FAD). The interaction between factors DC and FAD; PC and FAD also influenced the force. The endocarp rupture force varied from 5.81 to 8.85 kN, when considered the diameter class and application force direction interaction. Transverse force was higher than longitudinal one for two largest diameters classes. Considering PC and FAD, the highest observed compression force was in the transverse direction with oily pulp condition (7.5 kN). Only the fruit diameter affects the total displacement, with maximum observed value of 8.96 mm for the largest diameter class.*

Keywords: *machine design, mechanical properties, instrumentation.*

1. INTRODUCTION

The constant search for new energy sources has stimulated research for new types of renewable fuels. In this context, it is inserted biodiesel, which is a natural substitute for petroleum diesel. Among the oilseed plant species with technological potential for biodiesel production, there is an extremely important category, which are lauryl oils derived from palm trees, abundant in Brazil, named macaw palm.

The macaw fruit consists of four parts: outer shell (epicarp), pulp (mesocarp), endocarp and almond. It is called the macaw nut the endocarp and almond parts. Pulp and almond you get two different types of oil, the oil from the pulp with unsaturated fatty profile and almond oil with saturated fatty profile. In addition to the oil, processing the macaw of generates high benefit co-products. The pulp bran (mesocarp) and the seed can be used in human and animal food industry and the endocarp may be used in the manufacture of coal plant (Motoike et al., 2013).It is noteworthy that, the macaw culture is an important income source for poor communities in northern of Minas Gerais State. The establishment of procedures appropriate technically, but easy operation and low cost provides feasibility for the installation of sustainable units under the social, economic and environmental viewpoints (Silva et al., 2011).

One of challenges to change from subsistence to commercial exploitation of macaw palm is to develop planting technology. To implement a commercial macaw field, pre-germinated seeds should be used. The seed has to be intact, without damage, such as cracks or chipping. To access the seed, the macaw endocarp should be broken. The macaw seed extraction for germination has presented several drawbacks to development of alternative solutions. In the process of seed extraction, first ruptures the endocarp, which constitutes the larger part of mechanical strength. Its extraction requires meticulous work of high concentration by the worker who will run it manually. Most found ways to extract the seed is the intuitional type without standardized criteria. Stand out the use of hammer, knifes, hydraulic press and the use of mechanical clamps.

The seed extraction by mechanical clamps (or vise) is presented as the most practical solution. The macaw endocarp is pressed until rupture. In this method, the worker responsible is wants to be trained to know the exact moment to stop acting force. For a small excess effort after the endocarp break is enough to damage the seed making it inappropriate for germination. The exact time to stop the actuating force is determined by a characteristic noise. This requires the worker to have a "trained ear" to know when to stop pushing. Under these conditions, the employee responsible for seed extraction can only to work one fruit at a time, which makes it extremely repetitive process.

The lack of mechanical parameters related to the macaw fruit has become one of the gap in the development of machines design aimed at extracting seed systematically. One of the important parameters for the machine design is the rupture force of macaw palm, which is one of the starting points for mechanical design. This work aimed to evaluate the necessary compression force to break the endocarp and your displacement (deformation), with no damage to seed. The macaw endocarp displacement and rupture force were examined according to the qualitative parameters: application direction force, macaw pulp condition and diameter class.

2. MATERIAL AND METHODS

The work was conducted in the Design Machine Laboratory, Department of Mechanical and Production Engineering (DEP), Universidade Federal de Viçosa (UFV). The developed method to disrupt the macaw endocarp and maintain the integrity of the seed, consisting of compressing the whole fruit. Thus, when the endocarp is broken, the mesocarp (pulp) functions as an absorber of the impact generated by the rupture. In the present study used a similar method, where macaw fruit was compressed entirely, and retired only the outer shell (epicarp), which has no significant mechanical strength.

2.1. Definition of compression test device using in experiments

The device consist of a mechanical vise with load cell and linear variable displacement transducer, as shown in Figure 1. The force application was done manually by turning the handle of the movable jaw and compresses the macaw endocarp. This displacement was applied gradually, once a complete turn of the handle corresponds to an advance of 5 mm. The fixing and positioning sensors were performed with the aid of wooden battens. Since the load cell was placed in series with the macaw fruit she receives the same force that is printed on macaw fruit. The displacement sensor was placed on the end of the vise movable jaw. Thus, the displacement of the movable jaw corresponded to fruit subjected to deformation.

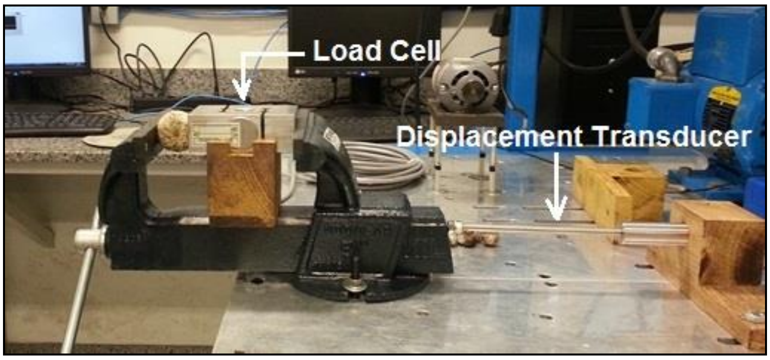

Figure 1. Compression test device: mechanical vise with force and displacement transducers.

It was used a data acquisition system, of the National Instruments® together LabView® software, to collect data from transducers. The system consists of two modules that make the acquisition of the measured variables, and a graphical interface that allows the visualization of data in real time. The sampling rate of 10 Hz was used in experiments. Table 1 lists the main characteristics of the components used.

Table 1. Components of the data acquisition system to measurement displacement and force in macaw palm endocarp.

Component	Features
Load Cell	S9M - 10 kN - 2 mV/V – HBM
Linear Variable Displacement Transducer	LVDT / 0-50 mm / 4-20mA – OMEGA
Analog Input Module	32 Channel / ±200mV to ±10V – NI 9205
Half/Full-Bridge Analog Input Module	4-Channel / ± 25 mV/V – NI 9237

2.2. Pulp condition definition of macaw palm endocarp

It was defined two classes to macaw pulp: oily and dry (Figure 2). Importantly, the oil content was not measured, only the qualitative aspect of the sample was taken into account. The classification was done using visual inspection of the pulp.

Figure 2. Macaw pulp condition: oily and dry, respectively.

2.3. Force application direction in macaw endocarp during compression experiment

The macaw has a rounded shape, which can be characterized by larger and smaller diameter. To verify the influence of the force applying direction were defined two main directions that would be analyzed: longitudinal and transverse (Figure 3).

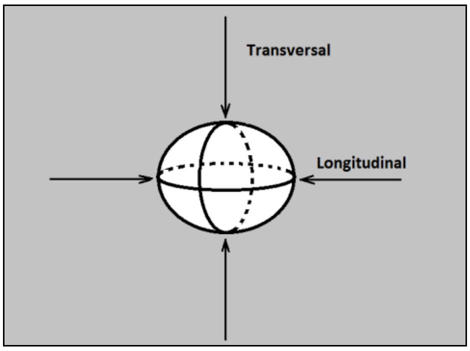

Figure 3. Force application direction during compression experiments of the macaw endocarp.

2.4. Diameter classes of macaw palm endocarp

The force application direction has different size ranges set according to the macaw diameter. In the direction of greater macaw diameter presented a variation between 32 and 38 mm. In the smaller diameter direction variation remained between 30 and 36 mm. Thus, the diameter range was divided into equal parts and sorted, in ascending order (Table 2). In this step, used the conventional caliper with a resolution of 0.01 mm in measuring the diameters.

Table 2. Diameter classes for the application of the force directions.

Direction	Class 1	Class 2	Class 3
Longitudinal (mm)	32-34	34-36	36-38
Transverse (mm)	30-32	32-34	34-36

2.5. Experimental design and statistical analysis

The experiment was conducted in a completely randomized design, factorial 2 x 2 x 3, two directions of application of the compression force (longitudinal and transversal), two conditions pulp (oily and dry) and three classes of macaw diameters (Classes 1, 2 and 3). Ten repetitions were performed for each experiment, totaling 120 samples tested. The response variables were rupture force and displacement of macaw endocarp. An analysis of variance (ANOVA) was realized to verify the influence of the above factors on the rupture force and displacement (deformation) of the macaw endocarp, and to see if there was interaction between the factors, analyzed at 5% significance level. The average rupture force and displacement were compared using the Tukey test, at 5% probability, for those factors with significance for the ANOVA. All statistical analysis was done in the software SISVAR 5.3®. It was also used the model box plot chart to show the distribution of data within the group that showed significant differences.

3. RESULTS AND DISCUSSION

3.1. Rupture force macaw endocarp

The results of ANOVA showed that diameter class (DC), pulp condition (PC) and compression force application direction (FAD) influenced the rupture force of macaw endocarp. The interaction among the factors also has influence: DC and FAD; PC and FAD (Table 3).

Table 3. Analysis of Variance for the rupture force of macaw endocarp in function of diameter class (DC), pulp condition (PC) and force application direction (FAD).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value
DC	2	86.312	43.156	61.435*
PC	1	5.620	5.620	8.001*
DAF	1	33.022	33.022	47.009*
DC*PC	2	0.126	0.0631	0.063^{ns}
DC*FAD	2	28.675	14.337	20.410*
PC*FAD	1	4.328	4.328	6.161*
DC*PC*FAD	2	2.935	1.466	2.089^{ns}
Error	108	75.867	0.702	
Corrected Total	119	236.886		
CV (%) =	12.74			

$^{n.s.}$ not significant; *significant at level 5% of probability; F(2,108)=3,081;F(1,108)=3,930. CV = coefficient of variation

The interaction between the DC and FAD, for diameter class 1, no significant difference between the means relative force application direction (Table 4). For the two others diameter classes, there was a significant difference, especially for smaller diameter force application direction. The analysis revealed that the transversal direction supports a relatively higher compressive load in the longitudinal direction, for diameter classes 2 and 3. One possible explanation is the constituent material characteristics, which can be anisotropic, with physical and mechanical properties varying with the direction of macaw fruit. Furthermore, the endocarp may also present irregularities on the surfaces (external and internal) and thickness variations, changing significantly rupture force values. In the Fig. 3 are presented two samples of macaw, after the rupture of the endocarp, used in the experiments.

Table 4. Rupture force of macaw endocarp (kN) for the interaction between diameter classes (DC) and application of the force directions (FAD).

DC/FAD	Longitudinal	Transverse
Class 1	5.805 Aa	5.640 Aa
Class 2	5.742 Aa	6.827 Bb
Class 3	6.621 Ab	8.850 Bc

Means followed by the same letter (uppercase in line and lowercase in column) not statistically different, by Tukey test at 5% of probability.

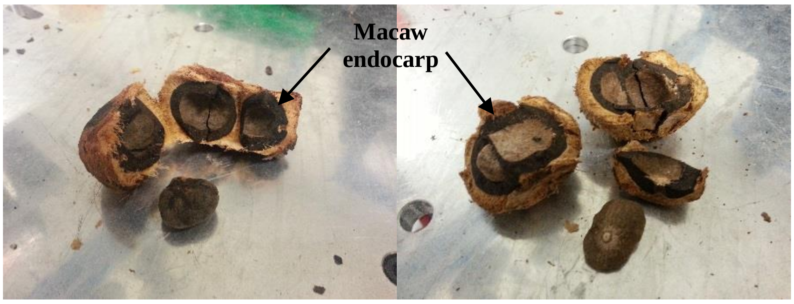

Figure 4. Macaw endocarp broken after the compression experiments.

In the interaction between PC and FDA, it was observed that the rupture force is not differ statistically, when the direction of force application is the same, for the two conditions pulp (Table 5). However, for a pulp condition "Oily" was difference between the averages, for the two directions of force application, however, to dry the same not occurs. In general, the rupture force presented higher values in transversal direction, oily pulp condition and diameter class 3. The endocarp rupture force varied from 5.81 to 8.85 kN, when considered the diameter class and application force direction interaction. Transverse force was higher than longitudinal one for two largest diameters classes. Considering PC and FAD, the highest observed compression force was in the transverse direction with oily pulp condition (7.5 kN).

Table 5. Mean rupture force (kN) for the interaction between pulp conditions (PC) and application of the force directions (FAD).

FAD/PC	Oily	Dry
Longitudinal	6.083 Aa	6.030 Aa
Transverse	7.512 Bb	6.999 Ba

Means followed by the same letter (uppercase in line and lowercase in column) not statistically different, by Tukey test at 5% of probability.

3.2. Displacement of macaw endocarp

The results of the ANOVA, for the deformation of the macaw endocarp, showed that only influenced by the diameter class (Table 6). The coefficient of variation was equal to 41.57%. In Table 7, is showed the result of Tukey test for the displacement of the macaw endocarp. The average of displacements not showed statistical difference for diameter classes 1 and 2. Nevertheless, it was difference when compared with higher diameter class (Class 3). The displacement increase with the diameter class. This fact reinforces the need of fruit classification before extraction of the seeds.

Table 6. Analysis of variance for the displacement (mm) as a function of diameter class, pulp condition and direction of force application.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value
DC	2	200.545	100.273	11.170*
PC	1	3.637	3.637	$0.405^{n.s.}$
FAD	1	10.355	10.355	$1.153^{n.s.}$
DC*PC	2	10.148	5.074	$0.565^{n.s.}$
DC*FAD	2	24.687	12.344	$1.375^{n.s.}$
PC*FAD	1	0.129	0.129	$0.014^{n.s.}$
DC*PC*FAD	2	15.950	7.975	$0.888^{n.s.}$
Error	108	969.510	8.977	
Corrected Total	119	1234.960		
CV (%) =	41.57			

$^{n.s.}$ not significant; *significant at level 5% of probability; F(2,108)=3,081;F(1,108)=3,930. CV = coefficient of variation

Table 7. Displacement of macaw endocarp (kN) for diameter classes (FAD).

	Mean displacement (mm)
Class 1	5.933 A
Class 2	6.633 A
Class 3	8.957 B

Means followed by the same letter (uppercase in line and lowercase in column) not statistically different, by Tukey test at 5% of probability.

4. CONCLUSIONS

The rupture force of macaw endocarp presented dependence on physical parameters, which should be considered in machine design intended to mechanical seeds extraction to produce seedlings. Only diameter class influenced the macaw endocarp displacements.

In general, the rupture force presented higher values in transversal direction, oily pulp condition and higher diameter.

Studies related to determination of physical and mechanical properties of macaw fruit are still scarce and need to be improved. This work certainly added knowledge for further studies and research involving the development of techniques related to macaw seed extraction.

5. ACKNOWLEDGEMENT

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7. RESPONSIBILITY NOTICE

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