HEAT TREATMENT OF *JATROPHA CURCAS* L. SEEDS UNDER COMPRESSION LOADING

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Using the compression device ZDM 50-2313/56/18 with a chart recorder, pressing vessel of diameter 60 mm and a plunger, the effect of heat treatment temperature on *Jatropha curcas* L. seeds was investigated where parameters including compressive force (N), seed deformation (mm), deformation energy (J) and seed hardness (N/mm) were determined. Before the experiment, the jatropha seeds were cleaned from all foreign matter and were grouped into five different samples. These samples were pre-heated at temperature levels from 75, 85, 95, 105 and 115 °C, respectively, at pre-heating time 30 minutes constant and each sample was replicated three times where average values were used in all calculations. Statistical analysis at 0.05 significant level showed that pre-heating temperatures of the jatropha seeds before compression increased seed deformation (mm), deformation energy (J) and compressive force (N). Contrary, seed hardness (N/mm) decreased in relation to the effect of pre-heating temperatures. Polynomial function best described all the measured dependencies. The study indicated that heat-treatment temperature could influence the mechanical behaviour of *Jatropha curcas* L. seeds under compression loading.

jatropha seeds; pre-heating temperatures; seed deformation; energy; seed hardness; compressive force

INTRODUCTION

Jatropha or physic nut, botanically *Jatropha curcas* L. is a perennial shrub and a member of the Euphorbiaceae family which has received global attention as an alternative energy resource (Olalusi, Bolaji, 2010). The plant thrives in arid conditions and the seeds contain 28-36% oil that can be processed to produce a high quality biodiesel fuel usable in a standard diesel engine (Bamgboye, Adebayo, 2012). For many it is seen as a potential saviour for marginal lands, a plant that could lift developing countries out of poverty and into a sustainable energy future as reported by Sanderson (2009).

As a result of the potential use of the crop, some researchers have shown great interest investigating the physical and mechanical properties (Sirisomboon, Kitchaiya, 2009; Olalusi, Bolaji, 2010; Herak et al., 2010; Kabutey et al., 2011; Bamboye, Adebayo, 2012) as a way to optimizing the processing technology for high oil recovery. Gutiérrez et al., 2008, cited from Sirisomboon, Kitchaiya, 2009, reported that oil extraction involves various preliminary operations such as cleaning, dehulling, drying and grinding but the total amount of extracted oil depends mainly on the extraction time, moisture content, particle size of the oil-bearing material and temperature.

However, for the design and construction of equipment and structures for handling, transportation, processing and storage associated with oil extraction from oilseed crops such as *Jatropha curcas* L., it is necessary to understand both the physical and mechanical properties. In the literature, the mechanical properties of the oilseed crop *Jatropha curcas* L. under conditions of heat treatment temperature are actually limited compared with the effect of moisture content (Kabutey et al., 2011). Usually the mechanical properties include rupture force, seed deformation at rupture force, seed hardness and deformation energy required for rupturing the fruits, nuts and kernels which could be determined from the area under the force-deformation curve (Grzegorz, 2007). Understanding these behaviours of oilseed crops such as jatropha would be important for determining the right pressing force and the amount of energy needed for obtaining the oil. These parameters are in most cases influenced by pressing temperature and seed moisture content at the time of pressing (Herak et al., 2010; Kabutey et al., 2011).

According to Shomer (1995); Bourne (1982), the softening phenomenon that occurs in plant materials upon heating result in cell separation or cell rupture and the firmness of biomaterials varies with temperature and that most biomaterials show slight linear softening with increasing temperature. Also Ramana et al., 1992 investigated cellular integrity during heating by microscopic examination. Their results showed that the protoplasts were disrupted at approximately 60 °C and the cells lost their integrity between 50 °C and 65 °C.

On the other hand, Burubai et al., 2007 reported that seed deformation of African nutmeg (*Monodora myristica*) increased with increasing temperatures whiles failure stress, stain energy and Young's modulus all tended to decrease with an increase in pre-heating temperature. The objective of this article was to investigate the effect of heat treatment of varying temperatures on compressive force, seed deformation, deformation energy and seed hardness of *Jatropha curcas* L. seeds under compression loading.

MATERIALS AND METHOD

Dried jatropha seeds of moisture content 9% w.b. obtained from Česká Skalice, Czech Republic and originally from Sumatra, Indonesia were used for the experiment. Before the compression test the seeds were manually cleaned from all foreign matter and damaged seeds were also removed and then grouped into five different samples. The temperature heating device type EB7 from Czech Republic was used to test the temperature effect on the samples. The samples were repeated three consecutive times and each subjected to the compression test. The STATISTICA Statsoft (2010) was used for the analysis of results.

Compression test

The compression machine ZDM 50-2313/56/18 of load set at 10 kN, pressing vessel of diameter 60 mm and a plunger (Fig. 1) were used to record the dependency between pressing force and deformation as a function of pre-heating temperatures ranging between 75 and 115 °C. Seed volume in the pressing vessel was measured at height, H = 30 mm for all heated samples before pressing with a pressing rate of v = 1 mm s^{-1}. Afterwards, the force-deformation curves obtained directly from the pressing were again analyzed using the software programme Engauge Digitizer 4.1; Mitchell (2002) to measure the points on the curve with respect to the amount of compressive force (N) and seed deformation (mm). Also the values obtained from the software Digitizer were further used to calculate the deformation energy (J), volume energy (J m^{-3}) and seed hardness (N mm^{-1}) as shown in equations (Eq.1; Eq.3 and Eq.4), respectively.

Fig. 1. Compression devices. Source: Mechanical Department Laboratory, Faculty of Engineering, Czech University of Life Sciences Prague

Compressive force and seed deformation

These parameters were determined directly from the force-deformation curve after processing the chart obtained from the compression test.

Deformation energy

This is the area under the force-deformation curve as described by Grzegorz (2007). (Eq.1) (Herak et al., 2012) was used to calculate this amount correctly.

$$E = \sum \left[\left(\frac{F_{n+1} + F_n}{2} \right) \times (x_{n+1} - x_n) \right] \quad (1)$$

where: E = deformation energy (J);
(F_{n+1} and F_n) = values of compressive force (N)
and (X_{n+1} and X_n) = values of seed deformation (mm).

Initial volume

This is the volume of the seeds before pressing and it was calculated using Eq. (2) (Herak et al., 2012)

$$V = \frac{\pi \times D^2}{4} \times H \quad (2)$$

where: V = the seed volume (m^3); D = diameter of the pressing vessel 60 mm; H = is height of seeds in the pressing vessel (30 mm).

Volume energy

The volume energy is the ratio of the deformation energy and initial volume (Eq. 3) (Herak et al., 2012)

$$e = \frac{E}{V} \quad (3)$$

where: e = volume energy (J m^{-3}); E = deformation energy (J) and V = seed volume before pressing (m^3).

Hardness

The seed hardness Q; (N mm^{-1}) calculation was determined using (Eq. 4) (Abbas et al., 2010) which is defined as the ratio of pressing force Fr; (N) to that of the seed maximum deformation Dr; (mm) and here with respect to pre-heating temperatures.

$$Q = \frac{Fr}{Dr} \quad (4)$$

The pressing force values were obtained directly from the force-deformation curve of the varying pre-heating temperatures of *Jatropha curcas* L. seeds.

Table 1. Calculated amounts from the compression test of jatropha seeds in relation to the effect of heat treatment

Heating temperature (°C)	Compressive force (N)	Seed deformation (mm)	Deformation energy (J)	Seed hardness (N mm^{-1})
75	95327.67 ± 3649.22	18.85 ± 0.12	229.24 ± 13.43	5058.13 ± 225.28
85	97636.67 ± 68.01	20.09 ± 0.15	254.56 ± 10.17	4859.34 ± 36.27
95	97456 ± 135.87	20.94 ± 0.06	268.22 ± 3.82	4654.07 ± 11.01
105	97970 ± 137.29	21.94 ± 0.14	271.68 ± 6.32	4464.83 ± 35.05
115	97787.67 ± 478.49	20.41 ± 0.06	281.6 ± 3.73	4791.23 ± 35.92

Mean values with ± SD

Table 2. Statistical analysis of measured amounts in relation to the effect of heat treatment

Parameters	R^2	F-value	F-critical	*P*-value
*Compressive force (N)	0.86	2.52	2.61	> 0.05
Seed deformation (mm)	0.88	41.73	2.61	< 0.05
Deformation energy (J)	0.97	35.48	2.61	< 0.05
Seed hardness (N/mm)	0.84	14.99	2.61	< 0.05

* Non-significant at significant level (0.05)

RESULTS AND DISCUSSION

From the compression test experiment of *Jatropha curcas* L.; seed deformation (mm), deformation energy (J), compressive force (N) and seed hardness (N mm^{-1}) were measured and statistically analyzed. Tables 1 and 2 and Figs. 2–6 show the summary of the results. The measured amounts; deformation energy, seed deformation and seed hardness, all as a function of heat-treatment were statistically significant at the level of significance ($P < 0.05$) while the dependency between compressive force and pre-heating temperatures was not statistically significant ($P > 0.05$).

Based on the results obtained, as pre-heating temperatures of the jatropha samples increased, the deformation (mm), deformation energy (J) and compressive force (N) also increased, respectively, while seed hardness decreased with an increase in pre-heating temperatures. For the dependency between seed deformation and heat-treatment temeperature as well as seed hardness and heat-treatment temperature, similar results were obtained by B u r u b a i et al., (2007) on the effects of temperature and moisture content on the strength properties of African nutmeg (*Monodora myristica*). The results also confirm the studies conducted by K h a z a e i , M a n n (2005).

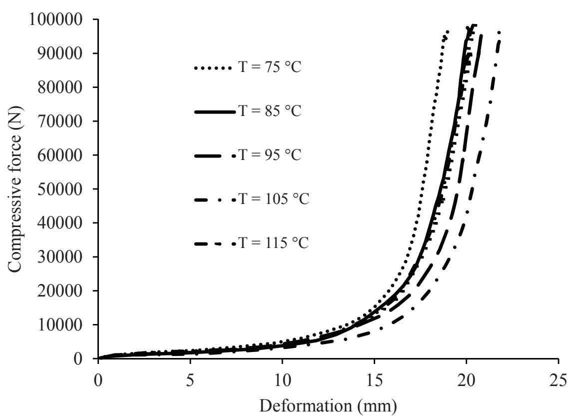

Fig. 2. Dependency between compressive force (N) and deformation (mm) of *Jatropha curcas* L. seeds as a function of heating temperature (°C)

On the other hand, the approximately positive effect of heat-treatment temperature on deformation energy (Fig.4) and compressive force (Fig.5) were contrary to the results reported by B u r u b a i et al., (2007) where these parameters decreased with increasing pre-heating temperature. This inconsistence of results could be due to the different seed materials and inherent seed mechanical properties. But the increase in deformation energy values with respect to pre-heating temperatures showed that bigger force was used to achieve the corresponding deformation of the jatropha seeds.

At the temperature of 115 °C the seed deformation and compressive force values decreased indicating that these amounts could show decreasing trend or vice versa at pre-heating temperatures higher than 115 °C. However, there was no decrease in deformation energy with respect to increasing pre-heating temperatures unlike seed deformation and compressive force. Though at pre-heating temperature of 115 °C seed deformation value declined its energy requirement was the greatest. This also suggests that seed deformation and deformation energy are not mutually related, that is, lower seed deformation does not necessarily mean that lower deformation energy and vice versa. Polynomial function with high coefficient of determination value of more than 80% best described all the measured dependencies examined in this research.

Comparing the results obtained in this study with other studies, e.g. the study investigated by O g u s i n a et al., (2008), the oil point pressure decreased significantly with increase in heating temperature. This was due to the complete removal of moisture from the oil bearing cells. In addition, the results of G u o et al.,

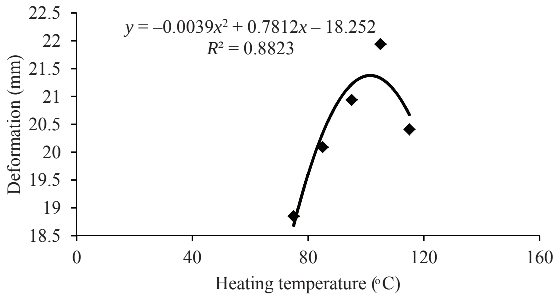

Fig. 3. Influence of heating temperature on deformation of jatropha seeds

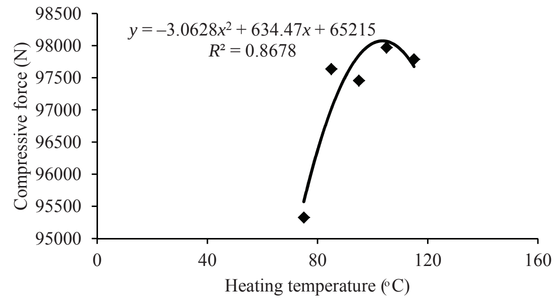

Fig. 5. Influence of heating temperature on compressive force of jatropha seeds

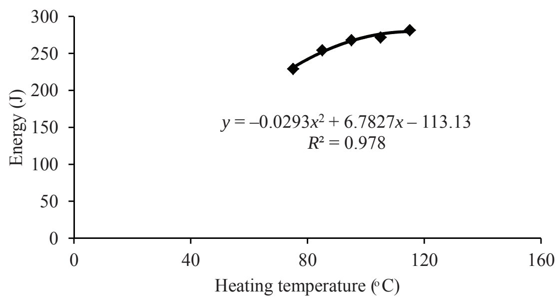

Fig. 4. Influence of heating temperature on deformation energy of jatropha seeds

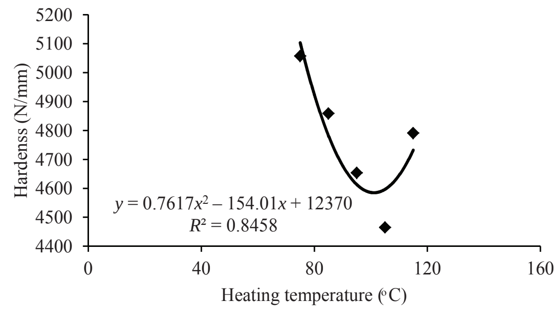

Fig. 6. Dependency between seed hardness and heating temperature of jatropha seeds

(2012) showed that elongation (E) of wheat gluten composite films first increased and then decreased with increasing heat-treatment temperature. Also tensile strength (TS) increased with the increase in heat-treatment temperature. Their results also confirmed the results reported by Cuq et al., (2000); Jeanjean et al., (1980) on the effect of thermal treatments on the mechanical properties and protein solubility of wheat gluten-based networks.

CONCLUSION

The compression test of *Jatropha curcas* L. seeds revealed that heat treatment temperature statistically influenced seed deformation, deformation energy and seed hardness while compressive force as a function of heat treatment temperature was not statistically significant. The study therefore indicated that heat treatment temperature could influence the mechanical behaviour of *Jatropha curcas* L. seeds under compression loading. Future experiment would consider the use of a microwave instead of an oven to analyze the mechanical properties of the *Jatropha curcas* L. seeds. The results, however, would be compared with th findings of this study.

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Tepelné zpracování semen *Jatropha curcas* L. pod tlakem

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Při tlakovém zatížení tepelně zpracovaných semen *Jatropha curcas* L byly sledovány tyto parametry: Velikost tlakové síly (N), deformace semen (mm), deformační energie (J) a tuhost semen (N/mm). Před vlastní tlakovou zkouškou byla semena *Jatropha curcas* L rozdělena do pěti vzorků a jednotlivé vzorky byly zahřáty na teploty 75, 85, 95, 105 a 115 °C. Při zvolené teplotě byla semena temperována po dobu 30 minut. Zkouška byla prováděna na lisovacím zařízení ZDM 50-2313/56/18. Lisovací nádoba měla vnitřní průměr 60 mm. Výstupem je závislost lisovací síly a deformace semen jako funkce teploty předehřátí. Statistická analýza na hladině spolehlivosti 0,05 prokázala, že předehřátí semen *Jatropha curcas* L před lisováním zvyšuje deformaci semen, deformační energii a lisovací sílu. Tuhost semen se snižuje v závislosti na vlivu předehřívací teploty. Všem naměřeným závislostem nejlépe odpovídá polynomická funkce. Studie ukázala, že tepelné zpracování je jedním z nejdůležitějších faktorů ovlivňujících mechanické chování semen *Jatropha curcas* L.

semena jatropha; předehřívací teploty; deformace semen; energie; tuhost semen; lisovací síla

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