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Physical, mechanical and chemical properties of Jatropha curcas L. seeds and kernels

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Introduction

Jatropha curcas L. is a drought – resistant shrub/tree belonging to the family Euphorbiaceae [1, 2]. Cultivated in Central and South America, *Jatropha curcas* was distributed by Portuguese seafarers in Southeast Asia, India and Africa [3]. Propagated by cuttings, is widely planted as a hedge to protect fields from browsed animals. The plant and its seeds are non edible to animal and humans; toxicity of seeds is mainly due to the presence of curcine and deterpine [2, 4].

The existing distribution of Jatropha curcas shows that introduction has been most successful in drier regions of the tropics. It grows on well-drained soils with good aeration and is well adapted to marginal soils with low nutrient content [2].

The potential use of extracted oil from Jatropha curcas as transesterified oil (biodiesel), or as a blend with diesel have been studied [1, 5-7]. The calorific value and cetane number of Jatropha curcas oil are comparable to diesel, but the density and viscosity are much higher [8].

Since the density of oil is high, the engine performance, emissions and combustion parameters can be reached by optimizing the injector opening pressure, injection time, injection rate and enhancing the swirl level of the operated engine [1, 6]. High viscosity of the Jatropha curcas oil is not advantageous for the compression ignition engine. Pramanik (2003) has studied the performance of the engine using blends and Jatropha oil in a single cylinder (compression ignition) engine and made comparison with the performance obtained with diesel. Adequate thermal efficiencies of the engine were obtained with blends containing up to 50 % volume of Jatropha oil. 40–50 % of Jatropha oil can be replaced without any engine modification and preheating of the blends [1, 6].

In the oil industry, different processes must be done before oil extraction occurs. When Jatropha curcas fruits arrive for oil extraction different processes are conducted before: (a) dehulling, separating hull from nut, (b) deshelling, separating shell from kernel, (c) drying and than (d) oil extraction.

Physical, mechanical and chemical properties of seed and kernel are needed for the design of equipment to handle, transport, process, store and assessing the product quality [1, 9, 10].

The aim of this study was to investigate the physical, mechanical and chemical properties of Jatropha curcas L. seeds, as part of optimization of de-shelling and oil extraction of *Jatropha curcas L.* for direct use in plant oil stoves. The considered parameters were bulk/solid density, volume, porosity, surface area, specific surface area, coefficient of friction, static angle of repose, rupture force, deformation at rupture point, deformation ratio at rupture point, hardness, energy used for rupture, moisture content, crude lipids, oil density, kinematic viscosity, gross calorific value, iodine value, water content of oil, C – impurities and acid value. These parameters will be useful in designing of handling and processing equipment.

Materials and Methods

Material used and separation

For this study, dried J. curcas seeds (mc. 9 db.) were imported from India. The place of seed's origin was characterized by an annual precipitation of 1000-1200 mm and a temperature range between 15-35°C. J. curcas plantation was 11-12 years old and its yields were as high as 7500 kg/ha/a. Seeds were harvested manually during November-December 2007 (harvest season) and stored in jute bags in a warehouse facility in a temperature range of 14-30°C.

J. curcas seeds were inspected and manually cleaned to avoid foreign matter. Seeds were separated by a pneumatic conveyor and labeled into four groups according to their average weight. Kernel groups were obtained breaking down the seeds and were classified following their respective seed groups. Seed and kernel groups were used to determine the physical, mechanical and chemical properties of *J.curcas*.

Measurements of physical, mechanical and chemical properties were performed in the Institute of Agricultural Engineering in Tropics and Subtropics, University of Hohenheim. Table 1 demonstrates the physical, mechanical and chemical parameters analyzed and the method used according literature.

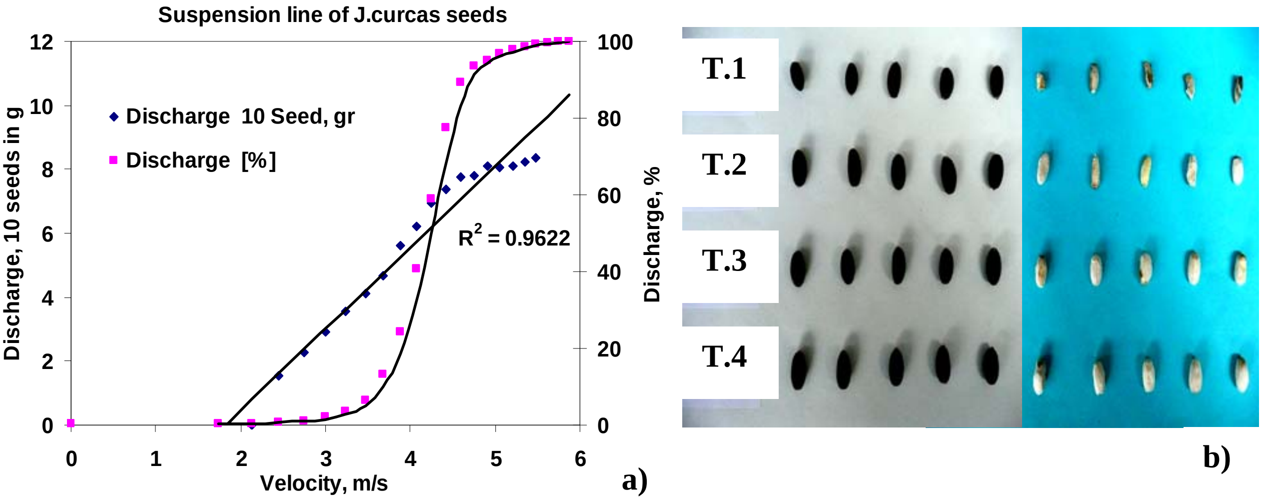
Table 1: Method used for analyzing physical, mechanical and chemical properties of Jatropha curcas seeds, kernels and oil

Physical properties	***Units***	***Literature***
Bulk density	g/cm³	[1, 11]
Solid density	g/cm³	[12]
Volume	cm³	[12]
Porosity	%	[12]
Surface area	mm²	[1, 12]
Specific surface area	cm²/cm³	[1, 12]
Static friction	Value	[13]
Static angle of repose	°	[1, 14]
Dynamic angle of repose	°	[1, 15]
Mechanical properties		
Rupture force	N	[1, 16]
Deformation at rupture force	mm	[1, 16]
Deformation ratio at rupture point	Value	[1, 16]
Hardness	N/mm	[1, 16]
Energy used for rupture	N/mm	[1, 16]
Chemical properties		
Moisture content (seeds & kernels	% db	[17]
Oil content (seeds & kernels)	% db	[18]
Density	kg/m³	[19]
Kinematic viscosity	mm²/s	[20]
Gross calorific value	MJ/kg	[11]
Iodine value	g/100g	[21]
Acid number	KOH/g	[22]
Impurities. C	% mass/max	[23]
Water content in oil	mg/kg	[24]

Results and discussion

Physical properties of *Jatropha curcas* seeds

Figure 1 shows the suspension line of *J.curcas* seeds, air speed needed for suspending different weight fraction of seeds (a), and the four groups of seeds selected based on average weight (b). The average weight of seed groups was; T.1: 0.20g - 0.35g (velocity 3.24 m/s); T.2: 0.36g - 0.50g (velocity 3.68 m/s); T.3: 0.51g - 0.70g (velocity 4.25 m/s) and T.4: 0.71g - 0.90g (velocity 5.88) as shown in Fig 1.b, kernel groups were obtained breaking down the seed of their respective seed groups.



a)

b)

Figure 1: ***Suspension line of J. curcas seeds (a) and selected groups of seeds and kernels based on their average weight (b)***

The groups of seeds and kernels selected shows sizeable differences on morphological parameters. Figure 1.a shows a positive linear correlation between air velocity and seeds weight discharge ($R^2 = 0.9622$).

Table 2 shows the physical properties of *J.curcas* seeds, bulk density, solid density and volume increased with the increase of the groups' size (T.1 – T.4). The statistical analysis for seeds shows significant differences between the groups of seeds at $p \leq 0.01$ % level (Tukey's Test).

Table 2: Physical properties of J. curcas seeds at 9 % mc db

Properties of seeds		***Groups***			
		T.1	***T.2***	***T.3***	***T.4***
	N	***0.2g - 0.35g***	***0.36g - 0,5g***	***0.51g – 0.7g***	***0.71g – 0.9g***
Bulk density, g/cm^3	5	0.25 ± 0.01^{a}	0.30 ± 0.01^{b}	0.38 ± 0.02^{c}	0.44 ± 0.01^{d}
Solid density,g/cm^3	500	0.51 ± 0.13^{a}	0.69 ± 0.13^{b}	0.83 ± 0.08^{c}	0.98 ± 0.06^{d}
Volume, mm^3	500	0.54 ± 0.09^{a}	0.63 ± 0.09^{b}	0.71 ± 0.07^{c}	0.79 ± 0.06^{d}
Porosity, %	500	49.87 ± 12.86^{a}	57.07 ± 6.90^{b}	54.87 ± 4.51^{cd}	55.11 ± 2.84^{d}
Surface area, mm^2	500	434.91 ± 53.57^{a}	474.59 ± 45.89^{b}	507.45 ± 36^{c}	532.89 ± 30.09^{d}
Spec area,mm^2/cm^3	500	4.19 ± 1.02^{a}	3.21 ± 0.43^{ab}	3.12 ± 0.35^{b}	3.05 ± 0.20^{c}
Coefficient of static friction on various surfaces					
Ply wood	10 kg	0.35 ± 0.02^{a}	0.33 ± 0.01^{a}	0.33 ± 0.03^{a}	0.34 ± 0.02^{a}
Aluminium	10 kg	0.36 ± 0.04^{a}	0.35 ± 0.02^{a}	0.33 ± 0.02^{a}	0.32 ± 0.01^{a}
Stainless steel	10 kg	0.22 ± 0.02^{a}	0.21 ± 0.01^{a}	0.22 ± 0.01^{a}	0.23 ± 0.01^{a}
Rubber	10 kg	0.44 ± 0.02^{a}	0.44 ± 0.01^{a}	0.45 ± 0.01^{a}	0.46 ± 0.01^{a}
Angle of repose, °					
Filling method	10 kg	34.80 ± 0.84^{a}	34.60 ± 0.55^{a}	34.00 ± 0.71^{a}	34.40 ± 0.55^{a}
Emptying method	10 kg	32.55 ± 0.46^{ac}	31.19 ± 0.84^{a}	29.84 ± 1.15^{ab}	29.64 ± 0.83^{ab}

* Group means with the same letters are not significantly different at 0.01 level of significance using Tukey's Test

This indicates that solid density, bulk density and volume of seeds have a positive association between groups; the seeds of group T.4 enclose highest magnitude then other groups. Porosity of the seeds increases between the groups T.1 to T.4 but statistical analysis shows that not all groups are significantly different from each other at $p \leq 0.01$ % (Tab 2). Surface area of seeds increases with the increase of groups demonstrating that seeds and kernels in group T.4 are having a higher surface area then other groups. Specific area of seeds decreases between groups; T.1 demonstrates highest value then other groups.

Coefficient of static friction of seeds (Tab 2) on various surfaces shows no significant difference between groups. This mean there were no association between groups and surface used for testing static coefficient of friction. The result shows, that static friction of rubber for seeds is higher then other surfaces and static friction of stainless steel for seeds is the lowest (Tab 2).

Angle of repose of seeds for the filling method is higher than angle of repose emptying method for all groups and the association between groups and angle of repose (filling and emptying method) it is not significant different at $p \leq 0.01$ % according Tukey test (Tab 2).

Mechanical properties of *J.curcas* seeds

The mechanical properties of J.curcas seeds including rupture force, deformation at rupture point, hardness and energy used for rupture on three different position loads (horizontal, transversal and vertical) are presented in Table 3. The force needed to rupture a seed is higher for group T.4 and lowest for the group T.1. This indicates that seeds with bigger mass needs higher compression load for rupture. Vertical position for seeds shows as well the highest force needed for rupture compared with other loading position.

Table 3: Mechanical properties of J.curcas seeds at 9 % mc db

Seed Groups	***Loading Position***	***Rupture Force (N)***	***Deformation at Rupture Point (mm)***	***Hardness (N/mm)***	***Energy used for Rupture (Nmm)***
T.1	Horizontal	78.20 ± 18.852^{a}	0.96 ± 0.25^{a}	85.44 ± 26.96^{a}	74.89 ± 25.92^{a}
T.2		95.21 ± 16.34^{ab}	0.93 ± 0.16^{a}	103.20 ± 17.80^{ab}	90.20 ± 26.78^{a}
T.3		114.23 ± 18.85^{bc}	0.94 ± 0.14^{a}	123.56 ± 27.82^{bc}	108.11 ± 25.66^{ab}
T.4		131.75 ± 21.39^{c}	1.03 ± 0.12^{a}	129.69 ± 23.20^{c}	135.41 ± 28.59^{c}
T.1	Transversal	69.41 ± 15.30^{a}	1.11 ± 0.30^{a}	67.30 ± 24.59^{a}	75.70 ± 21.17^{a}
T.2		70.80 ± 18.47^{a}	1.05 ± 0.23^{ab}	70.04 ± 21.35^{a}	74.82 ± 29.72^{a}
T.3		81.57 ± 26.49^{a}	0.85 ± 0.39^{ab}	104.87 ± 29.48^{bc}	73.42 ± 44.60^{a}
T.4		86.13 ± 24.34^{a}	0.78 ± 0.19^{b}	113.19 ± 24.11^{c}	69.25 ± 30.87^{a}
T.1	Vertical	118.22 ± 23.89^{a}	0.92 ± 0.26^{a}	141.40 ± 61.83^{a}	107.67 ± 35.15^{a}
T.2		121.21 ± 25.24^{a}	0.92 ± 0.29^{a}	140.86 ± 45.02^{a}	112.00 ± 39.29^{a}
T.3		151.11 ± 22.04^{b}	0.77 ± 0.18^{a}	208.53 ± 60.78^{b}	114.61 ± 25.73^{a}
T.4		174.96 ± 22.99^{b}	0.76 ± 0.20^{a}	242.00 ± 59.08^{b}	133.98 ± 40.64^{a}

* Group means with the same letters are not significantly different at 0.01 level of significance using Tukey's Test

The deformation at rupture point, statistical analysis shows no significant differences between groups of seeds at $p \leq 0.01$ % according Tukey test. This mean the deformation at rupture point is not influenced on seeds mass. Results show that the hardness of seeds is higher in vertical loading position than other loading positions. Consequently the energy used for rupture of seeds on vertical position required more energy for rupture than other loading positions.

Chemical properties of J.curcas seeds and kernels

The oil content of seeds and kernels were analyzed fro all four groups (T.1, T.2, T.3 and T.4) with soxhlet method [18] and the results are presented in Table 4. The oil content of kernel is approximately 20 % higher then the oil content of seeds on every group. Group T.4 demonstrate the highest oil content for seeds and kernel (T.4 kernels = 38 %; T.4 seeds = 56 %).

Statistical analyses for seeds oil content demonstrates that the association of oil content against groups is expressed with a very high linear correlation (R^2 =0.9771) and the mean values according Tukey's test and Fisher test are significantly different between the groups at $p \leq 0.01$. Kernels oil content demonstrates as well a very high linear correlation (R^2 = 0.936) but not all the group means (Tukey's and Fisher test) are significantly different, group T.3 is not different from group T.4 at $p \leq 0.01$.

Table 4: Oil content and dry matter content of seeds and kernels

Property	T.1	T.2	T.3	T.4
Oil content seeds (%)	7.19±2.63^{a}	18.66±3.94^{b}	33.01±0.61^{c}	38.94±0.99^{d}
Oil content kernels (%)	24.26±5.74^{a}	40.15±5.85^{b}	53.20±0.41^{c}	56.61±0.46d^{c}
Dry matter shells (%)	91.065±0.08^{a}	91.06±0.22^{a}	91.30±0.13^{a}	91.24±0.17^{a}
Dry matter kernels (%)	92.45±0.39^{a}	94.52±0.14^{b}	95.75±0.43^{c}	95.89±0.26^{dc}

* Group means with the same letters are not significantly different at $p \leq 0.01$ using Tukey's and Fisher Test

Results show dry matter of shells higher than dry matter of kernels; this indicates that kernels contain less moisture content. Shells dry matter proves no significant differences between groups at $p \leq 0.01$ probability. Whereas, dry matter of kernels proves that groups are significant different at $p \leq 0.01$ using Tukey's and Fisher test.

Chemical analyses were completed on *Jatropha curcas* oil extracted from mechanical screw press and results were compared with properties of Raps oil and EN 14214 (Table 5). The density and kinematic viscosity of *J.curcas* was lower than Raps oil but higher than the European Standard. Gross calorific value and iodine value was comparable with Rape seed oil and EN 14214.

Table 5: Chemical properties of J.curcas oil seeds compared with Raps oil and European Standard Norms 14214

Property	*J. Curcas oil*	*Rape seed oil*	EN 14214
Density kg/m³	914	920	860 - 900
Kin. Viscosity mm²/s (40°C)	31.2	35.8	3.5 - 5.0
Gross calorific value MJ/kg	39.66	39.6	>35
Iodine value g/100g	100	111	<120
Impurities. C % mass/max	0.11	0.19	<0.30
Water content mg/kg	822.8	609.4	<500
Acid value KOH/g	2.81	1.68	<0.50

Carbon impurities were lower in *J.curcas* oil compared with Rape seed oil and were fulfilling EN 14214 requirements. The water content and acid value displayed the highest negative properties compared with Rape seed oil and EN 14214.

Conclusions

As the main objective of this study was; investigation of physical, mechanical and chemical properties of *Jatropha curcas L.* seeds, as part of optimization of de-shelling and oil extraction of *Jatropha curcas L.* for direct use in plant oil stoves, following conclusion were determined.

1. Sorting *J.curcas* seeds into four groups (T 1, T.2, T.3, and T.4) based on average weight could distinct the product quality of *J.curcas* seeds.
2. Physical, mechanical and chemical properties of seeds were investigated in this study for:

    - designing of post harvesting equipment
    - deshelling equipment
    - optimizing press oil extraction (screw press dimension, press cylinder)

3. At present *J.curcas* oil has a great role as a resource for green fuel because the oil properties are compared with those of rape seed oil and EN 14214.

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