Cooking and Drying Process Optimisation of Shea (*Butyrospermum parkii*) Butter Extraction

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Abstract

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Cooking and drying conditions of the shea butter extraction process were determined using a response surface methodology. The influence of cooking time, temperature, and nuts/water mass ratio, drying time, and temperature on the content of free fatty acids, the peroxide value, as well as on the extraction yield was investigated. Results showed that both the free fatty acid content and the peroxide value were significantly affected by cooking and drying temperature; the cooking time and nuts/water ratio also affected significantly the peroxide value. Increasing cooking and drying temperature reduced the FFA content but contributed to increase the peroxide value. The cooking and drying temperature range of 75–80°C and < 54°C, respectively; cooking time of 70–100 min; drying time < 40 h, and cooking nuts/water mass ratio < 400 g/l of water were found to be optimum conditions for the extraction of shea butter.

Keywords*:* shea nuts pretreatmen; response surface methodology; shea butter quality

Shea [*Butyrospermum parkii* (G. Don) Kotschy or *Vitellaria paradoxa* Gaertn.] nuts are frequently used in Africa to extract oil called "shea butter". It is well known for its multiple uses in cosmetic, pharmaceutical, and food industries. Some antioxidant and anti-inflammatory properties of shea butter were also reported (UNDP-WATH 2010; Honfo *et al.* 2014).

The first shea butter quality criteria required on the market are the free fatty acid (FFA) content and the peroxide value. Cosmetic and pharmaceutical industries require first quality shea butter (FFA content < 1% and peroxide value < 10 meq/kg) while food industries require second quality shea butter (FFA content < 3% and peroxide value < 15 meq/kg) (Lovett *et al.* 2012). For indigenous people, in Benin for example, butter colour is the main quality criteria (Honfo *et al.* 2012). However, the accessibility of superior quality shea butter on the market remains a bigger challenge because shea butter producers are price takers and are unable to supply the requisite consistency of quality (Lovett *et al.* 2012). Customers are very exigent on the quality and consequently always complain about the quality of the marketed shea butters (Megnagnou *et al*. 2007).

During the extraction process, shea butter is subject to hydrolysis and oxidation, due to uncontrolled traditional pretreatments (Megnagnou *et al*. 2007), which alter the quality of the resulting butter and contribute to its wide variability [FFA: 1.8–22.5%; peroxide values: 14.7–30.9 meq/kg (Womeni *et al*. 2006; Olaniyan & Oje 2007; Aculey *et al.* 2012)]. There is no strict respect for any non-existing standards. The primary oxidation products are hydroperoxides (Spěváčková *et al.* 2012); their accumulation may be

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detrimental to the health of consumers (Wasowicz *et al.* 2004). Cooking and drying are critical steps responsible for shea butter hydrolysis and oxidation during extraction (Womeni *et al.* 2006); During shea nut cooking, the butter FFA content considerably decreases while the peroxide value increases (Womeni *et al.* 2006; Bup Nde *et al.* 2012).

Sun drying is a long process which can enhance lipolysis and production of free fatty acids (Womeni *et al.* 2007). The use of improved drying technique where drying time and temperature can be controlled is an alternative. Moreover, direct drying of kernels was found to be unsuitable for extraction of shea butter with acceptable quality because of the contact surface enzyme-substrate which is increased allowing the liberation of fatty acids (Womeni *et al.* 2007). The high temperature involved in the traditional extraction process was reported to be responsible for the oxidation of fat causing an increase in the peroxide values (Kar & Mital 1981).

These reasons have made the amelioration of the extraction process of shea butter questionable and standards need to be established if the quality is of prime importance. A contribution has been done by Womeni *et al.* (2006), Kapseu *et al.* (2007), Aculey *et al.* (2012), and Bup Nde *et al.* (2012). However,

Table 1. Central experimental plan presenting coded and real values of cooking and drying variables used for optimisation of cooking and drying of shea nuts

Trials	Coded values					Real values				
	x_1(°C)	x_2 (g/l)	x_3 (min)	x_4 (°C)	x_5 (h)	x_1 (°C)	x_2 (g/l)	x_3 (min)	x_4 (°C)	x_5 (h)
1	1	−1	−1	−1	−1	85	133	40	50	24
2	0	0	−α	0	0	67.5	233	15	60	48
3	1	−α	1	1	1	85	33	90	70	72
4	−1	−1	1	−1	−1	50	133	90	50	24
5	1	−1	1	−1	1	85	133	90	50	72
6	0	−α	0	0	0	67.5	33	65	60	48
7	1	1	−1	1	−1	85	333	40	70	24
8	1	−1	−1	1	1	85	133	40	70	72
9	0	0	+α	0	0	67.5	233	115	60	48
10	−1	-1	−1	1	−1	50	133	40	70	24
11	−1	-1	−1	−1	1	50	133	40	50	72
12	−1	1	1	−1	1	50	333	90	50	72
13	1	1	−1	−1	1	85	333	40	50	72
14	−α	0	0	0	0	40	233	65	60	48
15	0	0	0	0	0	67.5	233	65	60	48
16	0	0	0	0	+α	67.5	233	65	60	96
17	+α	0	0	0	0	102.5	233	65	60	48
18	0	0	0	+α	0	67.5	233	65	80	48
19	0	0	0	0	−α	67.5	233	65	60	0
20	1	−1	1	1	−1	85	133	90	70	24
21	0	+α	0	0	0	67.5	433	65	60	48
22	−1	1	1	1	−1	50	333	90	70	24
23	−1	−1	1	1	1	50	133	90	70	72
24	0	0	0	−α	0	67.5	233	65	40	48
25	−1	1	−1	1	1	50	333	40	70	72
26	1	1	1	−1	−1	85	333	90	50	24
27	−1	1	−1	−1	−1	50	333	40	50	24
28	0	0	0	0	0	67.5	233	65	60	48

x_1 – cooking temperature; x_2 – nuts/water ratio; x_3 – cooking time; x_4 – drying temperature; x_5 – drying time; +α – highest coded level of the variables; −α – lowest coded level of the variables

neither the variation of cooking parameters combined with drying parameters nor the cooking mass ratio (nuts/water), which is also a possible influencing parameter, have been investigated yet. The aim of this work is to estimate the optimum cooking and drying conditions of shea butter extraction process with a focus on the cooking temperature, time and mass ratio of nuts/water, and drying temperature and time.

MATERIAL AND METHODS

Materials. Fresh shea nuts were collected in different sites in Bangoua (Western Cameroon) in the month of June, the harvesting period of shea nuts. They were homogenised and washed prior to cooking and drying treatments.

Cooking and drying process. Cooking was done using a heating device of the LAUDA Company (Stockholm, Sweden) placed in a 5-l stainless pot. Drying tests were carried out in an oven with forced ventilation. Thereafter, nuts were cracked to obtain kernels which were ground for butter extraction and analysis.

Oil extraction. Oil content of kernels used was determined using the Soxhlet method (AFNOR 1981). The sample extraction yields were determined using a maceration method with hexane at a ratio of 1 : 3. It was done in Erlenmeyer flasks at room temperature for 48 h with regular shaking. The content of the flasks was filtered using filter papers and the filtrates were evaporated on a rotary vacuum evaporator. The extraction yield was calculated from the mass of the recovered oil and the mass of the kernels. The calculations were based on the mass of the kernels.

Analyses. Nut moisture content, FFA content and peroxide value in the samples of shea butter were analysed using standard methods of AFNOR (1981); protein content by the Kjeldahl method; carbohydrates, ash, total fibres using the AOAC methods (1980). The calculations were based on dry weight. The FFA content is expressed in % of oleic acid; the peroxide value is expressed in milliequivalents of active oxygen per kilogram of shea butter (meq/kg).

The central experimental plan. A response surface methodology was used and a total of 28 treatments were carried out randomly with respect to the central composite experimental plan (Table 1). Variables were: cooking temperature, time and mass ratio of nuts/water, drying temperature and time. The central point was repeated twice. The experimental data were fitted to the second-order polynomial equation (Eq. 1) and regression coefficients were obtained. The Statistica (Statsoft Inc., 2001) software was used. Analysis of variance (ANOVA) was done to determine the effect of variables. The analysis were carried out in duplicate (n = 2).

Table 2. Chemical composition of shea kernels used for treatments

	Values (%)
Dry matter	94.32 ± 1.01
Moisture content	5.68 ± 1.01
Carbohydrates	50.67 ± 2.16
Fat content	31.32 ± 1.04
Total fibres	10.52 ± 1.00
Total proteins	8.56 ± 0.20
Ash	3.77 ± 0.12

$$Y = \beta_0 + \beta_i x_i + \beta_j x_j + \beta_{ij} x_i x_j + \beta_{ii} x_i^2 + \beta_{jj} x_j^2 \quad (1)$$

where: Y – predicted response; x_i, x_j – variables; β_0 – constant coefficient; β_i, β_j – linear coefficients; β_{ij} – interaction coefficient; β_{jj}, β_{ii} – quadratic coefficients

RESULTS AND DISCUSSION

Chemical composition and water content of shea kernels. The chemical composition of shea kernels used in this work is summarized in Table 2. Fat content (31.32 ± 1.04%) was almost similar to the values reported by other researchers (Womeni *et al*. 2006; Kapseu *et al*. 2007) but lower than the value (47.47%) reported by Bup Nde *et al*. (2012). Data analysis of water content of dry shea nuts generated a regressive equation expressing the water content of shea nuts influenced by drying temperature and time of shea nuts (Eq. 2) (coefficients are in Table 3).

$$\text{Water content (\%)} = 51.485 + 0.512x_4 - 0.267x_5 - 0.001x_4x_5 - 0.0006x_5^2 \quad (2)$$

where: x_4 – drying temperature; x_5 – drying time

The model explains 91.93% (Table 3) of the variation of water content. Significant effects ($P < 0.05$) on shea nut water content during the drying process were due to the drying time and temperature. The contour plot of water content is presented in Figure 1.

As it can be seen, the water content decreased with the increase of drying time and temperature. Investigations done by Reddy and Dash (1992), and Tiencheu *et al.* (2006) have demonstrated similar results. Furthermore, Aculey *et al.* (2012) reported

Table 3. Model constants, *P*-values and r^2 of the second degree equation for shea nut water content and extraction yield according to the central composite experimental plan

	Water content		Extraction yield	
	MC	*P*-value	MC	*P*-value
x_4 (β_4)	0.512	0.0025*	–2.055	0.0100*
x_5 (β_5)	–0.267	0.0001*	–0.524	0.0222*
x_4^2 (β_{44})	–0.008	0.3934	0.016	0.1397
x_4x_5 (β_{45})	–0.001	0.8269	0.01	0.0584
x_5^2 (β_{55})	–0.0006	0.7617	0.0003	0.8534
Constant (β_0)	51.485		72.426	
r^2	91.94		82.76	

x_4 – drying temperature; x_5 – drying time; MC – model coefficient; *$P < 0.05$, the parameters with a *P*-value < 0.05 were chosen as the significant parameters

the influence of kernel boiling on the moisture content of shea kernels. Studies on the structure of shea kernels under scanning electron microscopy showed a pronounced effect of cooking on the sorption of water onto shea nut kernels. The effect was attributed to the loss of components containing water-binding hydrophilic groups like proteins, carbohydrates, and catechins during cooking (Bup Nde *et al.* 2013).

Extraction yield. Model coefficients and contour plots are shown in Table 3 and Figure 2, respectively. The extraction yield increased with drying temperature and time. The solvent extraction method was recommended for the production of shea butter free from oxidised fats since the high temperature involved in the traditional extraction process causes oxidation of fat and contributes to increase the peroxides values (Kar & Mital 1981). Similarly, the extraction method used in the experimentation was chosen in order to avoid any possible influence of the temperature required in the Soxhlet extraction method. All the values obtained (7.2–25.9%) were lower than (31.32 ± 1.04%) obtained by the Soxhlet method but were included in the range reported by Honfo *et al.* (2014). The chosen extraction method was reported to yield low values as compared to the Soxhlet method (Stanisavljevic *et al.* 2006). Furthermore, the method is dependent on several variables, among them the moisture content of the samples, the sample/solvent ratio, and the temperature. Considering the high efficiency of industrial scale solvent extraction, the extraction yield would be higher at industrial scale production (van Beek 1999). Moreover, the reported average efficiency of the traditional method of extraction is about 20–28% (Coulibaly *et al.* 2004) which was reported to be nearly the same as the centrifugal extraction process (Coulibaly *et al.* 2009). The highest values were obtained at high drying temperature and long drying time. However, at low drying temperature and time, the extraction yield increased as well. Probably during the cooking process, the shea kernel structure is modified in such a way that low drying temperature

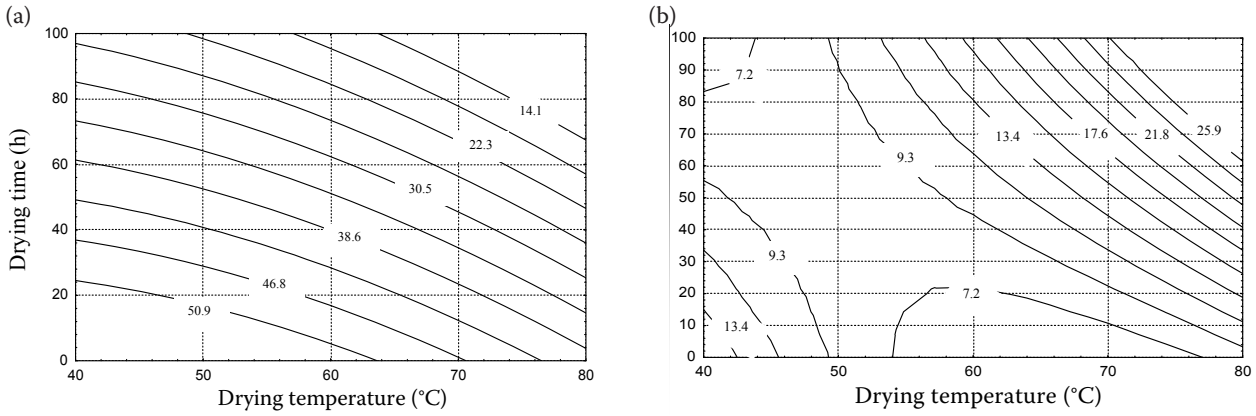

Figure 1. Contour plot of (a) the water (%) content of shea kernels and (b) the shea butter extraction yield (%) influenced by drying temperature and time

Table 4. Model constants, *P*-values and r^2 of the second degree equation for shea butter FFA contents according to the central composite experimental plan

	MC	*P*-value
x_1 (β_1)	–1.505	0.0037*
x_4 (β_4)	–1.122	0.0129*
x_1x_4 (β_{14})	0.01	0.0101*
x_1^2 (β_{11})	0.006	0.3938
x_4^2 (β_{44})	0.002	0.2187
Constant (β_0)	93.918	
r^2	87.66	

x_1 – cooking temperature; x_4 – drying temperature; MC – model coefficient; *P < 0.05, the parameters with a P-value < 0.05 were chosen as the significant parameters

and time become favourable to liberation of fats. It was similarly reported that the cooking of shea kernels prior to drying contributes to improve the extraction yield (Bup Nde *et al.* 2011, 2012).

FFA content. The model coefficients and contour plot for shea butter FFA content are presented in Table 4 and Figure 2, respectively. The FFA contents of shea butter varied from 0.06% to 12.60%. Most of the values were > 3% and 1% oleic acid recommended by Codex Alimentarius (1992) and Lovett *et al.* (2012), respectively. Values decreased linearly with the increase of cooking and drying temperature. However, values also decreased with a decrease in cooking and drying temperature. Olaniyan and Oje (2007) reported an increase of the FFA content with the increase of drying temperature. In fact, the variation of FFA content during shea butter extraction is due to endogenous lipases in nuts or colonising fungi (Bailey 1951). High temperatures probably denatured these lipases. The FFA content was minimised

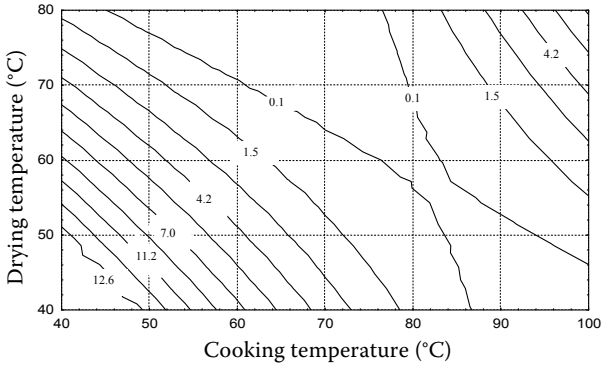

Figure 2. Contour plot of the FFA content (% oleic acid) of shea butter influenced by cooking temperature and drying temperature

either at cooking and drying temperature > 80°C or at the cooking temperature range of 75–85°C and low drying temperature (< 56°C).

Peroxide value. The model coefficients as well as parameters with significant effects are presented in Table 5.

The peroxide values in our experiments were lower than the values of 70 meq/kg reported by Hart and Fisher (1971) while some values were lower than those reported by other researchers (Megnagnou *et al.* 2007; Olaniyan & Oje 2007; Bup Nde *et al.* 2012).

The peroxide value, as shown in Figures 3a and 3b, increased steadily as cooking and drying temperature, and cooking time increased. Low peroxide values (< 10 meq/kg) were obtained at low drying temperature and short cooking time (70–100 min). This result is similar to the results of Womeni *et al.*

Table 5. Model constants, *P*-values, and r^2 of the second degree equation for shea butter peroxide values according to the central composite experimental plan

	MC	*P*-value
x_1 (β_1)	7.8678	0.2440
x_2 (β_2)	0.0993	0.0091*
x_3 (β_3)	5.6106	0.1051
x_4 (β_4)	23.1028	0.0002*
x_5 (β_5)	0.1080	0.0524
x_1x_2 (β_{12})	–0.0000	0.9858
x_1x_3 (β_{13})	–0.0069	0.4085
x_1x_4 (β_{14})	–0.0814	0.0044*
x_1x_5 (β_{15})	–0.0086	0.3257
x_2x_3 (β_{23})	–0.0000	0.8661
x_2x_4 (β_{24})	–0.0002	0.8309
x_2x_5 (β_{25})	–0.0003	0.5008
x_3x_4 (β_{34})	–0.0549	0.0053*
x_3x_5 (β_{35})	–0.0122	0.0699
x_4x_5 (β_{45})	0.0260	0.1125
x_1^2 (β_{11})	–0.0141	0.1908
x_2^2 (β_{22})	–0.0000	0.5612
x_3^2 (β_{33})	–0.0108	0.0574
x_4^2 (β_{44})	–0.1091	0.0081*
x_5^2 (β_{55})	0.0025	0.6437
Constant (β_0)	–1179.23	
r^2	95.18	

x_1 – cooking temperature; x_2 – nuts/water ratio; x_3 – cooking time; x_4 – drying temperature; x_5 – drying time; MC – model coefficient; *P < 0.05, the parameters with a P-value < 0.05 were chosen as the significant parameters

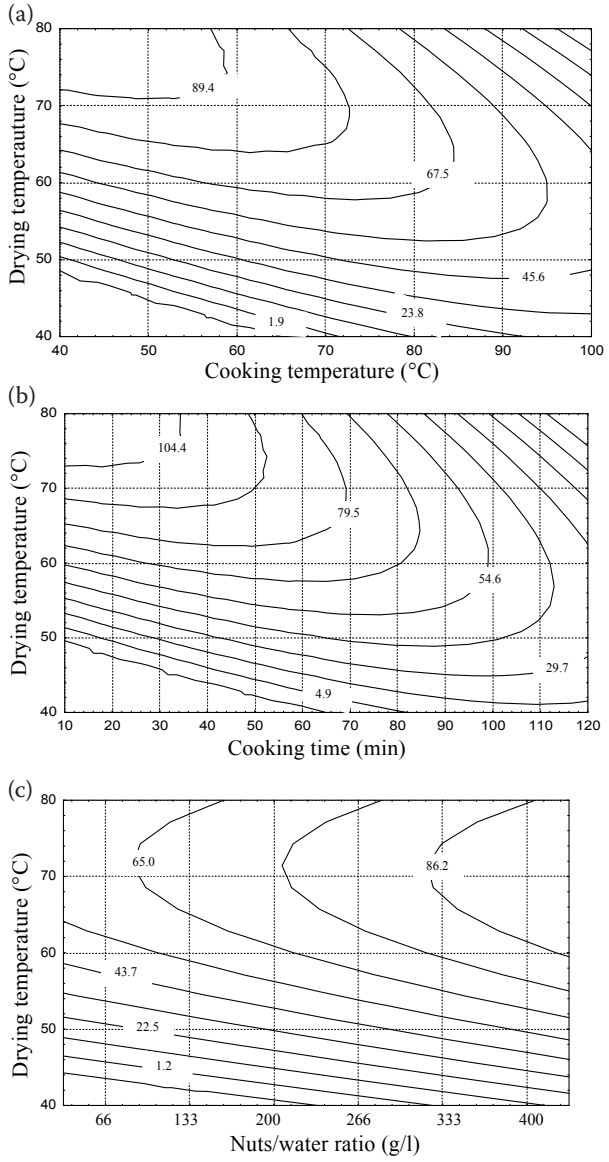

Figure 3. Contour plot of the peroxide value (meq/kg) of shea butter influenced by: (a) drying temperature and cooking temperature, (b) drying temperature and cooking time, and (c) drying temperature and nuts/water ratio

(2006) and Bup Nde *et al.* (2012). Peroxide values increased also with nuts/water ratio (Figure 3c). Cooking temperatures ≤ 80°C, cooking time range of 70–100 min, nuts/water ratio lower than 400 g/l and drying temperatures lower than 54°C were the conditions from which resulted shea butters with low peroxide values.

Cooking and drying conditions that maintain both the low FFA content and peroxide value during the extraction process, as is evident from the results obtained, were: cooking temperature 75–80°C, cooking time 70–100 min, cooking nuts/water ratio < 400 g/l, drying temperature < 54°C.

CONCLUSIONS

A response surface methodology was used in this study. Cooking and drying temperatures were observed to have a significant effect on both the FFA content and peroxide value in the samples of shea butter. Moreover, the peroxide value was additionally influenced by the cooking time and nuts/water ratio. The range of cooking temperature (75–80°C), cooking time (70–100 min), cooking nuts/water ratio (< 400 g/l), drying temperature (< 54°C), drying time (< 40 h) were obtained. Under these conditions the FFA content and peroxide value were 1.4% and 11.8 meq/kg, respectively, and the extraction yield was 13.5%.

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