A REVIEW OF THE PHISYCAL, MECHANICAL, THERMAL, AND CHEMICAL PROPERTIES OF JATROPHA CURCAS SEEDS AS BASIC INFORMATION FOR OIL PRESSING

Riswanti Sigalingging,

Agricultural Engineering, University of Sumatera Utara, Indonesia.
Department of Mechanical Engineering, Faculty of Engineering,
Czech University of Life Sciences, Prague, Czech Republic.

David Herak,

Department of Mechanical Engineering,
Faculty of Engineering,
Czech University of Life Sciences,
Prague, Czech Republic.

Abraham Kabutey,

Department of Mechanical Engineering,
Faculty of Engineering,
Czech University of Life Sciences,
Prague, Czech Republic.

Monika Divisova,

Department of Mechanical Engineering,
Faculty of Engineering,
Czech University of Life Sciences,
Prague, Czech Republic.

TerezaStatonova,

Department of Mechanical Engineering,
Faculty of Engineering,
Czech University of Life Sciences,
Prague, Czech Republic.

ABSTRACT

This article is concentrated on the physical, mechanical, thermal and chemical properties of *Jatrophacurcas* seeds base on review literatures. Because of them those properties that involve a reaction to an applied load to extract oil and also are used to help classify and identify them. Therefore, an understanding of them is important factors for a particular designs a machine. Being able to predict the energy demand for rupture them to extract oil because the cost of extraction oilseeds and processing oil into biofuel must be more little than the value of oilseeds, after it was extracted from seeds or the value of biofuel is higher than oilseeds so that the economic returns. The aims of this review are to detail the characteristic of physical, mechanical, thermal and chemical properties *Jatrophacurcas* seeds so that logically organize the knowledge around the function of Mathematics to describe it.

Keywords: properties, jatropha seed, oil pressing, mathematics formula

INTRODUCTION:

Bioenergy as a fuel other than beneficial to the environment, raw materials also come from renewable sources such as *Jatrophacurcas* seeds, Rape seeds, and Sunflowers seeds. The oil derived from the seeds of the plant can be used as diesel fuel (biodiesel). It is also a solution to meet the fuel that needs of industry and transport sector is increasing.

The problem of bioenergy especially biofuels is to extract oil from oilseeds and to convert oil such as biodiesel required some energy. An understanding of the mechanical behavior of seeds is an important factor to design a machine and to predict the energy demand to extract oil, because the cost of oil extraction and oil processing into biofuels should be lower than the value of the oil feedstock or biofuel value should be higher than the oil to obtain economic benefits. Therefore, it must be known the physical, mechanical, thermal and chemical properties of seeds because this is important during design, improvement and optimization of the rupture force of seeds, in order to estimating the rupture force so the machine will be more efficient of energy. In addition, data on thermophysical and mechanical properties such basic information not only engineers that require but also food scientists, processors, plant breeders and other scientists who may find new uses.

Moreover, mechanical pressing is most popular method in the world to separate oil from vegetable seeds crops. Thus, the impact of several variables on oil recovery, oil quality, rupture force of seeds, deformation, and energy cost for pressing is essential for an adequate design of equipment for pressing seeds crops. This paper is going to be focused on a review of the theories of mechanical properties of oil bearing seeds crops as specially Jatrophacurcas seeds.

Many manufacturing companies were trying to introduce such knowledge into production, but it has not been a description of the mechanical behavior of oil bearing crops seeds in the literature adequately described. This knowledge is only in an inert companies environment and usually not disclosed. The aims of this review are to detail the characteristic of physical, mechanical, thermal and chemical properties of *Jatrophacurcas* seeds as a basic for oil pressing to establish the Mathematics formula in the future.

PHYSICAL PROPERTIES:

Physical properties are those that can be observed without changing the identity of the substance. The general properties of matter such as density, porosity, volume, static friction, and angle of repose are examples of physical properties (Table 1).

Tabel 1. Physical properties *Jatrophacurcas* seeds

Physical Properties	Units	Value	Literature
Bulk density	g/cm^3	0.492-0.419[a]	[1,9]
		0.250-0.440[b]	[2,9]
		0.354-0.405[c,f]	[3,9]
		0.428-0.474[d]	[4,9]
True density	g/cm^3	0.510-0.980[b,e]	[2,9]
		0.863-1.035[d]	[4,9]
Porosity	%	58.14-63.49[c]	[3,9]
		50.3-54.2[d]	[4,9]
Volume	mm^3	0.540-0.790[b,e]	[2,6]
		84,834-628,400[c,f]	[3]
Surface area	mm^2	476.78-521.99[a]	[1,9]
		434.91-532.89[b,e]	[2,9]
Spesific surface area	cm^2/cm^3	3.05-4.19[b,e]	[2,9]
Static friction coefficient in different materials	value		
• Plywood	-	0.330-0.550	[1,2,4,5,6,9]
• Stainless steel	-	0.2100-0.6415	[1,2,4,5,6,9]
• Aluminium	-	0.3400-0.6863	[1,2,6,9]
• Rubber	-	0.4475	[2,6]
• Glass	-	0.30-0.39	[4]
Static angle of repose	o	34.00-34.80[b,g]	[2,6,9]
Dynamic angle of repose	o	29.64-32.55[b,h]	[2,6,9]

[a]4.75-19.57 % d.w moisture content; [b]9 % d.b moisture content; [c]8.5 % d.b moisture content; [d]5.85-25.85 % d.b moisture content for 1000 seeds with different size; [e]for 500 seeds; [f]Using three pressing devices and plungers of diameters 60, 80, and 100 mm with six initial heights 30, 40, 50, 60, 70, 80 and 80 mm; [g] using filling method for 10 kg seeds; [h]using emptying method for 10 kg seeds

The knowledge bulk density of *Jatrophacurcas* seeds is important to know for guiding as a reference tool to assist engineer in designing a production system. Because the bulk density of *Jatrophacurcas* seed varies greatly depending on how the *Jatrophacurcas* seeds have been handled, the information contained in this reference tool should be used for estimation purposes only. The bulk density is the ratio of the mass of the sample to its container volume (Eq. 1), which was measured by weighing a filled measuring cylinder with known volume. However, the bulk density of *Jatrophacurcas* seed is not only depended on moisture content and size of seeds but also diameters and heights of cylinder that was used as medium. Moreover, bulk density of the seeds would be influenced by the temperature of drying of seeds [9].

$$\rho_b = \frac{m}{V} \tag{1}$$

Where: $\rho_b$is the bulk density (g/cm^3), m is mass of the *Jatrophacurcas* seeds (g) and *V* is the volume of cylinder (cm^3). Furthermore, true density or solid density (Eq. 2) is the ratio between the mass of *Jatrophacurcas* seed and the true volume of seed which can be determined using the solvent displacement method [15] for instance using toluene (C_7H_8) displacement method (Eq. 3) [1,16]. Also, it can be determined (Eq. 4) based on the on assumption that *Jatrophacurcas* seeds are similar to ellipsoid (Fig. 1) where x>y>z [6,18].

$$\rho_{tr} = \frac{m}{N.V_{tr}} \tag{2}$$

$$V_{tr} = \frac{m_{tl}}{\rho_{tl}} \tag{3}$$

$$V_{tr} = \frac{\frac{4}{3}\pi.(x.y.z)}{1000} \tag{4}$$

Where: $\rho_{tr}$is the true density (g/cm^3), $\rho_{tl}$is the density of toluene (0.86 g/cm^3); m_{tl} is the mass weighed in toluene (g); N is number of seed in the sample (-) and V_{tr} is the volume of seed (cm^3). Based on Table 1, the true density is depended on moisture content and size of the seeds. The increase of true density is not only because of an increasing of moisture content [1] but also due to the increase of seeds size of Jatrophacurcas [2].

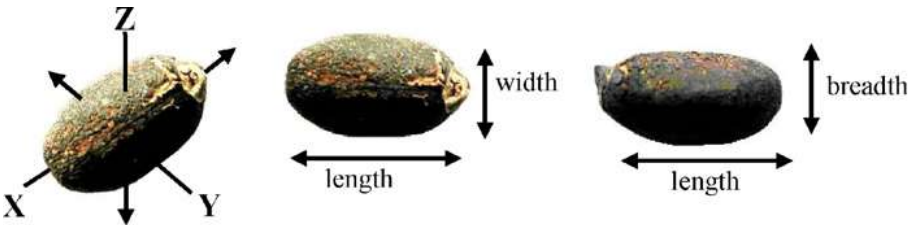

Figure.1. Three major dimensions of J. curcas seeds where x-axis is length, y-axis is width and z-axis is breadth

On the other hand, the porosity, ε (%) is the ratio of the volume of internal pores in the particle to its bulk volume (Eq.5) [17]. The porosity decreases linearity with the decrease of moisture content of seeds while bulk density increase linearity with the increase of moisture content of seeds [18]. Addition, the temperature of heat-treatment of *Jatrophacurcas* seeds affect for value of the porosity. It was investigated that the porosity of the driest seeds with 80 C was 46.00% while that of the more moist seeds with 40 C and 60 C was higher (57.93–59.31%) after each heat treatment [9]

$$\varepsilon = 1 - \frac{\rho_b}{\rho_{tr}}\ x\ 100\% \tag{5}$$

For the volumes (Table 1) are two types. The firstly, the true volume was determined by Eq. 4 which was used to know the true density of *Jatrophacurcas* seeds. The secondly, the volume of container (Fig. 2) was determined by Eq. 6 [19].

$$V = \frac{1}{4}\pi.D^2.H \tag{6}$$

Where: *D*is the diameter of cylinder (cm), *H*is the height of bulk Jatrophacurcas seeds (cm).

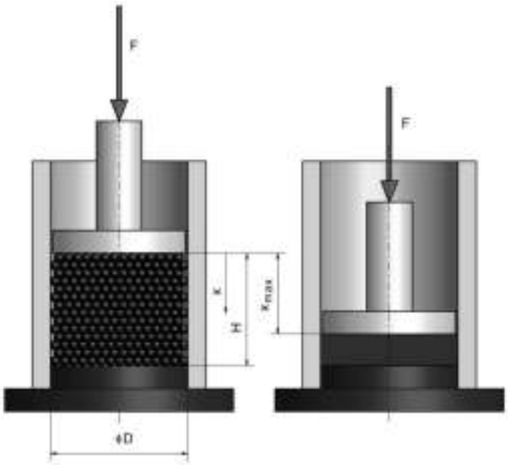

Figure 2. Scheme of pressing vessel diameter showing the influence of pressing force on measured bulk seeds pressing height

Surface area, S (mm^2) and specific surface area, S_{sp} (mm^2/cm^3) can be estimated by Eq. 7 and 8. It was determined by approximating of the geometrical shape of *Jatrophacurcas* seeds similar with spherical and ellipsoidal (Table 1) [5,6]. The specific surface area of dried kernels was more affected by the size of the kernels than the moisture content. The higher the specific surface area, the higher the mass or energy transfer rate through the surface [9].

$$S = 2\pi\left[\left(\frac{y}{x}\right)^2 + \frac{x.y}{4\left[1-\left(\frac{y}{x}\right)^2\right]^{1/2}}.arc\sin\left[1-\left(\frac{y}{x}\right)^2\right]^{1/2}\right] \tag{7}$$

$$S_{sp} = \frac{S.\rho_b}{m} \tag{8}$$

Coefficient of static friction, static and dynamic angle of repose can be determined by Eq. 9 (Fig.3) [5,20]. The angle of repose is the cohesion among the individual units of seed, which will increase with the increase of the cohesion. It can be measured in two ways: 1) the filling method, which is used to determine the static angle of repose, and 2) the emptying method, which is used to determine dynamic angle of repose [6], Table 1 shows the value of them.

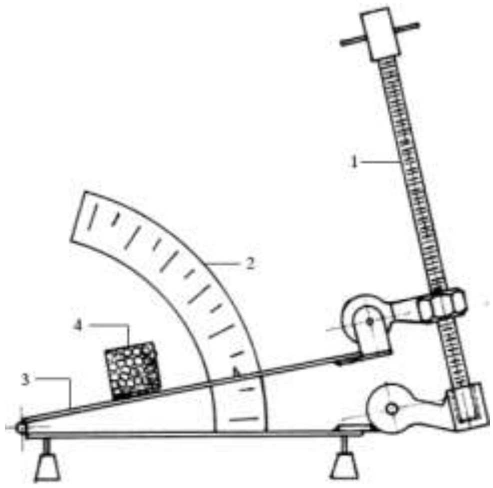

Figure 3. Determination of static coefficient of friction and angle of repose; 1. Screw for adjusting of tilt; 2. Scale for measuring angle of tilt; 3. Adjustable tilting plate; 4. Cylinder filled with the sample

$$\mu = \tan\theta \tag{9}$$

Where: $\mu$is the coefficient of friction (-), $\theta$is the angle of repose (^{o}). Addition, the angle of repose can be calculated by the measurement of height of free surface of the sample at the center [20].Addition, the values of angle of repose for the filling method of dried kernel and steamed kernels had reported by [9] that the dried kernel lower (26.10–33.06) than those for fresh kernels (60.23). This was because of the drier surfaces of the dried kernels and the moister and less viscous surfaces of the steamed kernels than the fresh kernels. This caused the dried kernels and steamed kernels to move or flow better, even though their sphericity was lower. For the emptying method, the value for dried kernels was not much different (39.87– 42.67) from the value for fresh kernels (42.92) [9]

MECHANICAL PROPERTIES:

Several researchers [2,4,6] have reported the mechanical properties of *Jatrophacurcas* seeds. Rupture force, deformation at rupture point, hardness and energy for rupture were calculated by them (Table 2). The rupture force, F (N) is the minimum force required to break the *Jatrophacurcas* seeds. It was determined in three major directions with unit mass for horizontal (x), vertical (z) and transversal (y) (Fig. 1). Vertical position was highest values of rupture force while the lowest was in transversal direction [6].
Deformation at rupture point is the deformation at loading direction (Table 2) [6]. For the description of mechanical behaviour and deformation characteristics of *Jatrophacurcas* seeds in linear compression test (Fig. 2), a single pressing diameter of 76 mm [19,21,22,24] and varying pressing diameters ranging between 40 mm and 100 mm [23,25] have been used whereby the deformation characteristics of *Jatrophacurcas* seeds pressing heights of 20 mm, 30 mm, 40 mm, 50 mm, 60 mm, 70 mm and 80 mm were respectively pressed [22,23,25] using the compression device ZDM 50-2313/56/18 with a chart recorder (VEB, Dresden, Germany) at constant compressive force 100 kN with pressing speed 1 mm·s^{-1}.
It was observed that after the compression test, the dependency between the compressive force and deformation characteristics curve was further analysed using the software Engauge Digitizer 4.1 [27] to measure the actual value of the compressive force and deformation in which the compression process completed. It is important to note here that the area under the linear dependency between the compressive force and deformation curve represent the deformation energy [21] which can be mathematically determined using the equation [22].
Experimentally, the linear dependency between the compressive force and deformation characteristic curve is shown in Fig. 4 [22,23,25]. This experimental dependency can be described by the function (Eq.10) [22].

$$F(x) = f(x) \qquad (10)$$

Where *F* is the compressive or pressing force (N) and (*x*) is the deformation (mm) of bulk seed. The tangent curve function was later modified as described in Eq. 10:

$$F(x) = A \cdot \tan(B \cdot x)^{n} \qquad (11)$$

Where *A* is the force coefficient of the mechanical behaviour (N), *B* is the deformation coefficient of the mechanical behaviour (mm^{-1}) and *n* is the exponent of fitted function (-) for *Jatrophacurcas* seeds n=2. Based on Eq. 11, the strain energy and modulus of elasticity in compression can be determined [21,22].

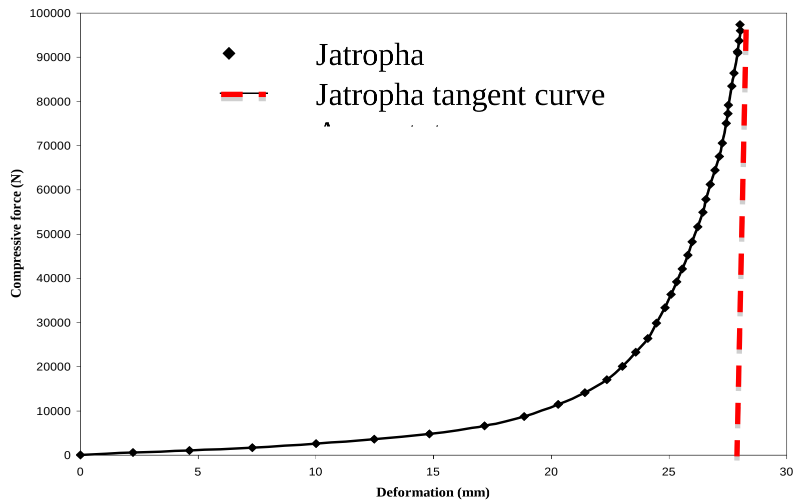

Figure 4. Compressive force and deformation of Jatrophacurcasseeds at 40mm pressing height

The authors in their studies indicated that using the above function (Eq. 11), an ideal method for regression using the Levenberg-Marquardt algorithm [26] that provides numerical solutions to the problem of minimizing deviations in non-linear functions in relation to function parameters can also be described. Most importantly, the Levenberg-Marquardt process is used in Mathcad software 14 (MathCAD 14, PTC Software, Needham, MA, USA), [28] which operates with “genfit” function thus it collaborates with Levenberg-Marquardt algorithm for the development of the tangent curve mathematical model. The tangent curve model as described in (Eq. 11) indicates that the linear experimental data with respect to the dependency between the compressive force and deformation can be fitted which is dependent on single pressing vessel diameter and bulk seed pressing height.

Tabel 2. Mechanical properties *Jatrophacurcas* seeds

Mechanical properties	units	value	literature
Rupture force	N	78.20-131.75[b,i]	[2,6]
		69.41-86.13[b,j]	[2,6]
		118.22-174.96[b,k]	[2,6]
		113.99-81.86[d,i]	[4,6]
		29.47-26.83[d,j]	[4,6]
		95.48-82.77[d,k]	[4,6]
Deformation at rupture force	mm	0.93-1.03[b,i]	[2,6]
		1.11-0.78[b,j]	[2,6]
		0.92-0.76[b,k]	[2,6]
		0.43-0.40[d,i]	[4,6]
		2.50-1.44[d,j]	[4,6]
		1.72-2.21[d,k]	[4,6]
Hardness	N/mm	85.44-129.69[b,i]	[2,6]
		67.30-113.19[b,j]	[2,6]
		141.40-242.00[b,k]	[2,6]
		68.78-61.40[d,i]	[4,6]
		67.75-45.50[d,j]	[4,6]
		55.51-36.72[d,k]	[4,6]
Energy used for rupture	N.mm	74.89-135.41[b,i]	[2,6]
		75-70-69.25[b,j]	[2,6]
		107.67-133.98[b,k]	[2,6]
		113.61-113.34[d,i]	[4,6]
		35.19-35.14[d,j]	[4,6]
		96.26-96.15[d,k]	[4,6]

[i]horizontal (x) loading direction; [j]transversal (y) loading direction; [k]vertical (z) loading direction

Energy for rupture, W (N.mm) is the energy required to rupture *Jatrophacurcas* seeds (Table 2) [6], which could be determined from area under curve the deformation and the rupture point (Fig.4). Also, it can be calculated by the integration of the tangent curve models (Eq. 11) produces an equation for the energy, W(J) (Eq. 12) determination of a particular *Jatrophacurcas* seeds in reference to the exponent function (n) value. On the other hand, hardness (Table 2) is the ratio of rupture force and deformation at rupture point. Addition, using of the tangent curve model satisfies the conditions of the linear compression which includes that when the compressive force increases to infinity the deformation reaches the maximum limit, zero compressive force means zero deformation and the integral of the tangent curve function is the energy (Fig. 4) [21].

$$W(x) = \int F(x)\,dx \tag{12}$$

THERMAL PROPERTIES:

The primary thermal properties of agricultural products are the specific heat, thermal conductivity and thermal diffusivity [7]. The specific heat is the amount of energy required to raise 1 gram the temperature of *Jatrophacurcas* seeds by 1 Kelvin, while the thermal conductivity and thermal diffusivity are involved in the determination of the rate of heat transfer which are useful in the design of efficient process equipment. Therefore, it is necessary to understand all of them to allow for efficient processing of *Jatrophacurcas* seeds, especially for oil extraction using mechanical method. Nowadays, only few researchers have reported the values of them (Table 2). The relationship among them can be established via Eq. 13 [7].

$$\alpha = \frac{k}{\rho_b . c_p} \tag{13}$$

where: α(m^2/s) is the thermal diffusivity, k(W/m °C) is thermalconductivity, Cp(J/g °C)is he specific heat. Equilibrium moisture content (Table 2) isthe moisture content of a hygroscopic material in equilibrium with a particular environment (temperature and relative humidity), which attractive approach to control the Free Fatty Acid (FFA) in the seed level is by controlling water activity of the seed to a level that disables any undesirable reactions or enzyme activities. A fundamental approach for controlling the water activity of the seed is by understanding of seed characteristics and its behaviour in responding the changes in environmental conditions, particularly the relative humidity. Because it can be known conditions of *Jatrophacurcas* adsorption or desorption. Thus fundamental understanding of the hygroscopic properties of *Jatrophacurcas* seed allowing the development of models correlating the equilibrium moisture content and the FFA content as a function of water activity and equilibrium moisture content [8].

Tabel 3. Thermal properties *Jatrophacurcas* seeds

Thermal properties	units	value	literature
Specific heat (25 to 100 °C)	J/g °C	$0.7852\text{-}1.3929^{l,n}$	[7]
		$1.3823\text{-}2.4510^{l,q}$	[7]
		$0.6258\text{-}0.9933^{m,n}$	[7]
		$0.8930\text{-}1.7810^{m,q}$	[7]
Thermal conductivity (25-100 °C)	W/m °C	$0.0663\text{-}0.1181^{l,o}$ $0.0593\text{-}0.1087^{l,p}$	[7] [7]
		$0.0536\text{-}0.1015^{l,q}$	[7]
		$0.0608\text{-}0.0977^{m,o}$	[7]
		$0.0527\text{-}0.0841^{m,p}$	[7]
		$0.0452\text{-}0.0740^{m,q}$	[7]
Thermal diffusivity	m^2/s	$9.303 \times 10^{-6 l,o}$	[7]
		$8.370 \times 10^{-6 l,p}$	[7]
		$7.456 \times 10^{-6 l,q}$	[7]
		$8.792 \times 10^{-6 m,o}$	[7]
		$7.723 \times 10^{-6 m,p}$	[7]
		$6.652 \times 10^{-6 m,q}$	[7]
Equilibrium moisture content (20 °C)		$0.33\text{-}6.71^{r}$	[8]
		$0.42\text{-}9.04^{s}$	[8]

^{l}ripe stage (yellow fruit); ^{m}fully ripe stage (black fruit); ^{n}small piece kernel; ^{o}whole kernels; ^{p}1/4 kernels; ^{q}kernel powder; ^{r}Lampung, Indonesia variety with 1-10 water activity; ^{s}Banten, Indonesia variety with 1-10 water activity

CHEMICAL PROPERTIES:

Many researchers had studied the characteristics and composition of seed oil from *Jatrophacurcas*. Those studies indicated that the processing condition resulted in different oil yield, acid value, oleic acid and viscosity. However, the viscosity, free fatty acids and density of the oil and the biodiesel are stable within the period of storage [46]. The oil content in *Jatrophacurcas*seeds is around 30–40% [43]. In addition, oil contents, physicochemical properties, fatty acid composition and energy values of Jatropha species were investigated [39,40,41,42,44,45], density, kinematic viscosity, and crushing strength of fruit and seed [1,18]. Several of the chemical properties were showed Table 3.

Tabel 3. Chemical properties *Jatrophacurcas* seeds

Chemical properties			
Oil content	% db	47.25	[12]
Density (20 °C)	g/ml	0.90317	[47]
Kinematic viscosity (30 °C)	cSt	17.1	[12]
Gross calorific value	MJ/kg	20.85^{t}	[10]
		37.83^{u}	[10]
		40.63^{v}	[10]
Iodine value	mg I_2/g	105.2-111.1	[12,13]
Acid number	mg KOH/g	3.5-4.24	[12,13

[t]seed with 0 % moisture content; [u]oil of the seed; [v]the hydrocarbon fraction

OIL PRESSING:

Review of the literature has revealed research, which has been conducted on the oil extraction methods. There are three main methods that have been identified for extraction of the oil: mechanical extraction, solvent extraction, and enzymatic extraction. In either way of utilization, the yield and properties of the extracted oil are very important, and needs to be well understood.

However, mechanical extraction is oldest, commonly, and the most conventional one among other methods. In this type, either a manual ram press or an engine driven screw press can be used and also can be operated on both batch and continuous processes [32]. The process used for mechanical extraction methods of *Jatrophacurcas* are the commonly used as reported in literature [29,30]. Mechanical oil extraction means using some short of pressing machine to force oil out of the oil seeds.

Pressing process has been widely described in the literature considering the effect of process parameters (pressure, temperature, etc.) and the impact of raw material (seed species, seed cultivar, pre-treatment, etc.) [34]. Some cell wall damage could be observed but the main oil flow is supposed occurring through plasmodesmas, meatus and extra cellular structure [37].

RESULTS AND DISCUSSION:

In many instances, knowing physical, mechanical, thermal and chemical properties of *Jatrophacurcas* seeds are basic to establish the Mathematics formula for helping to determine their values. Based on this can be extended a formula for oil extraction of *Jatrophacurcas* especiallymechanical method. Because of this method is still better option for oil extraction than others. For the process is more practical; the time required is shorter than the other processes. Therefore, more resources into research and development and machine design are needed. However, in designing a press machine requires information and knowledge to be extracted from the seeds of that great power that would be given right thus energy efficiency is achieved. Indeed, there are many studies that have reported on the technology of oil extraction using extraction techniques such as using a mechanical screw press. However, in this case there is no mathematical model as a tool that can help calculate the amount of force that must be given. By using the tangent curve function will be very helpful in designing the machine. However, the magnitude of the force that must be given to take out oil from compressed solid particles. Furthermore, physical, mechanical, thermal and chemical properties are important to know for the development of these functions. Required develop this formula with respect to grain hardness, viscosity of the fluid (a mixture of oil and water) as well as the texture of the seeds.

This review has highlighted by that, the absence of a complete study reported an association among moisture content [34], oil viscosity, oil quality, temperature during extraction [31,33,34,35,36,38], force, the energy required for the percentage of oil extraction yield. Therefore, it is needed developing a mathematical model that can able to cover all of them.

CONCLUSIONS AND SUGGESTION:

The physical, mechanical, thermal and chemical properties are really important to be known for developing Mathematics functions. Because it is needed to know the correlation among moisture content, temperature during process, yield oil, oil quality, rapture force, and energy demand based on these functions collaboration others formula which is conducted physical, mechanical, thermal and chemical properties of Jatrophacurcas seeds.

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