Effect of pre-processing conditions on oil point pressure of sheanut (*Vitellaria paradoxa*) kernel

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Abstract: Oil point pressure of sheanut kernel was determined under different pre-processing conditions of moisture content, heating temperature, heating time and particle size. Results show that the pressure decreased as moisture content increased from 4% to 6%, and thereafter, increased with further increase in moisture content. It equally decreased with increase in temperature and heating time. Highest oil point pressure value was 2.6389 MPa for coarse kernel particles at 4% moisture content heated at 50^{o}C for 5 min, and 1.5554 MPa for fine particles at 10% moisture content heated at 50°C for 5 min. Lowest value for coarse and fine kernel particles was 0.929 MPa and 0.6380 MPa respectively and this was obtained at the conditions of 6% moisture content, 100^{o}C and 15 min heating time. Analysis of Variance (ANOVA) showed that all the pre-processing variables and their interactions significantly affected the oil point pressure of at 1% level of significance. This was confirmed using response surface methodology. Multiple regression analysis yielded equations that expressed oil point pressure as a function of kernel moisture content, heating temperature and heating time. The models yielded coefficients that enabled oil point pressure of the kernel to be predicted with high coefficient of determination.

Keywords: sheanut, seed oil expression, oil seed processing, oil point pressure, moisture content

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1 Introduction

Shea tree (*Vittellaria*) belonging to the family Sapotaceae with sub species paradoxa and nilotica is a perennial and deciduous tree which grows naturally throughout the Guinea Savannah region. Shea trees in Nigeria grow naturally in the wild and thrive almost exclusively in the North. In general, trees do not usually yield fruit until they are 20 years old (Fleury, 2000). However, once productive, they will continue to bear fruits up until their 200th year. Shea tree is an important economic crop because of the heavy demand for its butter in the international market mainly as a substitute for cocoa butter in the production of chocolate (Nikiema and Umali, 2007).

The tree is mainly important for its nut which contains a kernel with an oil content ranging from 45% to 60% (Opeke, 1992). The oil, known as shea butter, is used in the manufacture of soap, candles, cosmetics, pharmaceutical

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products and butter substitutes. The kernel used for oil expression is obtained from the nut by cracking with stones, mortar and pestle. In the traditional process of extracting the oil, the kernel is subjected to a series of operations which include steeping, roasting, pounding or grinding, and boiling (Maranz et al., 2004a, 2004b).

Technologies used for extracting vegetable oil including shea butter are traditional boiling, mechanical pressing and solvent extraction (USAID, 2004). However, shea butter has been processed by indigenous traditional boiling method which has been described as labour intensive (Master and Puga, 1994). This has made the quality of indigenous traditionally extracted shea butter variable (FAO and CFC, 2005). Expressing oil from sheanut kernel traditionally involves roasting of the kernels with sand and ash before crushing in a local wooden mortar and thereafter milled on grinding stone. The paste is boiled in water until the fat begins to float on surface. After extraction, the butter or oil is transferred into storage plastic or glass containers. The above operations as presently carried out are labour intensive and time consuming. There is therefore the need to develop a machine that would efficiently express oil from sheanut kernel.

Oil expression is a consolidation and compression process as a result of applied pressure. There is reduction in volume which causes the oil to seep out of the compressed seed (Sivala et al., 1991). Seed oil expression has been analysed as a drained consolidation process in terms of stress-strain response of the seed bed and the dynamics of oil flow (Faborode and Favier, 1997). Tunde-Akintunde et al. (2001) noted that in Nigeria, small and medium scale production of vegetable oil is carried out using either mechanical expression (oil removal using machines) or extraction (oil removal using solvents). However, expression is preferred to extraction because it is not only more economical but also yields an end product that is free of dissolved chemicals, which makes it an inherently safer process (Khan and Hanna, 1983).

The pressure at which oil comes out of the inter-particle voids of an oil seed is known as oil point pressure. It indicates the threshold pressure at which oil emerges from a seed kernel during mechanical oil expression (Ajibola et al., 2002). The oil point pressure determines the effectiveness of an expression operation because subsequent flow and yield of oil are triggered by pressure applied beyond the oil point pressure (Olatunde and Owolarafe, 2011). Certain pretreatment operations known to influence oil yield in mechanical oil expression include heat treatment, moisture conditioning and size reduction (Adeeko and Ajibola, 1990; Ajibola et al., 1993, 2000; Dedio and Dornell, 1977; Hamzat and Clarke, 1993; Oyinlola et al., 2004). Heat treatment of oil seed has been observed to rupture the oil bearing cells of the seed, coagulate the protein in the meal, adjust the moisture level of the meal to optimum level for oil expression, lower the viscosity and increase the fluidity of the oil to be expelled and destroy mould and bacteria thereby facilitating oil expression from the material (Adeeko and Ajibola, 1990). The optimum heating temperature for most oil seeds has been observed to be in the range of 90^{o}C -110^{o}C at an average retention time of 20 min (FAO, 1989). Norris (1964) reported that size reduction, heat treatment and application of pressure are required for efficient oil expression from oil seeds with large particle sizes. Dedio and Dornell (1977) found that increasing the moisture content of flake seed from 8% to 16% decreased the oil yield.

Several investigations have been carried out on effect of processing parameters on the oil point pressure of oil seeds. These include studies on the oil point pressure of rape seed (Sukumaran and Singh, 1989), sesame seed (Ajibola et al., 2000), soyabean (Ajibola et al., 2002), locust bean (Owolarafe et al., 2003), cashew kernels (Ogunsina et al., 2008), melon seeds (Tunde-Akintunde 2010), neem seed (Olatunde and Owolarafe, 2011), Indian almond kernels (Aregbesola et al., 2012) and moringa oleifera seeds (Aviara et al., 2015). Studies on the oil point pressure of sheanut kernel, however, appear not to have been carried out. The objective of this study, therefore, was to determine the oil point pressure of sheanut kernel and investigate the effect of such pre-processing parameters as moisture content, heating temperature and heating time on the oil point pressure.

2 Materials and methods

2.1 Material procurement and preparation

The bulk quantity of sheanut used in this study was procured from a farm in Saki, Saki-East Local Government Area of Oyo State, Nigeria. The nuts were cleaned and sorted to remove foreign materials. They were manually cracked to obtain the kernels. A mortar and pestle was used to reduce the kernel sizes, which were passed through standard sieves to classify them into coarse and fine aggregates. Coarse particle passed through 4.7 mm sieve aperture while the fine particle passed through 2.36 mm aperture. The coarse and fine particles appear as shown in Figure 1.

(a) (b)

Figure 1 Sheanut kernel aggregates, a: coarse particle, b: fine particle

2.2 Moisture content determination and adjustment

The initial moisture content of the sheanut kernels was determined by heating 30 g of the kernel in triplicates at 130°C for six hours (ASAE, 1982). The moisture content was calculated using the following expression:

$$MC_{wb} = \frac{M_a - M_b}{M_a} x100 \quad (1)$$

where; MC_{wb} is moisture content wet basis (%), M_a is mass of sample prior to heating (g) and M_b is mass of sample after heating (g).

The average value of the moisture content was recorded.

In addition to samples at the initial moisture content, kernels at three different moisture levels were obtained through moisture adjustment which was carried out by the addition of calculated amount of water to the sample at the initial moisture content to raise it to the required moisture level. The amount of water that was added was determined using the expression:

$$M = W_2 \frac{(M_2 - M_1)}{(100 - M_2)} \quad (2)$$

where: M is mass of water to be added (g), W_2 is mass of the sample (g), M_2 is expected moisture content (%) and M_1 is initial moisture content (%).

Samples at different moisture levels were sealed in labelled polyethylene bags and kept in a freezer under a temperature of 10°C for 72 hours. This enabled the samples to attain stable and uniform moisture contents (Adebona et al., 1986; Singh et al., 2004; Aviara et al., 2015).

2.3 Heat treatment and duration

Samples of sheanut kernels at different moisture contents in sample trays were heated in an oven at the temperatures of 50°C, 70°C, 85°C and 100°C respectively, each for the durations of 5, 10, and 15 minutes.

2.4 Oil point pressure determination

The oil point pressure of sheanut kernel was identified using the method that was applied by Ajibola et al. (2002) on soyabean, Owolarafe et al. (2003) on locust bean, Tunde-Akintunde (2010) on melon seeds and Aviara et al. (2015) on *moringa oleifera* seeds. Prior to the experiment, the kernel samples were removed from the freezer and allowed to equilibrate at ambient condition for 24 hours. After this, the sample of either coarsely or finely ground kernels at specified moisture level, heating temperature and heating time was used to fill a cylindrical container which had several 2 mm holes drilled at the base to allow oil passage during pressing. The holes were stuffed with tiny strips of tissue paper to enable the oil to be spotted when the oil point was attained. The content of the perforated cylinder was pressed using the laboratory press that is diagrammatically presented in Figure 2. The lever which served as a pressure transfer medium had a dead weight of 90 kg and an effective length of 3000 mm. The pressure transferred from the lever arm to the sample in the test cylinder through the point load and compression piston was varied by moving the cylinder and its content along the lever arm. The test cylinder was a 50 mm long galvanized steel pipe with an internal diameter of 40 mm. The cylinder had one of its ends closed with a 12 mm thick metal base with 2 mm holes drilled at a pitch of 15 mm. The compression piston was a solid steel cylinder, 70 mm long and 39 mm in diameter. A 20 metric tonnes hydraulic jack was used to raise and lower the lever bar for applying pressure to the sample. The cylinder containing the sample was placed under the compression piston. The jack was released gently to allow the suspended lever arm to lower down gradually to rest on the pressing ram and compression piston. The jack was then used to lift the lever arm in order to remove the cylinder and piston. After each pressing operation, the tissue paper strips in the holes of the cylinder were removed and examined for oil marks (which was an indicator of whether the pressure at that point due to the load was sufficient to bring oil out of the kernel or not. The distance from this point to the support was measured and converted to pressure using the principle of moment of forces.

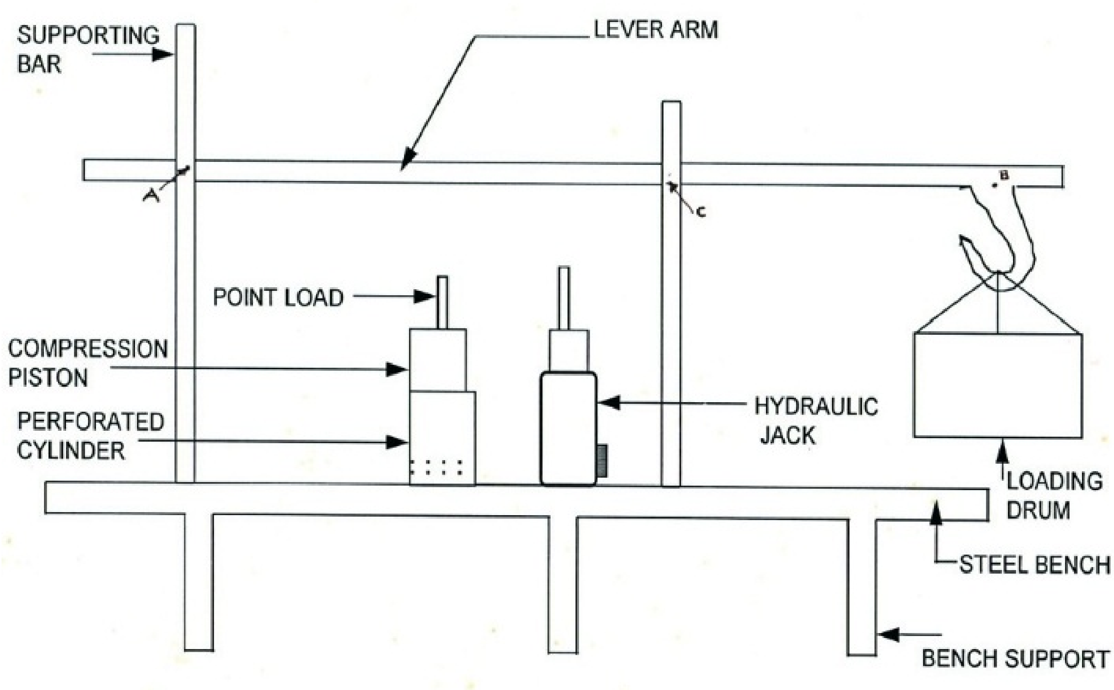

Figure 2 Laboratory oil expression press

2.5 Statistical analysis

The data obtained was subjected to Analysis of Variance (ANOVA) in a completely randomized factorial design using IBM SPSS statistics 20. Comparison of means was carried out using Turkey's test and Duncan's Multiple Range Analysis at the 99% confidence level. Response Surface Methodology was applied using the Design Expert software and multiple regression analysis was conducted to establish the model that expresses the relationship existing between the oil point pressure of sheanut kernel and the processing parameters.

3 Results and discussion

The results of the mean oil point pressure (*P*) of coarse and finely ground sheanut kernel at different pre-pressing conditions namely moisture content (*M*), heating temperature (*T*) and heating time (*t*) are presented in Tables 1 and 2 respectively.

Table 1 Oil point pressure of coarsely ground sheanut kernel at different moisture contents, temperatures and heating times

		Oil Point Pressure (MPa)		
		t (min)		
***T*(°C)**	***M* (%)**	5	10	15
	4	2.6389	2.4498	2.2545
50	6	1.4777	1.3906	1.3103
	8	1.8419	1.7347	1.6284
	10	1.9259	1.8205	1.7277
	4	2.0782	1.9321	1.7980
70	6	1.2370	1.1928	1.1436
	8	1.5291	1.4572	1.3900
	10	1.6325	1.5500	1.4731
	4	1.6821	1.5828	1.5001
85	6	1.1013	1.0586	1.0095
	8	1.3258	1.2678	1.2143
	10	1.4224	1.3781	1.3423
	4	1.4250	1.3560	1.2901
100	6	0.9786	0.9515	0.9229
	8	1.1646	1.1196	1.0778
	10	1.2521	1.2000	1.1569

Table 2 Oil point pressure of finely ground sheanut kernel at different moisture contents, temperatures and heating times

		Oil point pressure (MPa)		
		t (min)		
***T* (°C)**	***M* (%)**	5	10	15
	4	1.0934	1.0518	1.0202
50	6	0.8416	0.8197	0.7988
	8	1.4224	1.3565	1.2970
	10	1.5554	1.4582	1.3924
	4	0.9931	0.9657	0.9380
70	6	0.7778	0.7582	0.7396
	8	1.2352	1.1834	1.1345
	10	1.3157	1.2735	1.2148
	4	0.9125	0.8924	0.8658
85	6	0.7209	0.7032	0.6857
	8	1.0918	1.0487	1.0121
	10	1.1496	1.1082	1.0640
	4	0.8409	0.8194	0.7974
100	6	0.6682	0.6534	0.6380
	8	0.9761	0.9433	0.9114
	10	1.0640	1.0330	1.0011

From Table 1, it can be seen that within the ranges of processing conditions studied, the oil point pressure of coarsely ground sheanut ranged from 0.9229 MPa at the moisture content of 6%, heating temperature of 100°C and heating time of 15 min to 2.6389 MPa at the moisture content, heating temperature and heating time of 4.00%, 50°C and 5 min respectively.

Table 2 shows that oil point pressure of finely ground sheanut kernel ranged from 0.6682 MPa at the moisture content of 6%, heating temperature of 100°C and heating time of 15 min to 1.5554 MPa at 10% moisture content, 50°C heating temperature and heating time of and 5 min.

3.1 Effect of pre-processing conditions on oil point pressure of coarse aggregates of sheanut kernel

The response of the oil point pressure of coarsely ground sheanut kernel to variation in moisture content and heating time at 50°C is presented in Figure 3. The figure shows that the oil point pressure of coarsely ground sheanut kernel decreased with increase in moisture content from 4% to 6% to a minimum value and thereafter increased with further increase in moisture content for the heating times of 5, 10 and 15 min respectively. This may be an indication that some level of moisture presence is necessary for the transport of oil from the oil bearing cells and it suggests that 4% moisture content might have been too low for oil to flow out readily. This is in agreement with the findings of other investigators (Adeeko and Ajibola, 1990; Ajibola et al., 1993; Fasina and Ajibola, 1989; Owolarafe et al., 2003) on oil expression from groundnut, sesame seed, conophor nut and locust bean, respectively. The increase in oil point pressure after a moisture level was attained could be due to the cushioning effect of mucilage developed at higher moisture levels. The mucilage must have consumed some of the energy generated by pressure applied during the compression of the material to force the oil out of the cells, thereby increasing the oil point pressure (Ajibola et al., 2002; Tunde-Akintunde, 2010). Similar trend of oil point pressure with moisture content to that which is shown in Figure 3 was exhibited by the coarsely ground kernel at the heating temperatures of 70°C, 85°C and 100°C respectively.

Oil point pressure decreased with increase in heating temperature and heating. The result is similar to that obtained by Sukumaran and Singh (1989), Ajibola et al. (1993), Ajibola et al. (2002), Owolarafe et al. (2003), Ogunsina et al. (2008), Tunde-Akintunde (2010), Aregbesola et al. (2012), Aviara et al. (2015) on rape seed, conophor seed, sesame seeds, soya bean, locust bean, cashew nut, melon seed, Indian almond kernels and *moringa oleifera* seeds respectively. The decrease in oil point pressure with increase in heat treatment can be attributed to the fact that heating for long periods results in moisture adjustment (Olatunde and Owolarafe, 2011), reduction of viscosity, which enabled the oil to flow easier from the cell structure (Tunde-Akintunde, 2010) and protein coagulation which is one of the factors necessary for oil expression (Khan and Hanna, 1983; Adeeko and Ajibola, 1990).

The response of oil point pressure to heating temperature and moisture variation at the heating time of 5 min for coarsely ground sheanut kernel is presented in Figure 4. The figure reveals that the oil point pressure of coarsely ground sheanut kernel decreased with increase in heating temperature at constant heating time. Similar trend of oil point pressure with heating temperature and moisture content to that which is shown in Figure 4 was exhibited by the kernel at the heating times of 10 and 15 min. The response of the oil point pressure of coarsely ground sheanut kernel to heating time and heating temperature at 4% moisture content (Figure 5) shows that oil point pressure decreased with increase in heating time. Similar trend of oil point pressure with heating time to that which is shown in Figure 5 was exhibited by the kernel at the moisture contents of 6%, 8% and 10% respectively.

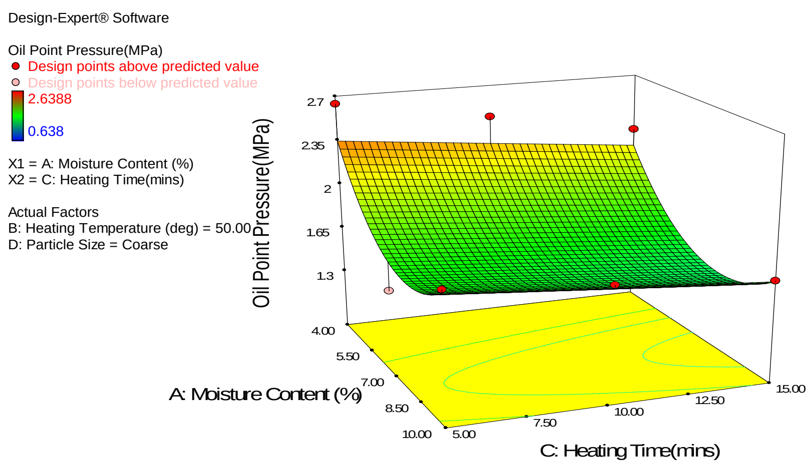

Figure 3 Response surface of oil point pressure of coarsely ground sheanut kernel to moisture content and heating time at 50°C

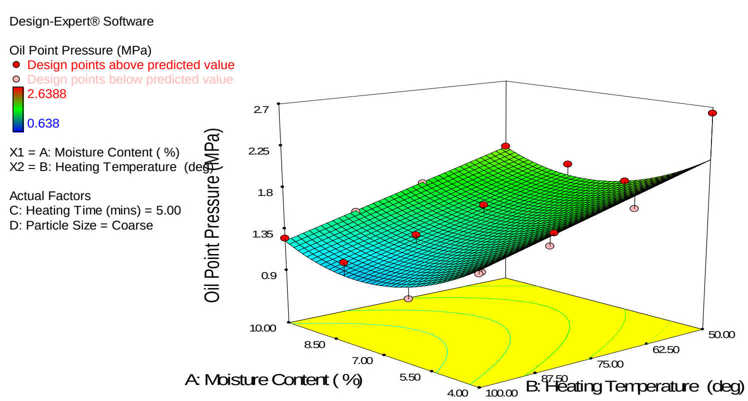

Figure 4 Response surface of oil point pressure of coarsely ground sheanut kernel to heating temperature and moisture content at 5 min

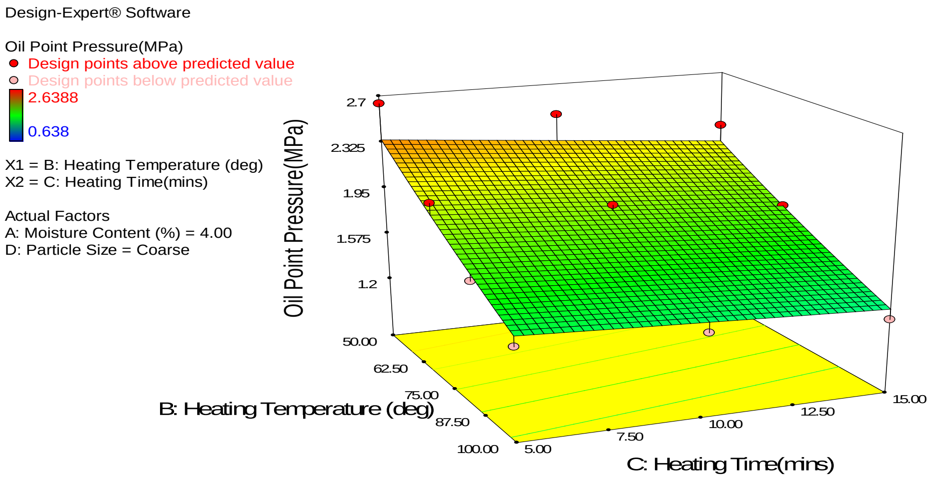

Figure 5 Response surface of oil point pressure of coarsely ground sheanut kernel to heating time and heating temperature at 4% moisture content

3.2 Effect of pre-processing conditions on oil point pressure of fine aggregates of sheanut kernel

The oil point pressure of finely ground sheanut kernel at 50°C (Figure 6) decreased remarkably with increase in moisture content from 4% to 6% to a minimum value and thereafter increased notably with further increase in moisture content for the heating times of 5, 10 and 15 min respectively. Similar trend of oil point pressure with moisture content to that which is shown in Figure 6 was exhibited by the kernel at the heating temperatures of 70°C, 85°C and 100°C respectively.

The response of oil point pressure of finely ground sheanut kernel to heating temperature and moisture variation at the heating time of 5 min is presented in Figure 7. This figure shows that the oil point pressure decreased with increase in heating temperature at constant heating time. Similar trend of oil point pressure with heating temperature and moisture content to that which is shown in Figure 7 was exhibited by the kernel at the heating times of 10 and 15 min. The response of the oil point pressure of finely ground sheanut kernel to heating time and heating temperature at 4% moisture content presented in Figure 8 shows that oil point pressure decreased with increase in heating time. Similar trend of oil point pressure with heating time to that which is shown in Figure 8 was exhibited by the kernel at the moisture contents of 6%, 8% and 10% respectively.

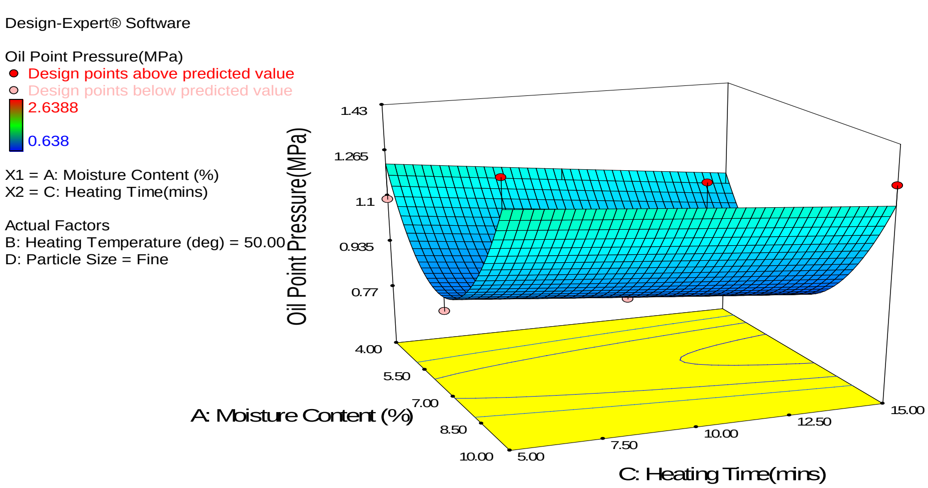

Figure 6 Response surface of oil point pressure of finely ground sheanut kernel to moisture content and heating time at 50°C

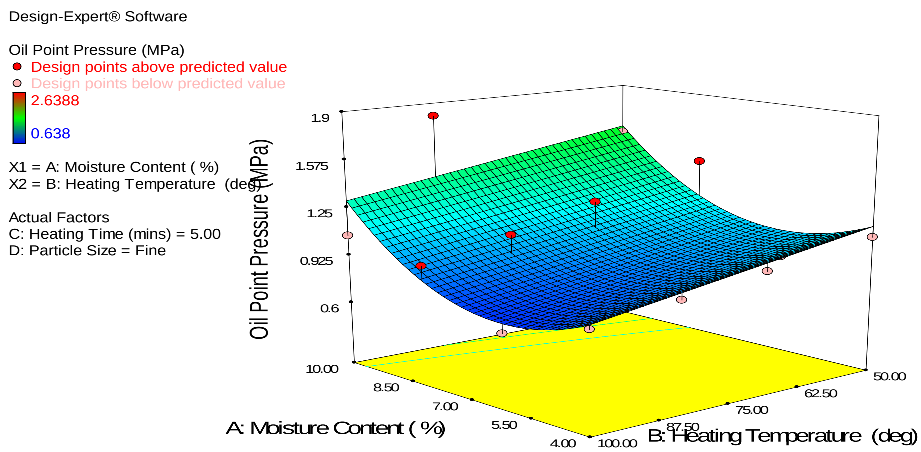

Figure 7 Response surface of oil point pressure of finely ground sheanut kernel to heating temperature and moisture content at 5 min

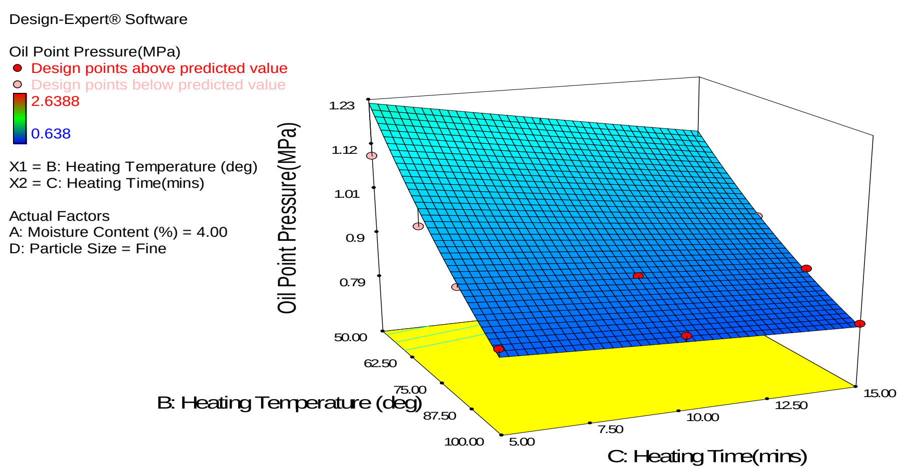

Figure 8 Response surface of oil point pressure of finely ground sheanut kernel to heating time and heating temperature at 4% moisture content

3.3 Effect of particle size on oil point pressure of sheanut kernel

The effect of particle size on the oil point pressure of sheanut kernel at different processing conditions considered namely; moisture content (*M*), heating temperature (*T*) and heating time (*t*) are presented in Figures 9, 10 and 11. Figure 9 shows the variation of oil point pressure of sheanut kernel with particle size and moisture content at the heat temperature and heating time of 50°C and 5 min respectively. From this Figure, it can be seen that the oil point pressure of coarsely ground sheanut kernel was higher than that of the fine particle at each moisture content. Similar trend to that observed in Figure 9 was exhibited by the kernel at other temperature and heating time levels.

The variation of oil point pressure of sheanut kernel with particle size and heating temperature at the moisture content of 4% and heating time of 5 min is presented in Figure 10. The figure shows that the oil point pressure of coarsely ground sheanut kernel was higher than that of the fine particle size at each heating temperature. Similar result was observed at other levels of moisture content and heating time. Figure 11 shows the variation of oil point pressure of sheanut kernel with particle size and heating time at the moisture content and heating temperature of 4% and 50°C respectively. From the figure, it can be seen that the oil point pressure of coarsely ground sheanut kernel was higher than that of the fine particle at each heating time. Similar trend was observed at other moisture content and heating temperatures.

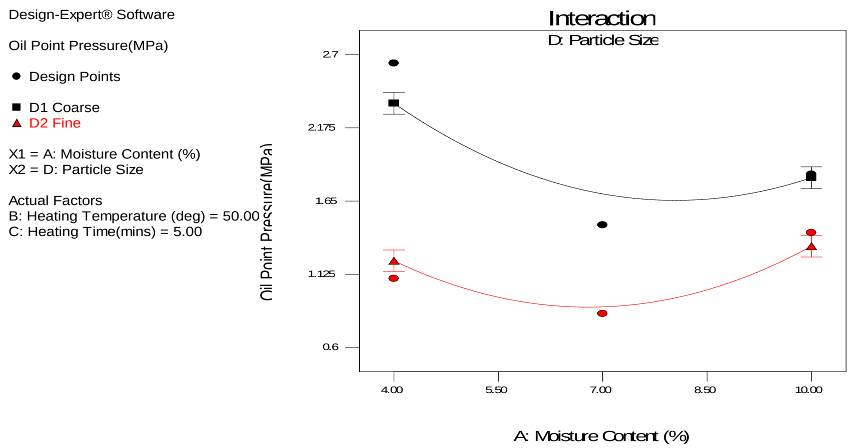

Figure 9 Variation of oil point pressure of sheanut kernel with particle size for different moisture contents at 50°C heating temperature and heating time of 5 min

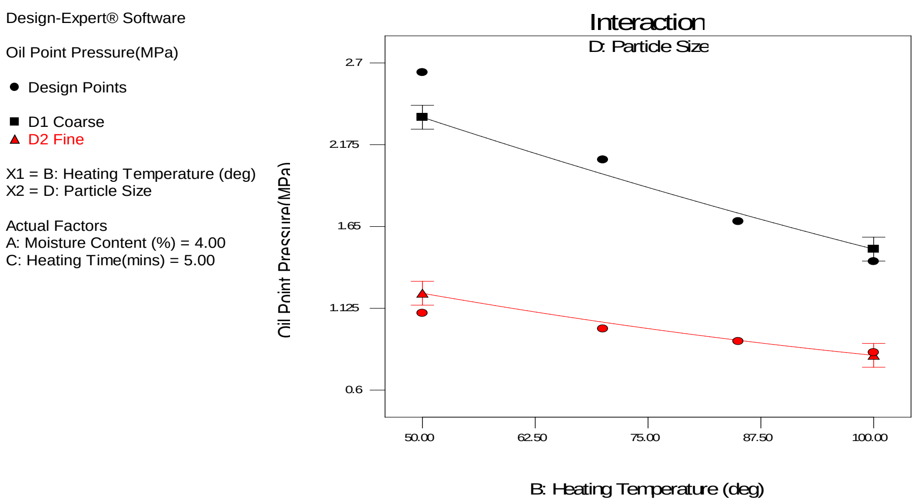

Figure 10 Variation of oil point pressure of sheanut kernel with particle size for different heating temperatures at 4% moisture content and heating time of 5 min

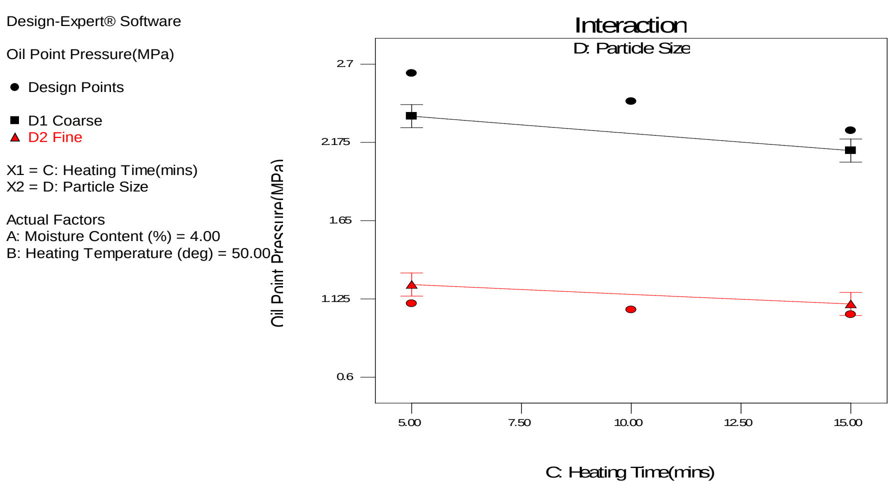

Figure 11 Variation of oil point pressure of sheanut kernel with particle size for different heating times at 4% moisture content and heating temperature of 50°C

3.4 ANOVA for coarse particle size of sheanut kernel

The ANOVA of oil point pressure with pre-processing conditions for coarse particle size kernel is presented in Table 3. From this table, it can be seen that oil point pressure varied significantly with coarse particle moisture content (*M*), heating temperature (*TE*) and heating time (*t*) at 1% level of significance. The interactions between the pre-processing conditions namely $M\times TE$, $M\times t$ and $TE\times t$ showed significant effect on oil point pressure at 1% level of significance. This implies that oil point pressure was significantly affected by all the pre-processing parameters studied.

Table 3 ANOVA of sheanut kernel oil point pressure with pre-processing conditions for coarse particle size

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	20.252[a]	47	0.431	375.208	0.000
Intercept	309.713	1	309.713	2.697E5	0.000
M	8.672	3	2.891	2.517E3	0.000
TE	9.625	3	3.208	2.794E3	0.000
T	0.574	2	0.287	249.834	0.000
$M\times TE$	1.219	9	0.135	117.909	0.000
$M\times t$	0.071	6	0.012	10.237	0.000
$TE\times t$	0.077	6	0.013	11.197	0.000
$M\times TE\times t$	0.015	18	0.001	0.743	0.759
Error	0.110	96	0.001		
Total	330.075	144			
Corrected Total	20.362	143			

Note: Dependent variable: P, R Squared=0.995 (Adjusted R Squared=0.992), M=moisture content (%), TE=temperature (°C), t =heating time (minutes)

Table 4 Multiple range comparison of coarsely ground sheanut kernel oil point pressure with respect to moisture content

	M	N	Subset			
			1	2	3	4
Tukey HSD[a]	6	36	1.1479			
	8	36		1.3959		
	10	36			1.4901	
	4	36				1.8323
	Sig.		1.000	1.000	1.000	1.000
Duncan[a]	6	36	1.1479			
	8	36		1.3959		
	10	36			1.4901	
	4	36				1.8323
	Sig.		1.000	1.000	1.000	1.000

Note: Means for groups in homogeneous subsets are displayed, based on observed means. Error term is Mean Square (Error) = 0.001. a. Uses Harmonic Mean Sample Size = 36.000

Table 5 Multiple range comparison of coarsely ground sheanut kernel oil point pressure with respect to heating temperature

	TE	N	Subset			
			1	2	3	4
Tukey HSD[a]	100	36	1.1579			
	85	36		1.3238		
	70	36			1.5345	
	50	36				1.8501
	Sig.		1.000	1.000	1.000	1.000
Duncan[a]	100	36	1.1579			
	85	36		1.3238		
	70	36			1.5345	
	50	36				1.8501
	Sig.		1.000	1.000	1.000	1.000

Note: Means for groups in homogeneous subsets are displayed, based on observed means. Error term is Mean Square (Error) = 0.001. a. Uses Harmonic Mean Sample Size = 36.000

Table 6 Multiple range comparison of sheanut kernel oil point pressure with respect to heating time of coarse particle size of sheanut

	T	N	Subset		
			1	2	3
Tukey HSD[a]	15	48	1.3900		
	10	48		1.4651	
	5	48			1.5446
	Sig.		1.000	1.000	1.000
Duncan[a]	15	48	1.3900		
	10	48		1.4651	
	5	48			1.5446
	Sig.		1.000	1.000	1.000

Note: Means for groups in homogeneous subsets are displayed, based on observed means. Error term is Mean Square (Error) = 0.001. a. Uses Harmonic Mean Sample Size = 48.000

The Tukey and Duncan separations of mean oil point pressure with respect to moisture content, heating temperature and heating time for coarsely ground sheanut kernel are shown in Tables 4, 5 and 6 respectively. From Table 4, it can be seen that the oil point pressure of the coarsely ground sheanut kernel at 4% moisture content was highest and significantly different from that of kernels at 10% moisture which was in turn different from that of 8%. The lowest value of oil point pressure occurred at 6% moisture content. Oil point pressure of coarsely ground sheanut kernel (Table 5) decreased with increase in heating temperature with the value at 50°C being significantly highest and different from others and that of 100°C was lowest. Table 6 shows that the oil point pressure of coarsely ground sheanut kernel decreased with increase in heating time with the value at 5 min being highest and different from that of 10 min. Oil point pressure was lowest at 15 min.

3.5 ANOVA for fine particle size of sheanut kernel

The ANOVA of oil point pressure with pre-processing conditions for fine particle size kernel is shown in Table 7. From this table, it can be seen that oil point pressure (*P*) varied significantly with fine particle size moisture content (*M*), heating temperature (*TE*) and heating time (*t*) at 1% level of significance. The interactions between all the processing conditions namely $M\times TE$, $M\times t$, $TE\times t$ and $M\times TE\times t$ showed significant effect on oil point pressure at 1% level of significance as well. This implies that oil point pressure was significantly different for all the ranges of pre-processing parameters studied.

Table 7 ANOVA of sheanut kernel oil point pressure with processing conditions for fine particle size

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	7.534a	47	0.160	301.921	0.000
Intercept	145.433	1	145.433	2.739E5	0.000
M	5.091	3	1.697	3.196E3	0.000
TE	2.000	3	0.667	1.255E3	0.000
T	0.097	2	0.049	91.711	0.000
$M\times TE$	0.289	9	0.032	60.558	0.000
$M\times t$	0.012	6	0.002	3.635	0.003
$TE\times t$	0.019	6	0.003	6.027	0.000
$M\times TE\times$	0.026	18	0.001	2.728	0.001
Error	0.051	96	0.001		
Total	153.018	144			
Corrected Total	7.585	143			

Note: Dependent variable: P, R Squared=0.993 (Adjusted R Squared=0.990), *M*=moisture content (%), *TE*=temperature (°C), *t* =heating time (minutes)

The Tukey and Duncan separations of mean oil point pressure with respect to moisture content, heating temperature and heating time for finely ground sheanut kernel are shown in Tables 8, 9 and 10 respectively. Table 8 shows that the oil point pressure of the finely ground sheanut kernel at 4% moisture content was highest and significantly different from that of the kernels at 10% moisture which was in turn different from that of 8%. The lowest value of oil point pressure occurred at 6% moisture content. Oil point pressure of finely ground sheanut kernel (Table 9) decreased with increase in heating temperature with the value at 50^{o}C being significantly highest and different from others and that of 100^{o}C was lowest. The oil point pressure of finely ground sheanut kernel (Table 10) also decreased with increase in heating time with the value at 5 min being highest and different from 10 min. Oil point pressure was lowest at 15 min heating time.

Table 8 Multiple range comparison of finely ground sheanut kernel oil point pressure with respect to moisture content

	M	N	Subset			
			1	2	3	4
Tukey B[a]	6	36	0.7338			
	4	36		0.9325		
	8	36			1.1344	
	10	36				1.2192
Duncan[a]	6	36	0.7338			
	4	36		0.9325		
	8	36			1.1344	
	10	36				1.2192
	Sig.		1.000	1.000	1.000	1.000

Note: Means for groups in homogeneous subsets are displayed, based on observed means. Error term is Mean Square (Error) = 0.001. a. Uses Harmonic Mean Sample Size = 36.000

Table 9 Multiple range comparison of finely ground sheanut kernel oil point pressure with respect to heating temperature

	TE	N	Subset			
			1	2	3	4
Tukey B[a]	100	36	0.8622			
	85	36		0.9379		
	70	36			1.0441	
	50	36				1.1756
Duncan[a]	100	36	0.8622			
	85	36		0.9379		
	70	36			1.0441	
	50	36				1.1756
	Sig.		1.000	1.000	1.000	1.000

Note: Means for groups in homogeneous subsets are displayed, based on observed means

Error term is Mean Square (Error) = 0.001. a. Uses Harmonic Mean Sample Size = 36.000

Table 10 Multiple range comparison of sheanut kernel oil point pressure with respect to heating time of fine particle size of sheanut

	t	N	Subset		
			1	2	3
Tukey B[a]	15	48	0.9722		
	10	48		1.0069	
	5	48			1.0358
Duncan[a]	15	48	0.9722		
	10	48		1.0069	
	5	48			1.0358
	Sig.		1.000	1.000	1.000

Note: Means for groups in homogeneous subsets are displayed, based on observed means. Error term is Mean Square (Error) = 0.001. a. Uses Harmonic Mean Sample Size = 48.000

3.6 Modeling of oil point pressure of sheanut kernel on pre-processing parameters

The result of multiple regression analysis carried out to express the oil point pressure (P) as a function of the pre-processing parameters of moisture content (M), heating temperature (T), heating time (t) for coarsely ground sheanut kernel is presented in Table 11. From the table, it can be seen that the analysis yielded coefficients with which the function that can be used to adequately predict the oil point pressure of coarsely ground sheanut kernel on the basis of pre-processing parameters was established. The model (Equation 3) is expressed as follows:

$$P= 6.705 – 0.863M – 0.039TE – 0.072t + 0.002M\times TE + 0.005M\times t + 0.001TE\times t – 3.965\times 10\text{-}5M\times TE\times t + 0.049M2 + 7.051\times 10\text{-}5TE2 + 8.512\times 10\text{-}5t2$$

$$R^2= 0.85 \quad (3)$$

where: P is oil point pressure (MPa), M is moisture content (%), TE is heating temperature (^{o}C) and t is heating time (min).

Table 11 Coefficients for the regression analysis on oil point pressure of coarse particle size of sheanut kernel

	Model parameter	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6.705	0.551		12.162	0.000
	M	-0.863	0.078	-5.133	-11.081	0.000
	TE	-0.039	0.009	-1.930	-4.354	0.000
	T	-0.072	0.049	-0.780	-1.481	0.141
	M×TE	0.002	0.001	0.973	2.060	0.041
	M×t	0.005	0.006	0.450	0.764	0.446
	TE×t	0.001	0.001	0.570	1.046	0.297
	M×TE×t	-3.956E-5	0.000	-0.338	-0.525	0.601
	M^2	0.049	0.003	4.084	15.290	0.000
	TE^2	7.051E-5	0.000	0.521	1.563	0.120
	t^2	8.512E-5	0.001	0.019	0.079	0.937

Note: [a] Dependent Variable: P. where: *M* is moisture content (%), *TE* is heating temperature (^{o}C) and *t* is heating time (min)

A t-test of coefficients showed that the constant, TE^2, t and t^2 terms did not make statistically significant contribution to the predictive function of the equation. The terms M, TE and M^2 however, made significant contribution to the equation at 1% level of significance. This model can be used to optimize the sheanut oil expression process and design and control the oil expression equipment.

Table 12 Coefficients for the regression analysis on oil point pressure of fine particle size of sheanut kernel

Model parameter	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1(Constant)	1.371	0.407		3.365	0.001
M	-0.084	0.058	-0.817	-	0.147
TE				1.457	
t	-0.002	0.007	-0.139	-	0.796
M×TE				0.259	
M×t	0.010	0.036	0.185	0.289	0.773
TE×t	-0.001	0.001	-1.196	-	0.038
M×TE×t				2.093	
M^2	-0.003	0.004	-0.552	-	0.440
TE^2				0.775	
t^2	0.000	0.000	-0.228	-	0.730
				0.346	
	3.757E-5	0.000	0.525	0.674	0.501
	0.018	0.002	2.437	7.536	0.000
	1.988E-5	0.000	0.241	0.597	0.552
	0.000	0.001	-0.041	-	0.886
				0.144	

Note: [a] Dependent Variable: P. where: *M* is moisture content (%), *TE* is heating temperature (^{o}C) and *t* is heating time (min)

Table 12 shows the result of multiple regression analysis carried out to express the oil point pressure (*P*) as a function of the pre-processing parameters of moisture content (*M*), heating temperature (*T*), heating time (*t*) for finely ground sheanut kernel. From the table, it can be seen that the analysis yielded coefficients with which the function that can be used to adequately predict the oil point pressure of finely ground sheanut kernel on the basis of pre-processing parameters was established. The model (Equation 4) is expressed as follows:

$$P= 1.371 - 0.084M – 0.002TE + 0.010M\times TE – 0.003M\times t + 3.757\times 10\text{-}5M\times TE\times t + 0.018M2 + 1.988\times 10\text{-}5TE2vvvv \quad R^2=0.78 \quad (4)$$

where: P is oil point pressure (MPa), M is moisture content (%), TE is heating temperature (oC) and t is heating time (min).

A t-test of coefficients showed that the constant, M, TE, TE2, t and t^2 terms did not make statistically significant contribution to the predictive function of the equation. The M^2 term however, made significant contribution to the equation at 1% level of significance. This model can be used to optimize the sheanut oil expression process and to design and control the oil expression equipment.

4 Conclusions

This study revealed that the oil point pressure of sheanut *(Vitellaria paradoxa)* kernel is affected significantly by moisture content, heating temperature and heating time. The oil point pressure of the kernel decreased with increase in moisture content from 4% to 6% to a minimum value and thereafter increased with further increase in moisture content for both coarse and fine particle kernels. Oil point pressure decreased with increase in heating temperature and heating time. For coarse particles, oil point pressure ranged from 0.9229 MPa at the moisture content of 6%, heating temperature of 100°C and heating time of 15 min to 2.6389 MPa at the moisture content, heating temperature and heating time of 4.00%, 50°C and 5 min respectively. In the fine particles, oil point pressure ranged from 0.6682 MPa at the moisture content of 6%, heating temperature of 100°C and heating time of 15 min to 1.5554 MPa at the moisture content, heating temperature and heating time of 10%, 50°C and 5 min respectively. The relationship existing between the oil point pressure and pre-processing parameters was adequately expressed by multiple regression models. The models yielded coefficients that are significant and useable in the optimization and control of sheanut kernel oil expression process.

Oil point pressure of sheanut kernel was greatly affected by particle size. The highest oil point pressure recorded was for coarse particles while finely ground sheanut kernel recorded the lowest oil point pressure.

The results suggest that in oil expression from sheanut kernel, high oil yield could be obtained by processing both coarse and fine particles at low moisture levels.

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