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Oil point and mechanical behaviour of oil palm kernels in linear compression**

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A b s t r a c t. The study described the oil point and mechanical properties of roasted and unroasted bulk oil palm kernels under compression loading. The literature information available is very limited. A universal compression testing machine and vessel diameter of 60 mm with a plunger were used by applying maximum force of 100 kN and speed ranging from 5 to 25 mm min^{-1}. The initial pressing height of the bulk kernels was measured at 40 mm. The oil point was determined by a litmus test for each deformation level of 5, 10, 15, 20, and 25 mm at a minimum speed of 5 mm min^{-1}. The measured parameters were the deformation, deformation energy, oil yield, oil point strain and oil point pressure. Clearly, the roasted bulk kernels required less deformation energy compared to the unroasted kernels for recovering the kernel oil. However, both kernels were not permanently deformed. The average oil point strain was determined at 0.57. The study is an essential contribution to pursuing innovative methods for processing palm kernel oil in rural areas of developing countries.

K e y w o r d s: bulk palm kernels, compression loading, deformation energy, oil point, percentage kernel oil

INTRODUCTION

The oil palm (*Elaesis guineensis*) is a tree crop originating from the tropical climates of West Africa. It requires a minimum rainfall of 1 600 mm per year. After five years of cultivation, it starts to produce fruits bunches varying in weight from 10 to 75 kg. The structure of the individual fruit consists of the exocarp (outer skin), mesocarp (a pulp containing the red palm oil), endocarp a central nut with the shell) and the kernel (holding the kernel oil similar to coconut oil) (FAO Agricultural services bulletin). Presently, Indonesia and Malaysia are major producers of palm oil in the world (Chang *et al*., 2014; Lam *et al*., 2009; Owolarafe *et al*., 2007; Ozumba and Obiakor, 2011). Generally, the palm oil is used in packaged edible products including cooking oils, margarine, mayonnaise, ice cream, cookies and chocolates as well as non-edible products such as soaps, detergents and cosmetics. Palm kernel oil is also used in commercial cooking, which is relatively cheaper and has a longer storage period. It can also be used for the manufacture of soaps and washing powder. The meal is used as a fertiliser and livestock feed (Morrison and Heijndermans, 2013; Oriaku *et al*., 2013).

The mechanical oil extraction method is commonly used in developing countries due to its relatively low-cost and non-contaminated oil. However, the oil recovery efficiency is between 60 and 80% (Chapius *et al*., 2014; Divisova *et al*., 2014; Khan and Hana, 1983). Solvent extraction, enzyme-assisted extraction and supercritical fluid extraction provide higher efficiency of oil recovery of 98%. Nevertheless, the disadvantage is that they provide much complexity and higher cost for application in rural areas (Achten *et al*., 2007; Chen *et al*., 2012; Subroto *et al*., 2015a,b). For the palm oil processing, the fresh fruit bunch undergoes sterilisation, striping, and digestion, leaving shelled palm nuts and fibres. The nuts are cracked to produce palm kernels and shells. Palm kernels are further processed to yield palm kernel oil. From the traditional point of view, the processing of palm kernel oil is energy -intensive and time-consuming as it involves drying of nuts, cracking of nuts, sieving of cracked nuts, separation of ker-

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nels, sun-drying of kernels, winnowing of kernels, removal of undesired materials, roasting of kernels, milling of roasted kernels into paste and cooking and, finally, collection of oil. The kernel cake or meal is a by-product.

In the literature, there is very limited information on compression loading test of oil palm kernels (Akinoso *et al*., 2009; Akinoso and Raji, 2011; Ozumba and Obiakor, 2011). The studies available, however, mainly focused on the effects of compressive force, speed, temperature, moisture content and loading positions of single or bulk kernels by evaluating the rupture force, deformation, energy and toughness. For instance, Ozumba and Obiakor (2011) indicated that rupture force of single palm kernels at vertical position increased from 181.23 to 208.60 N as moisture content increased from 5 to 10% w.b. while at the horizontal position, it increased up to 7% w.b. and then decreased at 10% w.b. However, at both horizontal and vertical positions, the rupture force first increased and then decreased as temperature increased from 70 to 110°C. Akinoso and Raji (2011) also reported that the force and energy of Tenera and Dura varieties of single palm kernels decreased with increased moisture content between 5 and 11% w.b. and temperature between 40 and 80°C. The deformation, on the other hand, increased for Tenera but decreased for Dura in relation to moisture content and temperature as already indicated above. For the bulk oil palm kernels under compression loading, our previously published studies indicated that a slight change in deformation of heat-treated or roasted bulk kernels was observed at a force of 100 kN and a speed of 60 mm min^{-1} (Kabutey *et al*., 2013). In addition, an optimal pressing force of 250 kN at a speed of 10 mm min^{-1} for maximum kernel oil was noticed after three repeated loadings of both roasted and unroasted bulk oil palm kernels (Kabutey *et al*., 2016a).

In the industrial practice, however, optimization of the mechanical oil extraction has been also centred on process parameters namely pressure, feeding rate, speed of rotation, temperature, pressing time, moisture content, size reduction and heat treatment (Akinoso *et al*., 2006, 2009; Deli *et al*., 2011; Karaj and Muller, 2011; Ogunsina *et al*., 2008). Akinoso *et al*. (2009) especially reported that maximum oil yield of 46.3 % was found at a compressive stress of 30 MPa, feed rate of 150 kg h^{-1} and rotational speed of 110 r.p.m. while minimum oil yield of 16.3 % was obtained at 10 MPa compressive stress, 50 kg h^{-1} feed rate and 110 r.p.m. of rotational speed employing the expeller Tite 002 (Tiny Plant, Rajkot, India) with 180 kg h^{-1} throughput and power of 30 kW electric motor with interchangeable speed.

The concept of oil point pressure also provides relevant information for design and performance evaluation of mechanical oil expellers or presses (Mrema and McNulty, 1985; Ogunsina *et al*., 2008). The oil point is the stage at which the oilseed has been adequately squeezed onto the surface of the seeds which is theoretically related to the kernel density of the oilseed (Faborade and Favier, 1996). The present study is a further continuation of our previously published studies, and now the objectives were to determine the oil point pressure with the corresponding strain and the mechanical properties namely the deformation mm, deformation energy (J) and oil yield (%) of roasted and unroasted oil palm kernels in relation to varying speeds under compression loading.

MATERIALS AND METHOD

Samples of roasted and unroasted oil palm kernels were brought from New Tafo in the Eastern Region of Ghana. The standard oven method with a temperature setting of 105ºC and a drying time of 17 h was used for the moisture content determination (ISI, 1996). The initial mass of the samples before and after oven drying was weighed using an electronic balance (Kern 440-35, Kern and Sohn GmbH, Balingen, Germany) with an accuracy of 0.001 g. The test was repeated thrice and the results were averaged. Using Eq. (1) given by Blahovec (2008), the moisture content of roasted and unroasted oil palm kernels was determined as 3.33 ± 0.19% w.b. and 9.67 ± 0.196% w.b., respectively.

$$MC = \left[\left(\frac{m_a - m_b}{m_a} \right) 100 \right], \tag{1}$$

where: MC is the percentage moisture content on wet basis (% w.b.), m_a and m_b are the masses of samples before and after heat treatment (g). A compression testing machine (ZDM 50, Czech Republic) and a pressing vessel of diameter 60 mm with a 170 mm long plunger were used for the test by applying a maximum compressive force of 100 kN and speed ranging from 5 to 25 mm min^{-1}. The initial pressing height of the bulk kernels was 40 mm. The oil point of the bulk kernels defined as the first drop of oil was determined by a litmus test for each deformation values of 5, 10, 15, 20, and 25 mm at a minimum speed of 5 mm min^{-1} (Faborade and Favier, 1996; Herak *et al*., 2013;). The percentage oil yield was determined by Eq. (2) (Deli *et al*., 2011; Kabutey *et al*., 2015).

$$O_y = \left[\left(\frac{O_w}{O_m} \right) 100 \right], \tag{2}$$

where: O_y is the percentage oil yield, O_w is the mass of kernel oil (g), and O_m is the mass of initial pressing height of kernels (g). The mass of kernel oil O_w was calculated as the difference between the mass of initial height of kernels O_m and the mass of kernel cake. The deformation energy of the kernels was numerically determined by Eq. (3) (Herak *et al*., 2012):

$$E = \sum_{n=0}^{n=i=1} \left[\left(\frac{F_{n+1} + F_n}{2} \right) \left(x_{n+1} - x_n \right) \right], \quad (3)$$

where: E is the deformation energy (J), $F_{n+1} + F_n$ and $x_{n+1} - x_n$ are the compressive force (N) and deformation (mm), n is the number of data points and i indicates the number of sections of axis deformation. The oil point pressure of the bulk kernel was calculated using Eq. (4) (Kabutey *et al*., 2016b):

$$P_{opt} = \frac{F}{A}, \quad (4)$$

where: P_{opt} is the oil point pressure (N mm^{-2} equal to MPa), F is the compressive force (N), and A is the cross-sectional area of the pressing vessel (mm^2). The oil point strain was also calculated applying Eq. (5) (Herak *et al*., 2010).

$$\varepsilon_{opt} = \frac{X_{dL}}{H}, \quad (5)$$

where: ε_{opt} is the oil point strain, X_{dl} is the deformation level of bulk kernel (mm) and H is the initial height of bulk kernel (mm). The data obtained was a repetition of two compression tests subjected to ANOVA analysis performed by employing STATISTICA 13 software (Statsoft, 2013).

RESULTS AND DISCUSSION

The determined amounts of roasted and unroasted oil palm kernels and their statistical evaluation are shown in Tables 1 and 2. The results were statistically significant at $p < 0.05$ or $F > F_{crit}$ with very high coefficients of determination $R^2 = 0.99$ (Table 2). This explains that the compression speed influenced the values of deformation (mm), energy (J) and oil yield (%) of both bulk kernels. Clearly, for roasted kernels, the amounts of deformation, energy and oil yield in relation to the different speeds ranged from 23.67 ± 0.03 to 22.82±0.18 mm, 488.79 ± 1.71 to 416.20 ± 0.14 J and 15.24 ± 0.04 to 10.85 ± 0.14% while that of unroasted kernels ranged from 23.83 ± 0.23 to 24.05 ± 0.09 mm, 553.43 ± 0.17 to 513.16 ± 0.41 J and 22.79 ± 0.37 to 18.32 ± 0.48%, respectively. The percentage oil yield and energy of unroasted kernels were higher than those of roasted kernels, which could partly be due to the higher moisture content. Moreover, at the minimum speed of 5 mm min^{-1}, the highest oil yield was observed (Table 1). This means that at a higher speed the processing time for the oil flow from the solids is reduced. The input pressure or compressive stress also determines the oil processing time and energy demand for maximum oil recovery (Akinoso *et al*., 2009; Karaj and Muller, 2011; Kabutey *et al*., 2015). Considering the energy-intensive and time-consuming nature of the traditional oil processing of roasted kernels, direct processing of unroasted kernels would be less labour intensive and more environmentally friendly. Therefore, identifying the suitable compression speed and pressure for processing unroasted bulk oil palm kernels is vital for the design and development of optimal processing technology.

The force-deformation curves of unroasted oil palm kernels in relation to speeds similar to roasted kernels are displayed in Fig. 1. The behaviour of the force-deformation curves is useful for the description of the oil point threshold as well as the optimal energy for the oil recovery. No curves

T a b l e 1. Measured parameters of roasted and unroasted bulk kernels at force 100 kN for different speeds

Speed (mm min^{-1})	Deformation (mm)	Energy (J)	Oil yield (%)
	Roasted kernels		
5	23.67 ± 0.03	488.79 ± 1.71	15.24 ± 0.04
10	24.07 ± 0.07	462.48 ± 0.27	14.81 ± 0.16
15	23.31 ± 0.26	440.51 ± 0.50	12.93 ± 0.08
20	22.93 ± 0.09	414.52 ± 0.51	11.56 ± 0.06
25	22.82 ± 0.18	416.20 ± 0.14	10.85 ± 0.06
	Unroasted kernels		
5	23.83 ± 0.23	553.43 ± 0.17	22.79 ± 0.37
10	22.51 ± 0.38	530.77 ± 0.07	20.45 ± 0.64
15	24.09 ± 0.21	530.35 ± 0.31	19.81 ± 0.17
20	22.52 ± 0.36	520.68 ± 0.28	19.33 ± 0.06
25	24.05 ± 0.09	513.16 ± 0.41	18.32 ± 0.48

T a b l e 2. ANOVA analysis of measured parameters of roasted and unroasted bulk oil palm kernels

Parameters	Roasted kernels				Unroasted kernels			
	R^2	F	F_{crit}	p-value	R^2	F	F_{crit}	p-value
Deformation (mm)	0.97	22.17	2.246	<0.05	0.96	17.08	2.246	<0.05
Energy (J)	0.99	2 822.90	2.246	<0.05	0.99	5 877.49	2.246	<0.05
Oil yield (%)	0.99	867.48	2.246	<0.05	0.98	34.16	2.246	<0.05

$p < 0.05$ or $F > F_{crit}$ means significant.

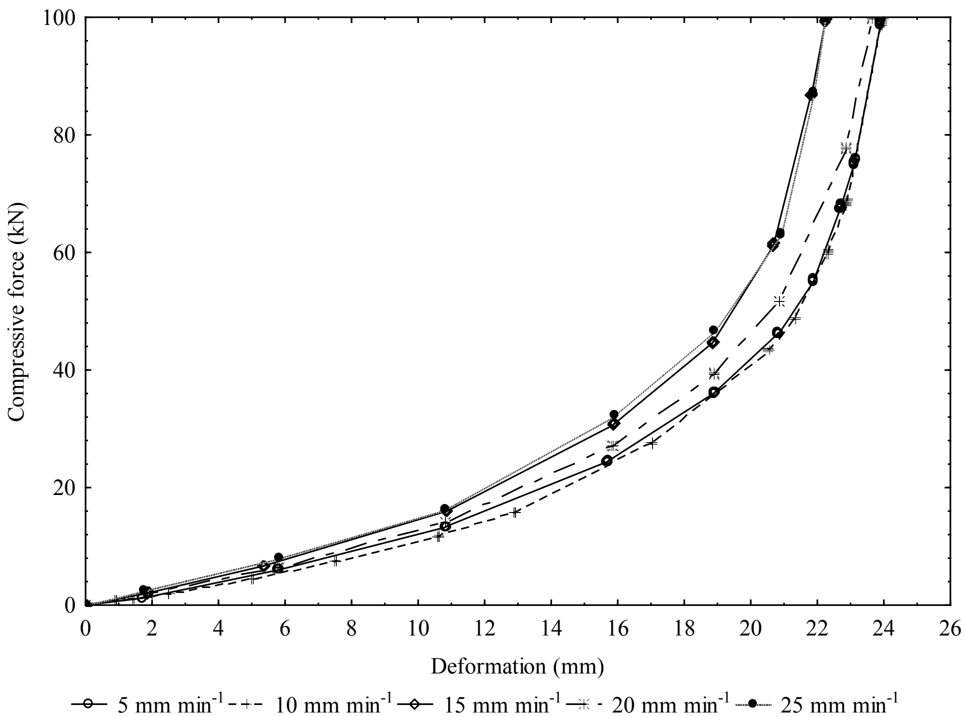

Fig. 1. Dependency between compressive force and deformation curves of bulk unroasted kernels in relation to different speed, similar to roasted bulk kernels.

showed any serration characteristics, which is mostly caused by the higher moisture content, compressive force and diameter of the pressing vessel (Divisova *et al.*, 2014).

The amounts of oil point pressure and strain are indicated in Table 3. These parameters were calculated using Eqs (4) and (5), respectively. The lower and upper oil points were observed at deformation levels of 20 and 25 mm with corresponding strain values of 0.5 and 0.63 of an average value of 0.57 (Fig. 2). The lower and upper oil points pressure of roasted kernels ranged from 10.08 ± 0.05 to 20.19 ± 0.06 MPa while that of the unroasted ones ranged from 10.09 ± 0.05 to 26.60 ± 0.14 MPa. The average values were 15.14 ± 0.06 and 18.35 ± 0.10. In the literature, the average oil point strain of some selected oilseeds or kernels of jatropha, melon, rapeseed, cashew, soybean and oil palm has been reported (Sukumaran and Singh, 1989; Faborade and Favier, 1996; Raji and Favier, 2004; Ogunsina *et al.*, 2008; Herak *et al.*, 2013). The values ranged between 0.38 to 0.69 at a moisture content between 4.3 and 8.5% w.b. For oil point pressure, it can be seen that roasted kernels showed a smaller amount compared to the unroasted ones, which explains the positive effect of heat treatment on oil flow from the oil-bearing cells. On the contrary, the higher oil point pressure of unroasted kernels could also be attributed to the high moisture content. Ogunsina *et al.* (2008) and Tunde-Akintunde (2008) have indicated that oil point pressure increases with an increase in moisture content. For instance, oil point pressure of 0.157 MPa was found for fine cashew kernel at a moisture content of 4% w.b. while 0.166 MPa was recorded for coarse cashew kernel at a moisture content of 6% w.b. Clearly, at higher moisture levels, the cushioning effect of mucilage develops, and this

T a b l e 3. Oil point strain and pressure of roasted and unroasted bulk kernels at speed 5 mm min^{-1}

Oil point deformation level (mm)	Oil point strain	Oil point pressure (MPa)	
		roasted kernels	unroasted kernels
20	0.50 ± 0.00a	10.08 ± 0.05	10.09 ± 0.05
25	0.63 ± 0.00b	20.19 ± 0.06	26.60 ± 0.14
Average	0.57 ± 0.00	15.14 ± 0.06	18.35 ± 0.10

a, b – lower and upper oil points of bulk kernels of initial pressing height 40 mm.

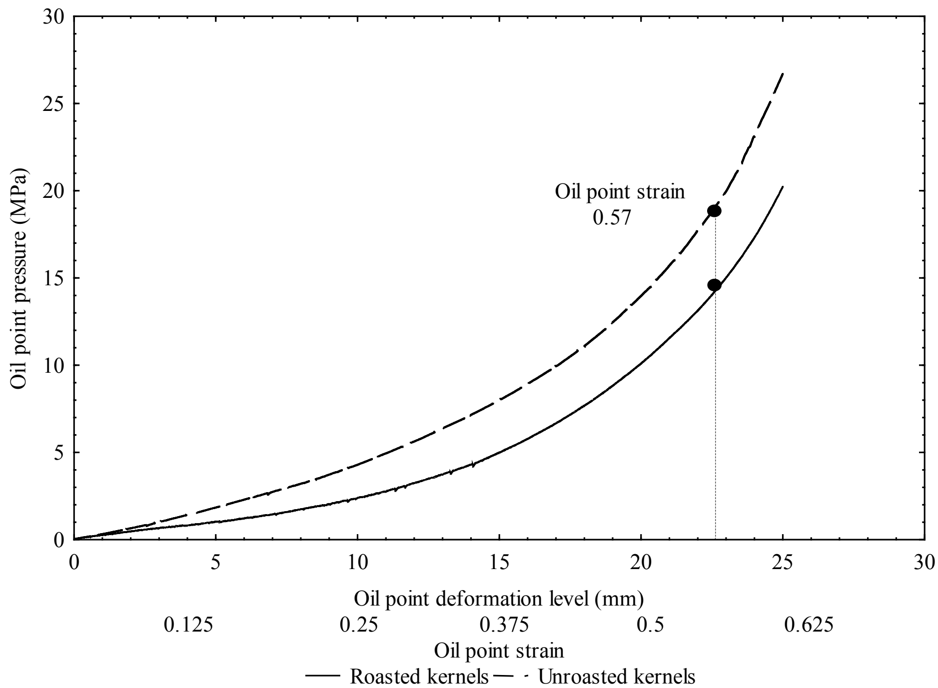

Fig. 2. Oil point pressure versus deformation level and strain of bulk roasted and unroasted kernels at pressing height 40 mm and speed 5 mm min^{-1}.

mucilage consumes energy generated by the pressure to compress the oil out of the oil-bearing cells thus increasing the oil point pressure (Ajibola *et al*., 2002). In this study, the average oil point strain of both kernels was higher in comparison with the findings of some of the above-mentioned authors. The reason could be related to the variation in the structural integrity of the oil bearing materials, that is, the change in the physical (moisture content, initial bulk density, kernel density, porosity) and mechanical (contact and gradient pressure and compressibility) properties.

CONCLUSIONS

1. The average oil point strain of roasted and unroasted oil palm kernels was observed at 0.57 with corresponding oil point pressure of 15.14 ± 0.06 and 18.35 ± 0.10, respectively.

2. Roasted kernels required less deformation energy than unroasted kernels for recovering the kernel oil in relation to the various speeds between 5 and 25 mm min^{-1}.

3. The bulk kernels were not permanently deformed at a maximum force of 100 kN confirming previous findings that a repeated compression or a higher force would be needed to obtain greater percentage kernel oil.

4. There was no serration effect or undulation behaviour on the force-deformation curves in relation to the different speeds.

5. Identifying the specific compressive force, speed, oil point pressure and strain among other indicators is vital for the design and development of optimal processing technology.

Conflict of interest: The Authors do not declare conflict of interest.

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