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EXPERIMENTAL STUDY OF SHEA BUTTER EXTRACTION EFFICIENCY USING A CENTRIFUGAL PROCESS

Yézouma Coulibaly[1], Stéphane Ouédraogo[1] and Nathalie Niculescu[2]
[1]2iE 01 BP 594 Ouagadougou 01, Burkina Faso
[2]GRET 211-213 rue la Fayette, 75010, Paris, France
E-Mail: yezouma.coulibaly@2ie-edu.org

ABSTRACT

The experiments carried out focused on shea butter extraction with a centrifuge machine. Experiments were carried out in the laboratory with a small centrifuge, with a view to determining how parameters such as kernel paste temperature, dilution rate and centrifugation speed affected extraction efficiency. High efficiencies (over 30%) were obtained with accelerations over 1,293 g, a kernel paste temperature over 90°C and dilution over 50%. The centrifuge machine that had been designed was then tested using the same variables as parameters for butter extraction efficiency at various sites. Extraction efficiency was found to be barely higher than 30% on average. Mean efficiency values with traditional methods were found to be virtually the same as for the centrifugal process.

Keywords: shea, butter, oil, extraction, efficiency, centrifugation.

INTRODUCTION

The shea nut tree (*Butyrospernum parkii*) is a tropical oil-yielding plant whose fatty matter has been used for years in Africa for different purposes, ranging from food and soap processing, to healthcare and other medicinal uses.

The traditional method of shea butter processing follows the basic steps described below. Nuts are gathered in the field, dried, and the shells broken. The nuts are then roasted, crushed, ground, and water is added. The paste acquired is churned and heated, in order to separate the oil from the residues. Oil production is completed by decanting and bailing from the container. The average efficiency for this method ranges from 20 to 28 % according to [5].

The main purpose of new butter extraction methods is to reduce the number of steps, thereby reducing the laboriousness of the activity, and at the same time improving efficiency.

Various methods have been explored over 20 years or so without leading to a fully successful system, approved by everyone. The reasons for partial or total failure are numerous. They range from the laboriousness of the work, low extraction efficiency and maintenance difficulties, to the degree of investment required and the limited profitability of projects involving them.

In order to take up that challenge, we proposed and tested a new shea butter extraction method.

EXPERIMENTAL PROCEDURE

The system designed was a centrifuge machine. It extracted oil from shea nut paste by centrifugation. Extraction involved separating oil from the water and from the paste cattle cake. The moving part of the device was driven by a motor, or by an engine, depending on the availability and convenience of either. A shaft driven by the motor or engine was equipped at its other end with a rotating drum. The drum, with a capacity of 10 kg of shea paste, had a rotation speed of 1,000 rpm. That speed was high enough to separate the three components of the paste, i.e. the oil, which had the lowest specific mass and floated to the surface, the water which had an intermediate specific mass, and the cattle cake which was heaviest and moved down to the bottom of the drum. Two bailing devices fitted inside the drum were used to take off the oil and then the water from the drum, once separation was considered to be sufficient.

When separation was insufficient, the colour of the oil was grey, and is referred to as grey oil in this article. In that case, the process was repeated to obtain clear oil. The shea butter extraction diagram is presented in Figure-1.

Figure-1 shows three different oil extraction processes. The central part of the diagram (Branch B) presents the traditional butter extraction method, as already explained. The left-hand part (Branch A) presents the pressing method, which is currently the most widespread or most common mechanical extraction method. The centrifugation method (Branch C), which we tested, is shown on the right-hand side of the diagram. The expected result in all three methods is the same i.e. they all aim to squeeze the oil from the cells containing it.

The oil of the kernels or nuts is more or less strongly confined in oil cells, depending on the capillary strength retaining them [1]. All the methods mentioned above are designed to overcome forces and burst the cells in order to release the oil they contain [13]. That is done by heating, pressing, or centrifuging i.e. thermal or mechanical processes. The final step, in all the methods, i.e. once the oil has been released, is to separate the oil from the other components of the initial paste. The process tested here set out to dilute the shea paste with water to facilitate diffusion of the oil from the burst cells into the water. Several types of treatment were tested prior to centrifugation, the goal being to expel oil from the cells into the water [11]. Each operation, such as churning, heating or centrifuging, needed to keep the oil clean and clear, meaning that, after treatment, the oil should display low oxidization and low acidity, a low moisture content, and a low solid matter content.

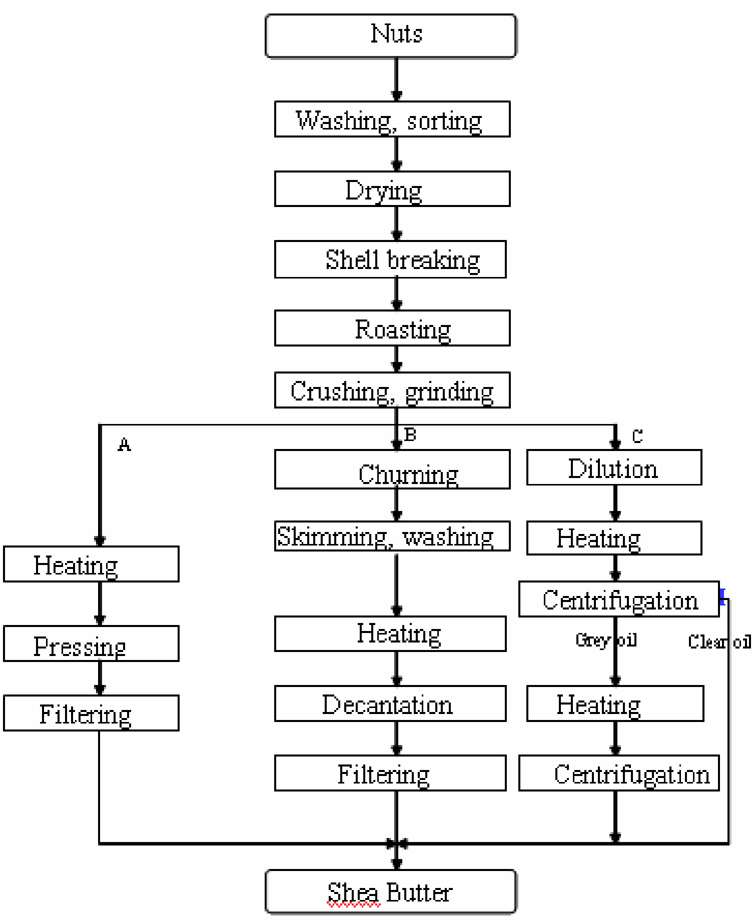

Figure-1. Shea butter extraction diagram: (A) manual press, (B) traditional, (C) centrifugation.

The butter extraction cycle began with the addition of water to the paste. The water used was first heated. The diluted paste was then heated or poured directly into the centrifuge for a 5 to 30 minutes runtime. The oil acquired might then be reheated and passed again through the centrifuge, depending on its quality after the first operation. The purpose was not only to obtain pure oil but also to achieve high extraction efficiency. The extraction efficiency was computed at the end of each experiment from the total amount of oil acquired.

Extraction parameters

The oil content of the nuts was calculated as follows:

$$X = \frac{\text{mass of fatty matter}}{\text{mass of initial nuts or paste}}$$

The initial oil content of the shea nuts, X, was estimated to be as high as 40 to 45% depending on nut quality [5]. On the other hand, extraction efficiency was dependent on the heating temperature and dilution rate. It also depended on the rotation speed of the centrifuge or, more precisely, on the centrifugal force applied to the mass of rotating paste. That is why all the graphs plotting the extraction efficiency against the rotation speed are generated with the centrifugal force on the x-axis.

The separation force expressed for two mixed components whose specific masses were, respectively ρ_1 and ρ_2 was:

$$F = (\rho_2 - \rho_1)\,\omega^2\, r \text{ N/m}^3$$

Where ω was the rotation speed and r the radial coordinate of the rotating masses measured from the axis of rotation. The centrifugal acceleration, which makes it possible to compare systems with different rotation speeds and also different bulks in relation to separation capacity or efficiency, was:

$$\gamma = \omega^2\, r \text{ m/s}^2$$

The centrifugal force and the corresponding acceleration were always higher on the circumference of the rotating system than near the axis, according to the proportionality with the radial coordinate r. We then considered a mean value, R, of that parameter which enabled us to define a relative mean acceleration.

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$a = \omega^2 R / g$

A was the mean value of a relative acceleration applied to a rotating volume with an angular speedω; and g was the gravity acceleration whose value was assumed to be 9.81 m/s^2. a was then expressed as a gravity acceleration value g and was the parameter characterising the effect of the rotation speed on oil extraction efficiency. Extraction efficiency was defined as follows:

$$\eta = \frac{\text{mass of clear oil}}{\text{mass of initial nut paste}}$$

LABORATORY TEST RESULTS

The tests were conducted with a view to showing that extraction efficiency depended on the rotation speed of the centrifuge. They were carried out using a small centrifuge with a speed ranging from 0 to 6,000 rpm. Those rotation speeds corresponded to accelerations ranging from 0 to 2,200 g. The experimental procedure was as follows.

Figure-2 shows extraction efficiency versus acceleration in relation to paste temperature. The dilution rate was kept constant for all the experiments at a value of 60%.

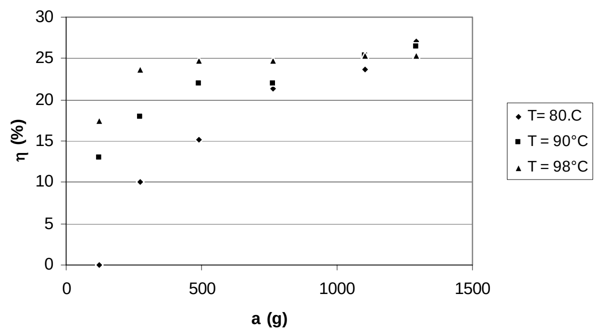

Figure-2. Butter extraction efficiency versus acceleration with a 60% dilution rate and different heating temperatures.

The temperature effect on efficiency is highlighted by the difference in the position of the three curves plotted. It can be seen that efficiency increased in line with the acceleration rate and reached a steady state at around 1,300 g. The curves show that efficiency was less than 30% for all dilution rates of less than 60% water. That low efficiency needed to be considered in relation to the low oil content of the pastes used, with an average X of around 35% according to the test conducted by [3].

Figure-3 shows oil extraction efficiency versus acceleration when the temperature of the paste before centrifuging was kept constant.

In these experiments, the heating temperature of the paste was 98°C and the dilution rate was made to vary. The efficiency values in these curves were all of a uniform high level when compared to those in the previous figure. That difference was mainly due to the high heating temperature. The dilution effect on efficiency is also highlighted in this figure. The same saturation effect was found when the dilution rate was over 60% or when the acceleration rate was higher than 1,300 g.

The two figures show that extraction efficiency was high and increased in line with acceleration, and also in line with an increasing paste dilution rate and heating temperature prior to centrifugation. However, it was found that a large amount of grey oil (containing cattle cake residues) was obtained for all the centrifugation speeds, thus decreasing the extraction efficiency calculated with clear oil only. It was also found that efficiency was always high for heating temperatures as high as 100°C. The influence of acceleration was then less noticeable. At such heating temperatures, high efficiencies were mainly due to sufficiently high temperatures to allow oil cell rupture, releasing the oil without any mechanical effect. Centrifugation was just used to separate free oil from the cattle cake. The process was then made easier. In order to achieve good efficiency levels, i.e. higher than 30%, when heating temperatures were low, i.e. under 80°C, the centrifugation speed had to be increased to around 3,000 rpm, corresponding to 1,300g. It needs to be emphasized, however, that high heating temperatures led to high energy consumption, which might reduce the profitability of any project using the centrifuge.

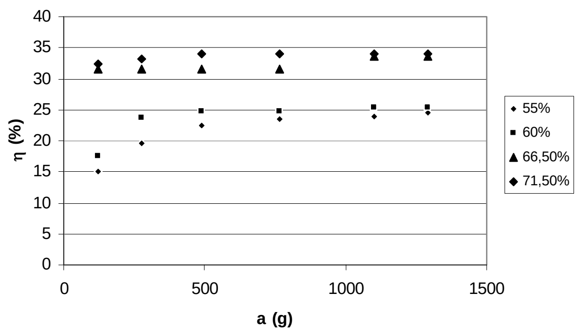

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Figure-3. Butter extraction efficiency versus acceleration with a nut paste heating temperature of 98°C and varying dilution rates.

FIELD TEST RESULTS

The first prototype of the centrifuge machine was installed for use at two sites involving a women's association. However, the first test was carried out in Ouagadougou, at the School of Engineering (EIER). The machine's high capacity of 10 kg of paste per running cycle meant that not as many tests could be carried out as in the laboratory using the small machine. Neither did the constant rotation speed enable plotting of efficiency versus acceleration. The experimental conditions indicated below were used in all the tests.

Mass of paste used: 10 kg
Dilution rate: 61.5%
Nut pre-treatment: all boiled before drying and crushing

Heating temperature fixed
Centrifugation time fixed

Oil extraction was achieved in two steps. The first centrifuge run produced an amount of clear oil and a complementary amount of grey oil, in variable proportions depending on the experiment. A second run, using the grey oil, made it possible to re-process that oil into a given amount of clear oil. Extraction efficiency was calculated by combining the two clear oils.

We found that paste quality, which varied from one experiment to another, played an important role in extraction efficiency. The quality of the nuts, and their traditional pre-treatments before crushing, led to a substantial disparity in the oil content of the pastes used; that needed to be borne in mind when analysing and comparing the results of the experiments.

The efficiency calculated for twelve experiments did not allow the plotting of the efficiency versus one of the numerous parameters of the extraction process. Table-1 summarizes the results of the 12 experiments carried out. The average clear oil efficiency obtained from the first centrifuge run was 18.6%. We defined a global extraction efficiency taking into consideration the amount of grey oil not retreated. That global efficiency was 28.6%. It was found that the centrifugation time, as a parameter, was also important in improving efficiency. However, increasing the centrifugation time led to an increase in energy consumption. That energy consumption was measured at 0.58 l of engine fuel per hour of centrifugation. In order to make a comparison, heating energy was also measured. It was found that the various heating operations required to extract 10 kg of shea paste, in one cycle, was 221.5 g of butane gas.

Table-1. Butter extraction efficiency obtained at the EIER site using a prototype 1 centrifuge machine.

Tests	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Paste temperature (°C)	71	71	70		66	74	69	71	69	76	63	63
Centrifugation time (minutes)	145	75	150	30	45	30	45	30	60	30	60	70
Clear oil mass (g)	1939	1985	2465	2178	2284	1584	1543	1344	1744	1513	1939	1847
Grey oil mass (g)	963	1185	326	1030	959	1107	1200	1363	904	1090	831	996
Sum of clear and grey oil (g)	2902	3170	2791	3208	3243	2691	2743	2707	2648	2603	2770	2843
Clear oil efficiency (%)	19.39	19.85	24.65	21.78	22.84	15.84	15.43	13.44	17.44	15.13	19.39	18.47
Global efficiency (%)	29.02	31.7	27.91	32.08	32.43	26.91	27.43	27.07	26.48	26.03	27.7	28.43

DISCUSSIONS

The work presented in this paper highlighted how various parameters affected the efficiency of shea butter extraction using a centrifugal method. The most important of those parameters were found to be:

- The centrifugal force and corresponding rotation speed of the machine,
- The required heating temperature,
- The paste dilution rate or the proportion of water added to the paste,
- The fineness of the paste.

There were other parameters, such as churning (or not) prior to centrifugation, centrifugation time, etc. For a loading capacity of 10 kg of paste per cycle, the extraction efficiency for 30 minutes of centrifugation was estimated at around 25 to 35%. The test carried out in the laboratory highlighted the effect of centrifugal acceleration on efficiency. The constant rotation speed of the designed machine prevented any variation of that parameter in the field test. The dilution rate of the shea paste, and its heating temperature, were found to be the key parameters for maximizing extraction efficiency. The dilution rate in our work ranged from 55 to 71.5%. The higher the dilution rate, the higher the efficiency. However, the amount of water used could be too high and could be detrimental to the cost-effectiveness of the machine, especially in Sahel rural areas where water can be costly [4]. A compromise was reached with 10 kg of nut paste and 16 kg of dilution water, which led to a dilution rate of 61.5%. Of further concern is the cost of fuel for heating the paste to temperatures ranging from 70 to 100°C. Of all the parameters that played some role in improving efficiency, paste quality was the least easy to control. It was found for some tests that extraction efficiency could be nil with the centrifugation method as well as the traditional method. Such efficiency values were undoubtedly due to the quality of the paste used.

It was found that extraction efficiency using the centrifugal method was similar to that achieved with manual methods. The butter extracted, whilst not undergoing systematic chemical analysis, was found to be of very good quality. With an estimated extraction efficiency of 30%, the loading capacity of 10 kg of paste yielding 3 kg of butter was found to be low by all the users.

CONCLUSIONS

The work presented here was carried out using a small laboratory centrifuge along with a prototype machine used in the field to study shea butter extraction. Various parameters were found to have an effect on shea butter extraction efficiency: the most important were the rotation speed of the centrifuge, or centrifugal force, the temperature of the kernel paste and the paste dilution rate. The laboratory tests made it possible to distinguish between the effects of temperature, dilution rate, and centrifugation speed on extraction efficiency. These tests led to high efficiencies (around 35%) for high dilution rates (around 70%) and high paste temperature (around 100°C). The prototype, whose rotation speed was fixed at 1,000 rpm, was used at various sites. We found at first that the varying quality of paste from site to site played an important role in extraction efficiency. However, the mean trends of the results were the same as those found with the laboratory tests. For 1 litre of engine fuel consumption and 350 g of butane gas consumption, for the various heating operations, the mean efficiency was found to be 28.6% at the EIER site in Burkina Faso. The levels of extraction efficiency obtained were similar to those obtained by traditional methods, thus leading to the conclusion that the current machine would not be as profitable as expected. However, it was found to be of interest by its users with regard to the consistency of the efficiency values obtained, less laborious work, and the time saved on the activity. The quality of the oil extracted from the centrifuge was also found to be better than that of oil extracted with the traditional method. However, it was found that some ergonomic problems needed to be addressed. Improvements and the construction of the second prototype are already under way. The processing capacity is to be increased from 10 to 20 kg of paste, but the main problem that needs to be addressed is low butter extraction efficiency. All the solutions put forward, such as heating the paste, or diluting it and churning it prior to centrifugation led to the same levels of efficiency. There were two reasons for that: firstly, the initial oil content of the nuts and secondly the force with which the oil was retained inside the cells. The first step towards solving that problem is to make sure that the nuts used contain more than 40% oil in mass. Chemical tests are to be conducted in the EIER laboratory to address that issue. If the tests are conclusive, we intend to find a method, whether it be thermal or mechanical or even chemical, for breaking the oil cells in order to release oil before centrifugation. A process using enzymes has been proposed for that, and tests are already under way.

Nomenclature

X	Nut oil content, %
F	Separation force, $N.m^{-2}$
R	Radial coordinate, m
R	Mean value of the radial coordinate, m
A	Mean value of the relative acceleration
g	Gravity acceleration, $m.s^{-2}$
η	Efficiency, %
ρ	Specific mass, $kg.m^{-3}$
ω	Rotation speed, $rd.s^{-1}$
γ	Acceleration, $m.s^{-2}$

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Project coordination GRET - Martine François / Agir - Claude Uzureau
Partners in Burkina Faso: Sicarex - Zacharie Badini and EIER - Yezouma Coulibaly.
Partners in Mali: ICSahel - François Picard
Partners in Portugal: Inde - Luis Alvarez
Partners in France: Esip - Jean-Hugues Thomassin

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