Putting the Press to the Test:
Effects of Temperature on Shea Nut Oil Output

by

Lisa Cristina Tacoronte

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Signature of Author: ....
Department of Mechanical Engineering
May 27, 2010

Certified by: ....
Barbara Hughey
Instructor
Thesis Supervisor

Accepted by: ....
John H. Lienhard V
Collins Professor of Mechanical Engineering
Chairman, Undergraduate Thesis Committee

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Abstract

In northern Ghana, part of a belt reaching from Sub-Saharan Africa to northern Uganda, women collect and process Shea nuts for their valuable oil. This oil is then used in various cosmetic, cooking, and medicinal products. However, the traditional process to extract oil from Shea kernels is time and labor intensive, and the quality is inconsistent, preventing it from being a primary source of income. In order to address these problems, a hydraulic jack press for extracting Shea oil was designed for a woman's co-operative in the village of New Longoro during the summer of 2009 as part of the International Development Design Summit.

This thesis presents the results of a study of the effect of temperature and roasting on the Shea oil yield of a hydraulic jack press in order to evaluate its practicality. Extraction efficiency was measured for ground Shea kernels, either unroasted or roasted, for pressing temperatures ranging from 50-70°C. It was found that a pressing temperature of 60-62°C produced the highest oil yields for both roasted and unroasted nuts, with unroasted, ground kernels producing slightly more oil than roasted, ground kernels. The highest yield produced was $(23 \pm 2.8)\%$ for unroasted Shea kernels at 60.7°C. Furthermore, it was observed that the optimal press chamber configuration is one with perforations along the circumference of the cylinder and on the base with slits to allow oil to escape. It was also confirmed that post-press filtering will be necessary to purify the oil for marketability. Finally, although the initial results are promising, more investigation is needed in order to determine the economic viability of using the hydraulic jack press.

Thesis Supervisor: Barbara Hughey
Title: Instructor

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1. Introduction

In northern Ghana, part of a belt reaching from Sub-Saharan Africa to northern Uganda, women collect and process Shea nuts for their valuable oil. This oil is then used in various cosmetic, cooking, and medicinal products. According to the Cocoa Research Institute of Ghana, as quoted by Peace Corps [1], Shea butter serves as the main edible oil of Northern Ghana and a significant source of fatty acids and glycerol in the local diet. Additionally, it is used as an unguent and in herbal medicines because of its anti-microbial properties [1]. It can be used as a sedative or pain reliever for the treatment of sore muscles, sprains, and minor pains. Shea butter also helps facilitate healing when applied to open wounds. In the pharmaceutical and cosmetic industries, it is used a raw ingredient in soaps, candles, and cosmetics [1]. It is useful as a moisturizer, for dressing hair, and as skin protection from the sun. Shea butter is also a pan-releasing agent in bread making and a lubricant for donkey carts. Even the by-products (i.e. crushed shells), are used as a water proofing agent [1]. Photographs of Shea oil, butter, and a container of locally made ointment are presented in Fig. 1.

Figure 1: Traditionally-produced Shea oil (left), Shea butter to be sold in local market (middle), and locally made Shea ointment (right). Photographs taken by the author while researching in Ghana.

Shea oil has played an important role in local economies of central sub-Saharan Africa. Its traditional uses have not changed significantly since 1830, according to accounts by French explorer Roger Callie in his trip to West Africa [1]. Today, it stands as the second most important oil crop in Africa after palm oil [1]. However, it is most important in regions where palm is not suitable, such as West Africa. It also serves a cultural role, sacred to many ethnic groups and used in religious ceremonies.

In the global economy, Shea oil was initially used primarily in margarine and other edible fats, and subsequently became increasingly important in the soap and perfume industry until it lost popularity during World War II [1]. Its use was revived in the mid-1960s, particularly in the cosmetics and sweets industry [1]. About 95% of kernels produced at present serve as an important raw material for Cocoa Butter Replacers (CBRs) and for manufacturing chocolate and other candy [1].

The traditional process to extract oil from Shea kernels is time and labor intensive, and the resulting quality is inconsistent, preventing it from being a primary source of income for local African women. Because of the inconsistency in quality, locally made butter cannot effectively compete with corporations such as the Body Shop, whose representatives buy Shea nuts from local women for less than the value of the butter. On average, a woman can collect three to five jute sacks of Shea nuts in one week (1 jute sack = 50 kilograms). She can only process approximately two of those bags in a season using the traditional process, requiring about thirteen days of labor per bag. When a woman processes one full bag of nuts, the amount of butter is worth 80 – 100 Ghana cedis (GHS). Unprocessed bags are sold to local and international companies for 28 GHS per bag ($1 = 1.4 GHS).

Once the oil cools into butter it can be preserved and used for up to ten years. While it is up to four times as profitable to extract oil and sell as butter, the traditional process limits a woman's ability to produce oil. Moreover, there is a constant demand for Shea butter in local markets and in the southern region, where Shea trees don't grow. If women could produce a good-quality Shea butter faster and more reliably, they could take advantage of the demand and more of the economic value of Shea butter would trickle down to their local level.

1.1 The Traditional Shea Nut Process

The Shea nut season spans three months, from April to June, during which time the women collect the brown nuts from the ground. The following months are the processing months. When the Ghanaian Queen Mother of the village confirms the Shea nuts are ready for collection, she initiates the season and decides when women from the village are allowed to collect nuts. Once the announcement is made, the women collect nuts from Monday to Thursday, boil the collected nuts on Friday and then spread them out on the ground to dry, repeating the process the following weeks. Fig. 2 shows the Shea nuts at various points during the traditional process. The nut itself has 3 layers: 1) a fruit layer that is often eaten by animals when it falls from the tree to the ground; 2) a brown shell; 3) and a small, tough oil-bearing kernel inside. The nuts are collected in basins with the help of children and used to fill 50-kilo jute sacks. The women carry the sacks back on their heads, typically collecting nuts within a 2-mile radius of their home. Table 1 outlines each step of the traditional process and the time involved in each step.

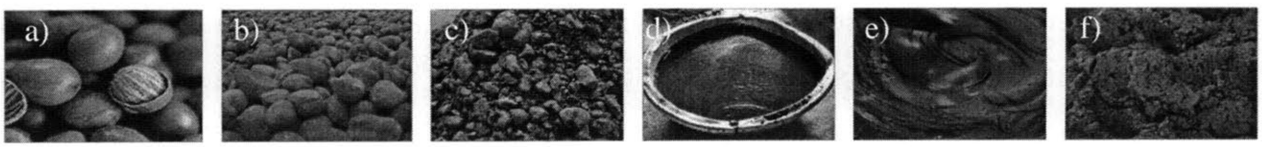


Figure 2: Shea nuts shown throughout the various processing steps. a) The Shea nuts shown in their outer shell. b) After the shell has been removed and the kernels dried, c) the kernels are crushed and d) ground. e) The paste is kneaded and f) cleaned before it is boiled for its oil. [2].

Table 1: Steps in the traditional process and the time of labor required to complete each step.

Step	Time	Figure
Collect	1 day	-
Boil and Dry	1 week	Figure 2a
Shell	1 day	Figure 2b
Crush	30 min	Figure 2c
Roast	30 min	-
Grind	20 min	Figure 2d
Knead and Clean	1 hour	Figure 2e, f
Boil	30 min	-
Scoop oil	15 min	Figure 1, left
Stir and Cool	20 min	Figure 1, middle

1.2 Alternative Shea Nut Oil Extraction Process

In an attempt to improve productivity for local women in the Shea nut oil extraction process, recent work by international development scientists, engineers, and local Ghanaians at the International Development Design Summit (IDDS) in 2009 focused on developing a hydraulic jack-powered press for oil extraction in Ghana. The core team consisted of a Ghanaian village chief; two American university students, including myself; a professor from a Columbian university; and a Zambian Peace Corps director. The press shown in Fig. 3, was developed for a women's co-operative to help them reduce the time required to process Shea nuts to half that of the traditional process, hence increasing productivity and income. The goal of the present work is to study the effect of pressing temperature and roasting on the oil yield of hydraulic jack pressing in order to evaluate its practicality and to optimize the oil output per mass of nuts. The study results are compared to the results from other oil pressing studies, described in Sect. 4.

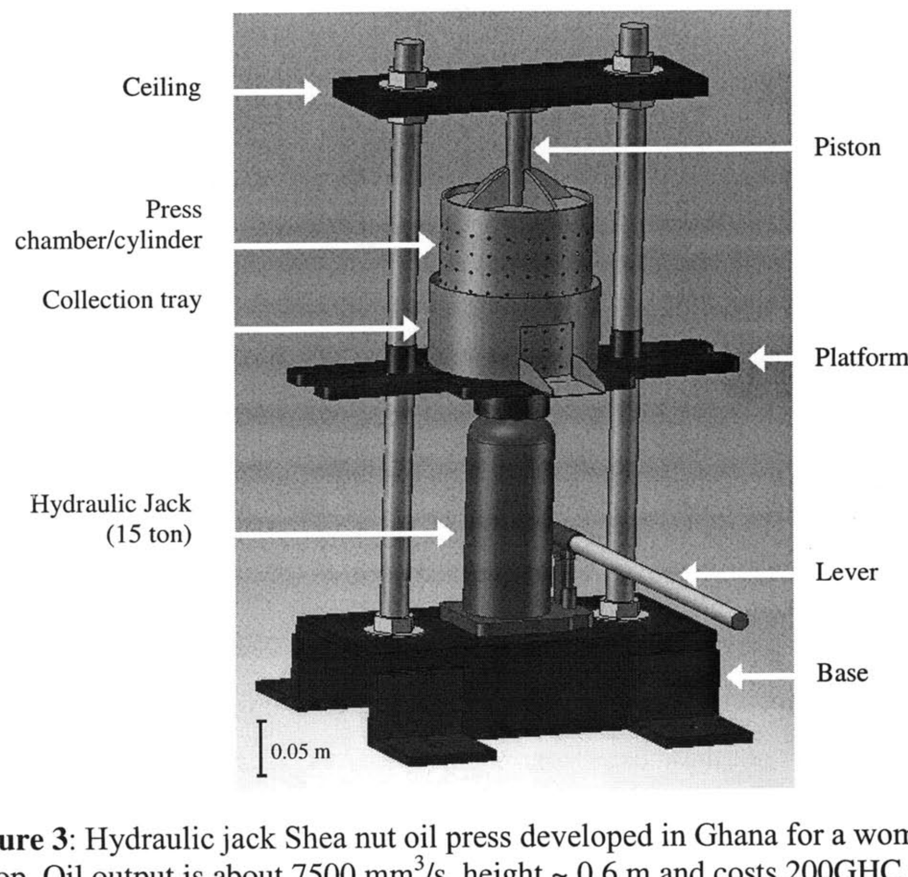


Figure 3: Hydraulic jack Shea nut oil press developed in Ghana for a women's co-op. Oil output is about 7500 mm^3/s, height ~ 0.6 m and costs 200GHC ($140) [2]. Average efficiency is estimated at about 22% [3].

2. Existing Alternative Oil Extraction Methods

Most alternative methods use mechanical processes to extract oil from nuts, but a few rely on chemistry or filtering. In this section we summarize the operating and cost parameters of existing alternative methods, ending with an overview of the vertical hydraulic jack used in the present work.

2.1 Vertical Manual Screw press

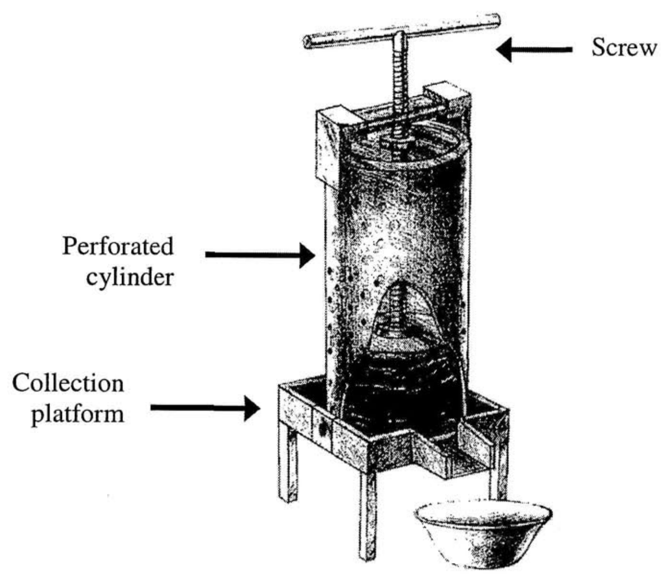


Figure 4: Typical manual screw press. The rotational motion of the screw transfers to vertical motion of a piston through a perforated cylinder. Oil collects and pours out from a basin to a collection bowl [4].

The screw press, shown above in Fig. 4, consists of an elevated collection platform that holds a perforated cylinder. Mounted on the cylinder is a frame that holds a rotational screw with a piston face that moves up and down through the cylinder. The cost of this press varies but it requires a significant amount of labor and material to create. This press was evaluated locally to be more expensive and time-consuming to make than the hydraulic jack press. It is not the most ergonomically-friendly for women as the levers to turn the screw tend to be short and require upper body force to operate when the Shea nuts require more torque to further press. It is also difficult to maintain and requires frequent cleaning.

2.2 Piteba Oil Expeller

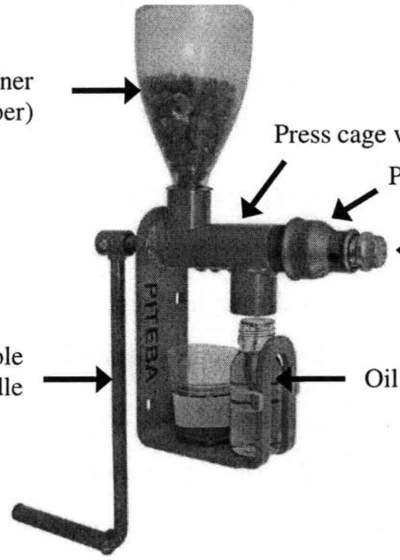


Figure 5: The Piteba Oil Expeller [5].

The Piteba oil expeller, as seen above in Figure 5, and other similar mechanical expellers, consists of a loading container on the left, a horizontal auger screw powered by a rotatable handle, a horizontal press cage with slots for oil expulsion, a press cage cap with a terminal adjustment bolt on the right end, and a oil burner to heat the press cake (the blue liquid bottle). The apparatus is about 20×13×6 cm in size, weighs about 2.3 kg, costs $127 (including shipment) and ships to any country. For recommended use, it requires that the oilseeds have at least 25% oil content and be dried to 8-10% moisture content [5]. Seeds such as peanuts, walnuts and hazelnuts do not need to be deshelled before use, but larger nuts, such as palm kernels, walnuts, and babassu are suggested to be crushed, not ground, to reduce in size for easier expulsion [5]. The recommended operation instructions claim high efficiencies (such as 68% oil yield for oil palm kernel [5]), and tips for oil extraction depending on the oil seed, yet it does not list Shea nuts.

To use, the machine first needs to be assembled. The threads of the cast iron end cap must be cleaned before being screwed on to avoid bursting during use. The washer and cap should be greased with vegetable oil, placed on and adjusted for the type of oilseed (it may not require the terminal bolt). The press cage should be heated for 10 minutes using the small oil-burner. Then, simply turn the crank clockwise to begin expelling the oilseeds. According to Piteba's instructions,

> The seed enters through the funnel into the expeller screw. The screw moves the seed towards the press cage outlet. Near the press cage outlet the seed is ground and exposed to a very high pressure. The oil is expelled near the press cage outlet and runs against the direction of the flow of the seed to the oil outlet. The oil needs time to move to the oil outlet. The press cake leaves the press cage at the end of the cap or the small holes depending on the use of the terminal adjustment bolt as indicated for each type of seed [5].

Fig. 6 illustrates the oilseed cake expelled at the terminal end. After expelling, the cap must be removed immediately, while still warm and the cake is soft for easier removal and cleaning Otherwise, it dries and stiffens and becomes difficult to remove without soaking or reheating [5].

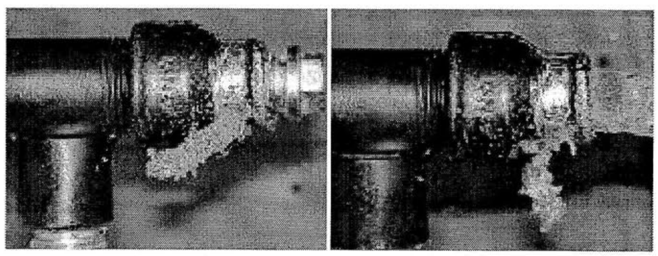


Figure 6: Expulsion of oilseed cake through press cage cap and terminal bolt (left), and through press cage cap sans terminal bolt (right) [5].

The slits in the press cage must be cleaned often to avoid impedance of oil. Other issues include impurities. Once the impurities settle to the bottom, the oil must be decanted before use [5]. The main issues with this apparatus are accessibility to the local people and proper use and maintenance. It jams often and must be cleaned and set-up properly for optimal performance. It would be worth trying on Shea nuts and measuring efficiency to compare to the press tested in this study.

2.3 Bielenberg Ram Press

Figure 7: The Bielenberg Ram Press of Kakute, Tazania, made in Madagascar [6].

The Bielenberg Ram press, shown above in Figure 7, has a long lever on one end and a hopper on the other where the oilseeds are loaded. The lever creates a large torque that transfers into a high pressure. The oilseeds enter a press chamber, and when the lever is moved up and down, they are pressed under a very high pressure, and oil is expelled. Figure 8 shows the essential components of the press, including the piston, the press cage, and the cake outlet. The press requires a significant amount of upper body force and is much too difficult for women to use alone and achieve high oil yields. Women are the primary harvesters and processors of oilseeds like groundnuts and Shea nuts.

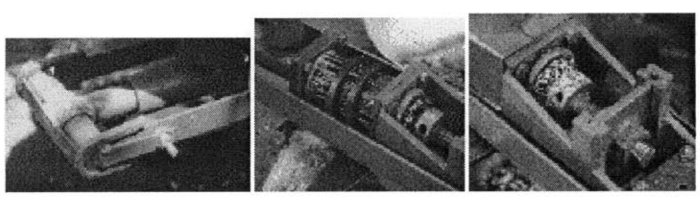


Figure 8: The piston (left), the cage (middle), the oilseed cake outlet (right) [6].

The cost is not well specified, and varies depending on where it is made. It is a rather large machine requiring a considerable amount of steel. The labor involved in making it plus the cost of materials are reasons to speculate that the overall production cost is high and more suitable for a village or large co-operative.

2.4 Fractionation

Fractionation is described as the mechanical separation of the liquid and solid, crystallized components of an oil or fat [7]. The split between liquid and solid depends on the temperature in which the process is undergone. Familiar to industry for over about a century, the first forms of fractionation were 'dry fractionation'- filtering or centrifuge. The rotary vacuum filter, developed in the 1950s became a very common tool for dry fractionation [7]. The other alternative was detergent fractionation. It has the advantage of higher oil yields, however, in detergent fractionation, such as the LIPOFRAC process, it requires the use of expensive chemicals and introduces waste, since, after the solution has been used in the process, it must be discharged after its lost its wetting power [7]. In some countries, in fact, the use of a wetting solution with edible oils is illegal [7].

Solvent-based fractionation for the production of fats with similar melting properties as cocoa butter was developed in the 1950s [7]. It is the most efficient fractionation process, considering separation performance and pure oil yield; however, it is the most expensive and requires far more capital investment than other fractionation processes. For example, installation of a fractionation plant for production of palm olein costs approximately $2,250,000 [7]. Additionally, it requires a safety process because of the use of flammable liquids. Hence, this form of fractionation is only used for production of oils having high added value, [7] such as palm mid-fraction and Shea oil. When using fractionation for Shea oil, it is especially important to remove isoprenoid gum-material found in the crude oil [7] using acetone or hexane. Solvent fraction is not the most effective for production of other raw oils, such as coconut oil, palm kernel oil, and sal fat. For those cases, dry fractionation by use of hydraulic pressing has produced higher yields than solvent fractionation [7]. This form of fractionation is not suitable for the local level because of the financial constraints, accessibility to resources, and the safety concerns.

2.5 Intermediate Moisture Content Method

This method involves raising the moisture content of a partially dried oil-seed to be pressed in a low-pressure system. It requires crushing, grinding, modifying the moisture content of the Shea nut paste, heating the paste, and pressing in a manual screw press. The advantages of using this method as compared to the traditional method include:

- No water or firewood are needed
- Oil extraction can be completed in one day
- The oil yield is comparable or higher and oil quality is generally superior [8]

The disadvantages include:

- Difficulties of drying the gratings in the field
- The capital cost of the press [8]

This process has been applied to coconut oil and a recent publication from the Food and Agricultural Organization of the United Nations describes positive results of using the IMC method with Shea nuts [8]. A financial analysis should be conducted to determine its viability as a women's co-operative venture with an appropriate manual press.

2.5 IDDS 2009 Hydraulic Jack Press [2]

A team of international development scientists, engineers, and local Ghanaians developed a hydraulic jack-powered press for oil extraction in Ghana as part of the 2009 International Development Design Summit (IDDS). The IDDS team was able to define and focus the problem by working with the women of New Longoro. A small prototype of the design with only local materials at Suame Magazine was first built. It was used for tests and to gather feedback from the women. After the third village visit, a larger prototype of the revised design was built in four days. It successfully extracted oil, of a quality visually approved by the women. They were able to learn and operate the press with ease after one demonstration. However, it needed to be larger and more stable, and while the lever mechanism was acceptable a foot-powered option would be preferred. The cost to make was about 200 GHS, within the range the women requested (in a group of 8-10 women, each could contribute 10-20 GHS). The prototype was left with the women of New Longoro, who planned to form a co-operative and begin a Shea nut oil production workshop with the machine. The women planned to further test the machine in comparing the quantity of oil produced with the machine and by the traditional process. The investigation was carried out the following January of 2010, lead by Caroline Hane-Weijman, and is further discussed below [3]. Other future work suggested includes chemical analysis of the pressed oil, and optimizing size for maximum oil yield. More potential improvements include exploring foot-pedal power and refining the new process with the Shea oil press. It was envisioned that the co-op could, over time, mechanize other steps of the process and create its own small-scale Shea oil refinery using the hydraulic jack press. The features of the press and its operating procedures are listed below.

Design Features of the Press

- Manually powered with lever
- Removable, food-grade stainless steel oil collector, oil filter, and piston
- Maximum Shea nut volume of 4.5 L per load ~ 1 large bowl
- Oil output flow rate of 27 L/hour ~ 6 bowls/hour
- Cost 190-200 GHc to make
- Designed for cooperative of 8-10 women
- Payback period within 1 season
- Quality of oil comparable to traditional standards
- Cake usable for animal feed and cooking fuel
- Potential use with other nuts

The following are the recommended operating procedures for the existing hydraulic jack press developed during IDDS [3]:

1. **Crush and roast**: Just as in the traditional method, crush the kernels using a mortar and pestle. Use a sieve with 0.7 cm diameter holes to control for the size of the crushed kernels. Roast the kernels for 20-30 minutes over an open fire or at about 100°C.
2. **Fill cloth bags and the cylinder**: Fill the cloth bags, as in Fig. 9 with the desired amount using a ladle and weigh them on a 4 kg scale. Loosely pack the kernels. Place the cloth bag(s) into the cylinder resting in the basin, and place the piston on top so that it is as level as possible.

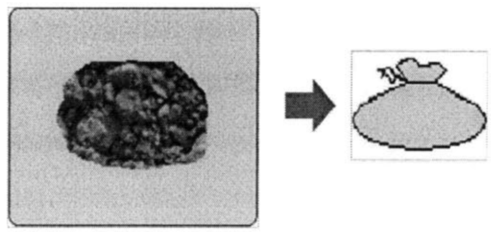


Figure 9: Fill cloth bags with crushed nuts.

3. **Assemble parts**: Place the basin, cylinder, and piston configuration onto the platform, as in Fig. 10.

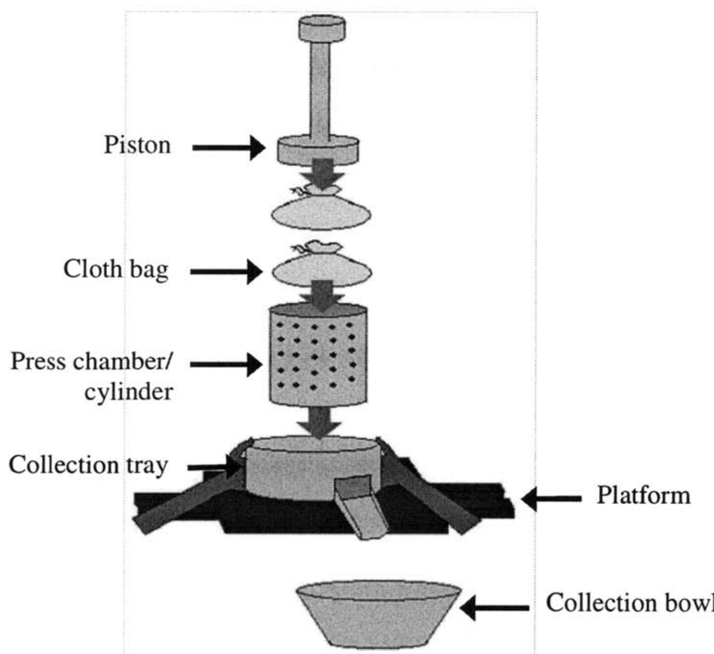


Figure 10: Assemble and fill press chamber with cloth bags.

4. **Use the hydraulic jack press**: Tightly close the screw at the bottom of the jack and start moving the lever arm up and down, as indicated by Fig. 11, until the piston touches the ceiling of the press, making sure the piston and cylinder are perpendicular to the platform and base of the press.

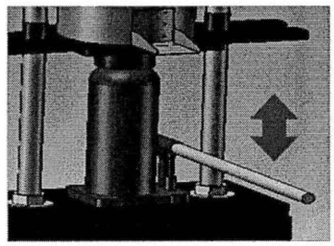


Figure 11: Close the screw near the base and move the lever arm up and down to use the press.

5. **Press at intervals**: Continue pressing until oil starts flowing out and collecting. Press at intervals to allow oil to flow out (especially since the bags may break if the pressure is increased too rapidly). Tilt the entire press to help oil flow into the collection container held below the nozzle of the basin.
6. **Collect oil:** When oil has stopped flowing (approx. 20 minutes time), discontinue. Release pressure on the hydraulic jack by opening the screw near the base, and use the handles attached to the platform to push down to the initial, lowered position, as in Fig. 12. Disassemble as needed to remove pressed cake, clean and re-prepare.

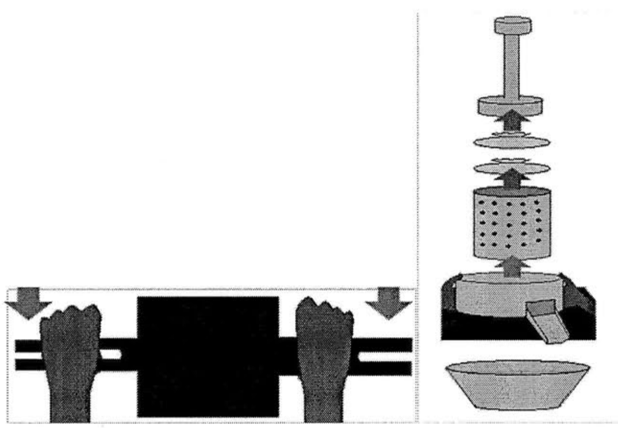


Figure 12: When oil stops flowing, release the screw near the base and press down on the handles. Disassemble and remove the pressed cake to clean and re-prepare for another press.

7. **Reheat and press the residue**: To extract more oil from the residue, re-roast it and re-press it [3].

3. Factors Affecting Oil Yield and Purity

All the mechanical extraction methods described above have several common features, as shown in Fig. 13.

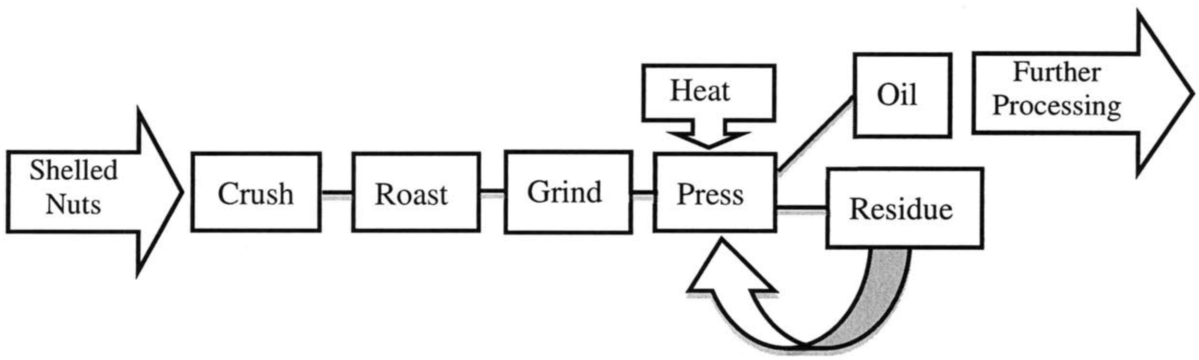


Figure 13: Flow chart of the steps involved in mechanical extraction methods.

There are various parameters that affect oil yield in mechanical pressing that should be considered. These include:

- **Roasting**: is a part of the traditional process. Some research indicates that this step is necessary for optimal oil yield, while the most recent studies conducted by students at the Kwame Nkurah University of Science and Technology (Sect. 4.4), as well as the results of the present work, show that roasting is unnecessary to obtain high oil yield. However, more studies need to be conducted to determine whether the roasting process is necessary to achieve the right chemical properties and quality of Shea butter.
- **Fineness of ground**: a finer ground of Shea nuts allows for more oil expression per surface area. It also reduces the pressure needed for oil expression, as force is not required to crush large chunks of Shea nuts.
- **Temperature while pressing or extracting oil**: The Shea nuts can be heated at various times before and during pressing. In the study discussed in Sect. 4.4, the grinding plates

were heated just before the crushed Shea nuts were ground, and hot water was added to the kneaded paste before pressing to raise its temperature in cold climate. In Ghana, the average high temperature is in the upper 20°C range and the average low is in the lower 20°C range [9]. The optimal temperature of 60°C determined in the study conducted at KNUST is the temperature of the paste when hot water was added to it. The present work determined the optimal temperature by using heating tape to heat the container and nuts together to a specified temperature, then pressing for oil expression.

- **Moisture content**: Results in the literature indicate that increasing moisture content improves oil expression [10]. The IDDS hydraulic jack presses Shea nuts with their initial natural moisture content level of about 6%. The present work did not investigate the effect of moisture content on oil yield or purity. This topic should be investigated in the future for the hydraulic press.
- **Geometry of the press chamber**: Previous studies examined the effect of area and diameter of the cylindrical press chamber on oil yield. Most studies indicate that smaller diameter results in higher oil extraction efficiencies for similar cylinder height. This is likely due to shorter pathways for oil to escape from the Shea nut cake as it is pressed. Additional considerations in geometry are how the oil flows out from the press chamber; whether it is allowed to flow through holes from the bottom alone, holes around the perimeter, a combination of the two, and whether the press chamber is composed of multiple structural or filtering layers.
- **Pressing speed:** a slower pressing speed allows for more oil to escape from the cylinder and maintain a higher kernel pressure, thus causing more oil expression, as will be discussed in Sect. 4.3. If the speed is too great, oil remains in the kernels longer, creating a higher pore pressure, and reducing oil expression.
- **Pauses to allow for oil flow and relaxation of the nut mash**: Adding pauses mid press or at the end of press help give more time for the oil to flow out and the Shea nut cake to relax and rearrange as oil seeps out.

3.1 Shea Nut Chemistry and Purity

The quality of the Shea nut produced by any method is important in its success economically. The most important chemical components of Shea butter are the Free Fatty Acids, peroxides, impurities, and moisture [1].

Free Fatty Acids (FFA): are undesirable and create variation in the quality of the Shea butter. Mature nuts should be selected over unripe nuts from the trees; hence women often collect the fallen nuts from the ground. Additionally, boiling denatures FFAs and is an important step in the Shea butter process [1].

Peroxides: however, if boiled for too long, there could be an increase of peroxides in the butter, which is also undesirable. Peroxides denature the antioxidants that give Shea butter its natural protection [1].

Impurities: such as water, metal, and dirt should be kept out of the Shea oil and cooled Shea butter. Useful measures to ensure pure butter include well-sealed containers, caution when grinding and extra filtering [1].

Moisture: just a small amount in the Shea butter can cause fungus to grow and spoil large amounts. This can be prevented by boiling, storing nuts in jute sacks (not fertilizer bags), and not adding water to the finished butter [1].

If the hydraulic jack press is economically and ergonomically the most appropriate technology, the steps in the refining process after pressing will need to ensure oil and butter purity for the press to be widely adopted for use.

3.2 Mechanics of Extracting Oil from Oilseeds in a Vertical Press

Previous work on extraction of oil from pressed peanuts by R.M. Patel [11] found that the point at which oil appears on the surface of the oilseeds, called the oil-point, occurs at a pressure that is an exponential function of the rate of deformation of the bed of nuts, *R*, and the moisture content of the nuts, *m*. This oil-point pressure, p_o. is given by,

$$p_o = K_1 e^{K_2 m^{\alpha} + K_3 R}, \tag{1}$$

where K_1, K_2, K_3, and α are constants that are particular to the type of oilseed. Patel found that the pressure that is applied to the peanuts is distributed between the kernel pressure, that which the peanuts carry, and the pore pressure, that which the oil fluid carries. The pressure that actually contributes to oil expression is the kernel pressure. The more oil that remains in the peanut bulk, the higher the pore pressure, and the less the amount of oil that can be further expressed.

Fig. 14 shows a schematic of axial force applied by a pressing piston in a cylinder. As the nuts are compressed, the compaction and increasing resistance of the nuts to further compression, friction between the piston and the cylinder walls, and radial and hoop stresses in the cylinder walls, result in increasing force that must be applied by the press.

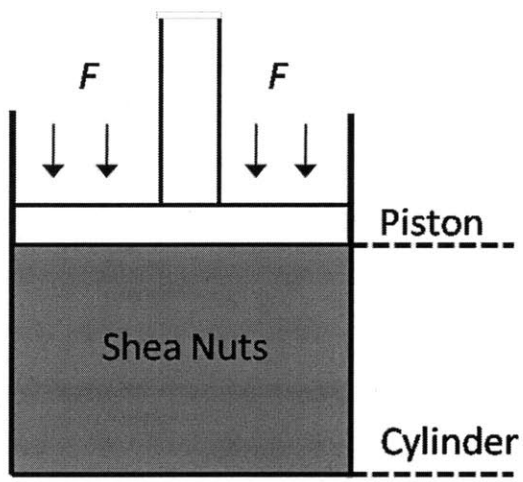


Figure 14: An axial force is applied by the piston on the ground Shea nuts inside a constraining cylinder.

The pressure profiles for varying areas are similar but reach higher peaks for smaller cylinder diameters, as described in Sect. 4.2 below. This rise in force and pressure is counteracted by relaxation caused by release of oil from the solids and rearranging of the particles, especially if the crushing piston is held in place.

As the piston applies an axial pressure to the ground Shea kernels, the cylinder constrains the kernels to a radius of r_i, as shown in Fig. 15. The cylinder is assumed to support the resulting radial and hoop stresses, so that the radial and hoop strains are minimal, with a typical design value of $\sim 0.1\%$.

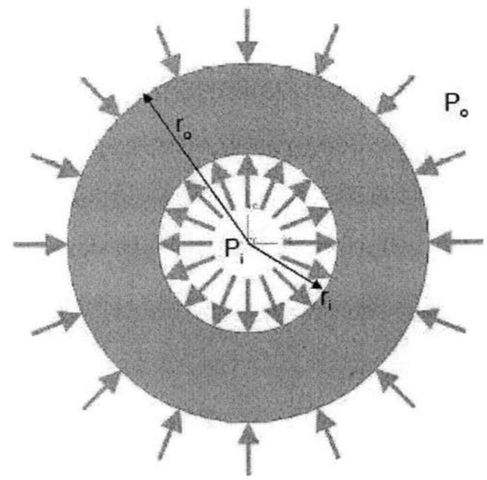


Figure 15: Force diagram of a thick-walled cylinder with inner radius, r_i, and outer radius, r_o, under internal pressure, p_i, and gauge pressure, p_o. [12]

The maximum radial, axial, and hoop stress in the cylinder walls can be derived from Hooke's law and the maximum force that the press can apply. Since the cylinder must be perforated to allow the oil to escape, a safety factor must be added to account for the stress concentrations created by the perforations. The derived stresses can be used in a set of governing static equations for thick-walled cylinders to find the thickness needed to support the maximum applied axial load. The analysis can be conducted for varying cylinder diameters and the resulting value for inner radial stress used to determine the geometry and material properties required for the press structure, while minimizing the cost of materials.

Lastly, the nuts undergo at least three states in the compression. As discussed in Ref. [11], with regard to peanuts, the nut volume is comprised largely of air voids and oil. As the nuts are pressed one observes the air voids closing and oil expression until the nuts reach an incompressible state in which the nuts have been fully compressed. These states are visible in the force versus displacement graph as shown below in Fig. 16 [11].

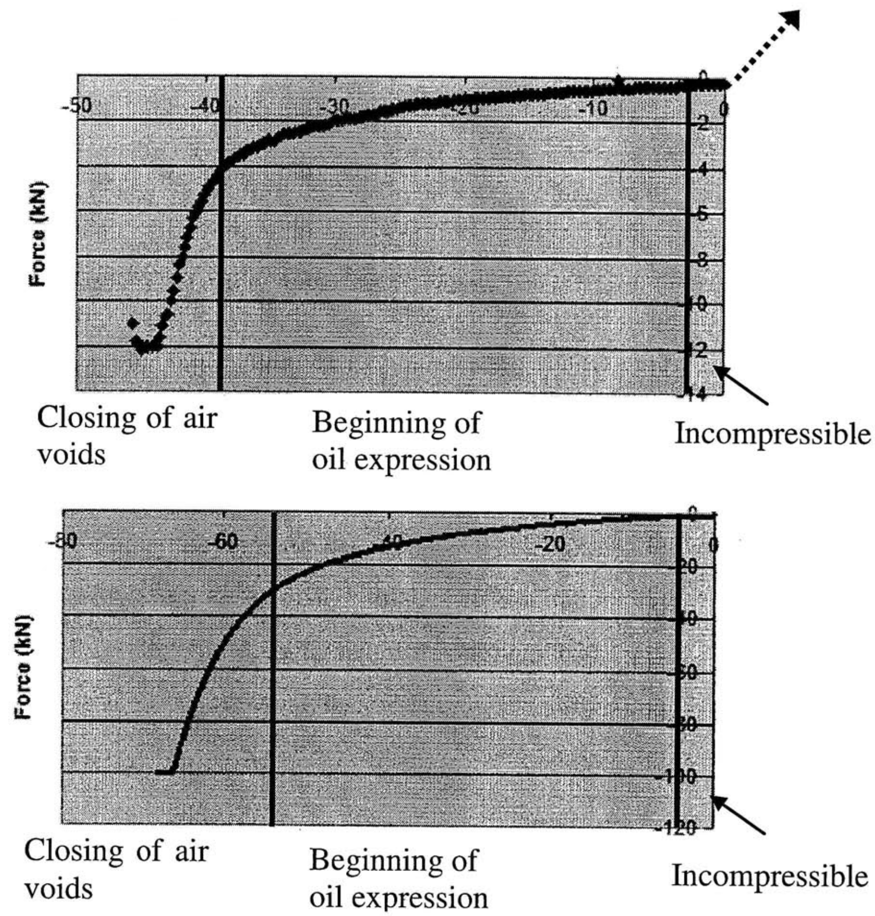


Figure 16: Force-displacement curves for peanut pressing. The first steep rise in force occurs as the air voids close. Then in the second phase, as the nuts continue to be pressed, one sees oil expression as the air voids continue to be closed. The third phase, incompressibility, when no further oil expression from the cake is possible, is indicated by a sharp rise of force (not clearly visible here as the data was not included- but it is shown by the dotted arrow in the upper right corner) [11].

Oil must travel through the solids to escape. Different configurations or arrangements of openings in the cylinder allow one to examine how and where the oil escapes while the Shea nuts are pressed. The larger the area, the more distance the oil must travel to escape and the likeliness that some oil gets trapped in the solids [3, 13]. Creating more pathways to allow oil to escape would improve oil yield [3, 13]. There is also a balance between the height and area for the maximum capacity of the pressing mechanism that will give an optimal output per press. The smaller the area, the greater the oil yields, however, the higher the pressure created; hence the frame must be sturdier [13].

4. Previous Studies of Oil Pressing

In general, not many focused studies have been conducted on Shea nut oil extraction methods. Consequently, the optimal low-cost extraction process for smaller scale settings has yet to be determined. Previous studies conducted on Shea nuts have explored how various design parameters, such as geometry and moisture content, affect the oil yield of different oil extraction methods. Few have looked at the mechanical properties of the Shea nuts themselves, though many have investigated the chemical properties of the oil. Relevant research and previous fieldwork of interest on this topic are described below.

4.1 Shea Nut Oil Press Project Report [3]

The goal of this study was to evaluate the current press design, developed during IDDS 2009 in Ghana, and compare the oil output and quality of the press process to the traditional process. The study also looked at how the size of the cylinder, temperature of the nuts, number of cloth bags and amount of kernels affected oil output. The current press has a 0.16 m inner-diameter cylinder for loading the Shea nuts and 15-ton hydraulic jack for pressure input. Two additional stainless steel cylinders of 0.18 m and 0.12 m inner-diameter with respective pistons and a larger basin for the larger cylinder were fabricated. Two batches of Shea nuts were used for experimentation. The first batch, used only for testing of the additional method, belonged to a local woman and was of lesser quality due to late collection and improper drying before storage. The second batch, used for both testing of the traditional process and the press, was of higher quality and bought from the local market. The press had a lower oil yield than the traditional process. With re-pressing of the leftover Shea nut cake, similar percentages could be reached. On average, the traditional process had a 32.9% oil yield. Using the press, no oil was produced without heat. The 0.12 m inner-diameter cylinder produced the most oil with an average oil yield of 22.4%. The average oil yield using the 0.18 m cylinder was about 21.5%. A repress of cake from the large cylinder produced an additional 8.33%.

Summary of results found:

- Smaller diameter produced higher oil yield
- Oil was clearer and extraction rates were higher when Shea nuts were separated into more bags and pressed.
- Temperature is important for oil yield but not enough tests were conducted to determine the optimal temperature for pressing. It was observed that at higher temperatures and longer periods of time, the cake mixed more with oil and the resulting oil was browner in color.
- A filtration system for post-processing is necessary as cake and dirt mixed with oil.

Design problems observed:

- Unstable platform created difficulties in lining up piston and cylinder. If the angle of the platform is too great, there is the potential hazard of the press components slipping out under great pressure.
- Longer neck for the piston is needed. Must be longer than height of the cylinder.
- Gathering oil in the basin was difficult and a modification is needed to facilitation the collection.
- Filter bags constantly broke through the holes in the cylinder and could not be reused. This incurred a cost. About 40 cloth bags cost as much as 26 GHC. Ways to facilitate the most oil extraction through additional pathways without cloth bags should be explored. A post-harvesting filtration process is necessary.

Overall conclusion: future work should focus on a drying mechanism for better Shea nut kernel quality, a post-press filtration system, an improved press design, and more research in the Shea butter market system for the benefit of the local women.

4.2 Making Peanuts Sweat: Maximizing Oil Output [13]

This study investigated the pressure profile of pressing peanuts to analyze the affect of pressure, piston area, and the loaded height of peanuts on oil output. Although this study was conducted on peanuts, it is a model of the experimental methods for the present research and the patterns found in the effect of geometry on oil yield are applicable to Shea nuts. Wrapped in cloth, peanuts were loaded at heights of 0.025 m and 0.051 m for each cylinder and pressed using a Universal Testing Machine (UTS) using three perforated cylinders of varying diameters and matching pistons. The resulting mean pressures were: 476±3 MPA in the 0.025 m pipe; 235.0±0.4 MPa in the 0.051 m pipe; and 143.0±0.4 MPa and in the 0.064 m pipe. Taller peanut loads at smaller pipe diameters seem to produce more oil than larger areas with shorter or even taller heights. The pressures are relatively similar despite the area, however, smaller areas reached higher peak pressures. The measured pressure profiles and oil yield can be seen in Fig. 17 and 18 below.

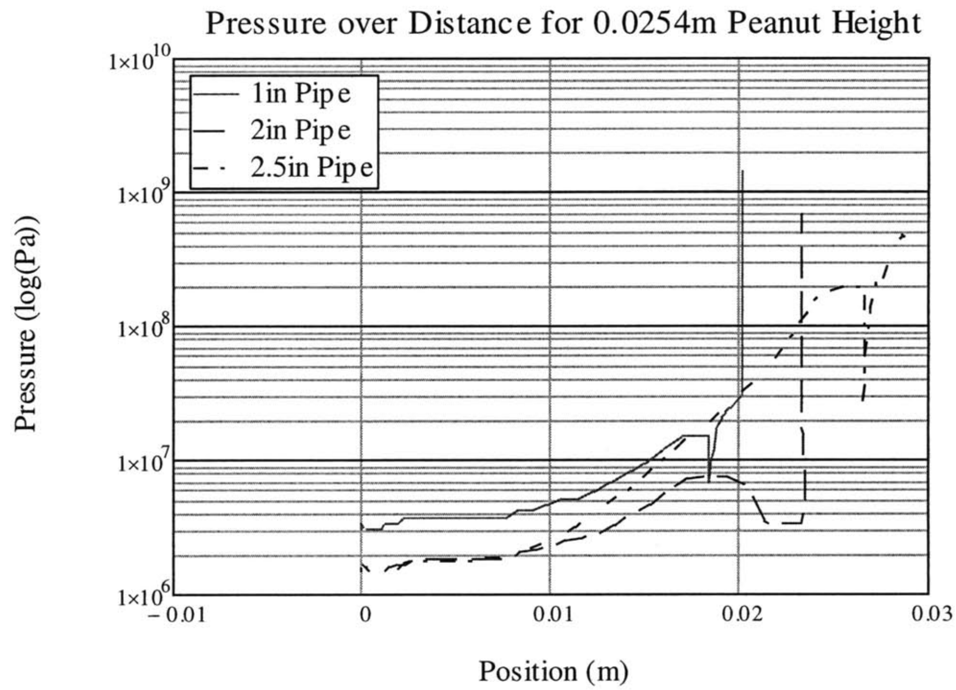


Figure 17: Pressure profiles for each the 0.025 m, 0.051 m and 0.064 m pipes with 0.025 m height of peanuts. The results are unexpected and disagree with the original assumption that the pressure profiles, for varying areas, are comparable for the same type of nut.

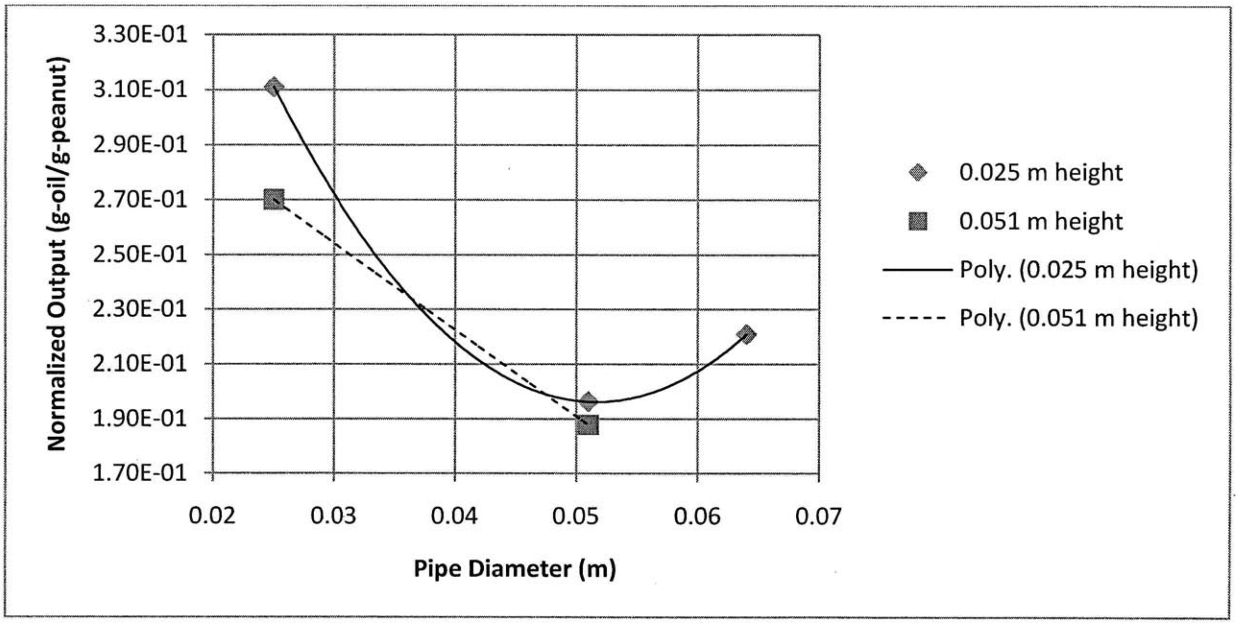


Figure 18: Output of oil per peanut (gm/gm). With increasing press diameter, the volume of oil output followed a second order curve. The larger height of peanuts produced less oil in general, but the results are not conclusive, given the small number of points

4.3 Maximizing Oil Output of a Treadle-Powered Peanut Oil Press [11]

This MIT undergraduate thesis by R.M. Patel studied methods to increase oil yield of a cam-design peanut oil press that transfers the horizontal treadle motion to vertical press motion. A variety of displacement profiles were used and the amount of oil extracted from pressed peanuts was measured in order to determine the optimal cam design. Patel's thesis evaluated modern oil press technologies for the developing world and the theory behind peanut oil expression. Many of the properties necessary for optimal peanut oil expression cannot be applied to Shea nuts as the characteristics of peanuts, a ground-nut, are rather different from those of Shea nuts and other tree nuts. He found that the pressure that is applied to the peanuts is distributed between the kernel pressure, that which the nuts carry, and the pore pressure, that which the oil fluid carries. The pressure that actually contributes to oil expression is the kernel pressure. The more oil that remains in the peanut bulk, the higher the pore pressure, and the less the amount of oil that can be further expressed.

This study also examined the pressing speed which resulted in the most oil expression. Slower speeds allow oil time to leave the chamber and maintain a higher kernel pressure. Patel used the same Instron machine used for the present thesis to measure displacement and force vs. time. His setup included a piston to press the peanuts, a cylinder with slits to hold the peanuts, a tray to collect oil, and the Instron machine. The piston was vertically moved at a constant speed in and out of the peanut-filled container. The peanuts were roasted and heated to 100°C for pressing. He also used two different sized cylinders to observe the effects of area. Oil yield was measured in grams of oil expressed divided by the grams of peanuts used. The force-displacement data indicated how far the piston could compress before the mass of peanuts became incompressible. At incompressibility, the Instron could not longer press any further, no oil can be further extracted, and the forces increased rapidly.

Figures 19 and 20 below show the results from this study for two sizes of cylinders. It was confirmed that slower speeds and the smallest cylinder expressed the most oil. For the smaller container, oil expression began at about 2kN or a pressure of 2.5 MPa. The peanuts reached incompressibility at about 12 kN, or 15.1 MPa. For the larger container, oil expression began at 15 kN, or a pressure of 6.6 MPa. Peanuts were incompressible at 100KN, or 44.1 MPa. It can be observed in his data that the most oil expression occurred at a region of 3-7 MPa. The highest yield achieved was about 27%. These results will be compared below to those found in this Shea nut study.

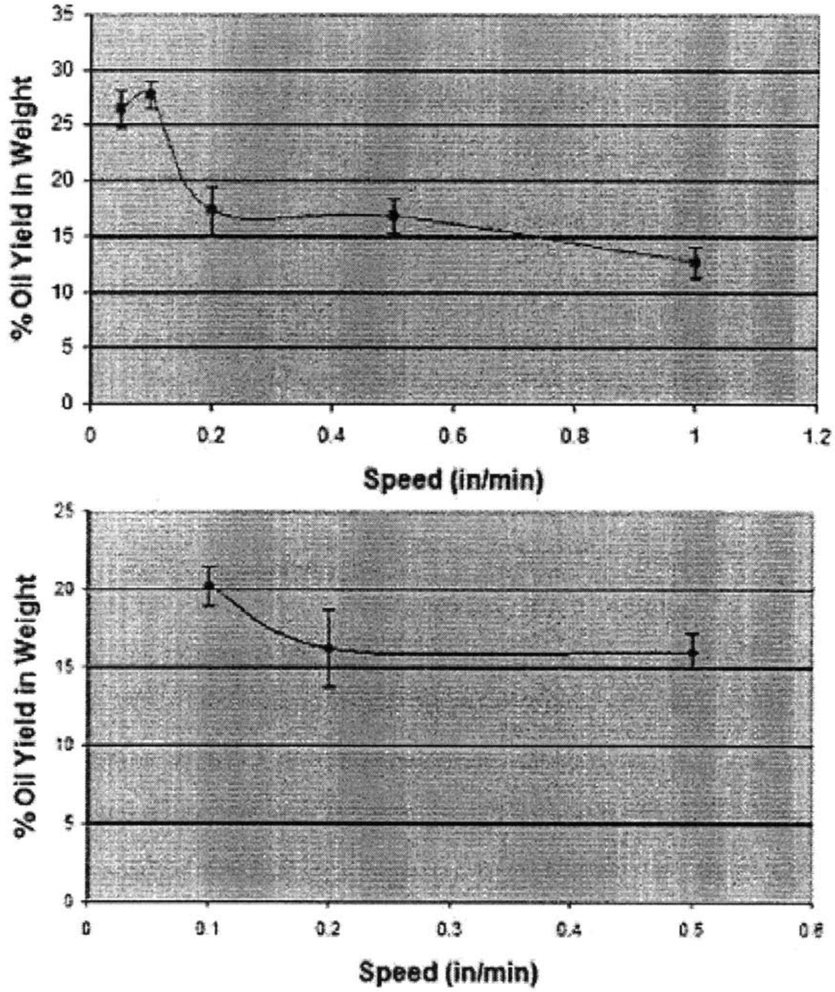
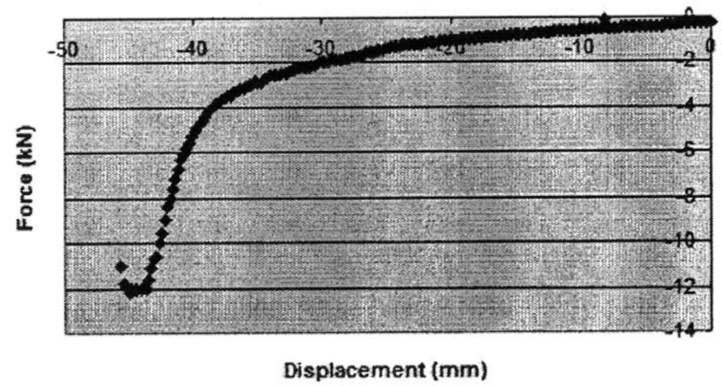


Figure 19: Speed of pressing vs. oil yield for the 31.8 mm diameter container (top) and the 72.6 mm diameter container (bottom)



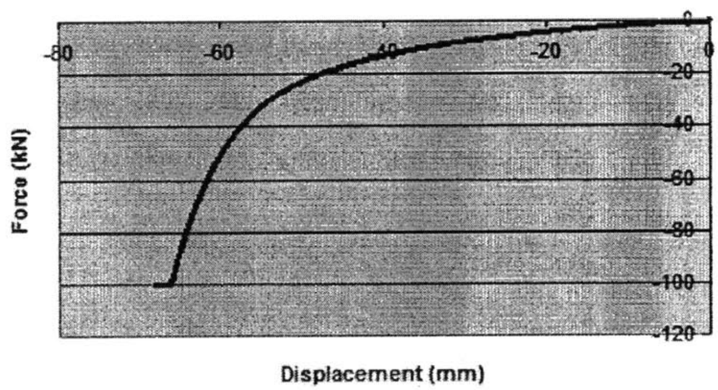


Figure 20: Force-displacement curve for the small container (top) and the larger container (bottom)

4.4 Effect of Temperature, Moisture Content, Particle Size and Roasting on Shea Butter Extraction Efficiency [10]

The purpose of the study was to find the optimal extraction temperature, moisture content, particle size, and to test the effect of roasting on Shea nut kernels on the oil yield using the Intermediate Moisture Content (IMC) method with a manual screw press. The IMC method involved the use of a low-pressure manual screw press to extract oil from She nut kernels with modified moisture contents between 10% and 20%. It involved six steps:

1. Decorticating by removing the outer shell and crushing the internal kernels in a mechanical crusher,

2. Grinding the crushed nuts into a fine paste using a corn mill or wet grinder. Before grinding, the plates were warmed up for 10 minutes. The resulting paste had a temperature between 65°C and 70°C,
3. Determining the moisture content of the paste,
4. Moisturizing the paste to raise its moisture content from an approximate initial moisture level of 6%, by kneading,
5. Adding hot water in cold weather to raise the temperature of the moisturized paste to reduce viscosity of the oil in the paste and,
6. Press oil in the manual screw press by putting paste in cloth bags and loading it in the press container.

The moisture content of the paste was determined using an oven drying method at the Food Processing Laboratory of the Technology Consultancy Center in Ghana. A series of trials tested combinations of moistures levels and temperature levels: 10%, 12%, 15%, 18%, and 20% with 50°C, 55°C, 60°C, and 65°C. One series of trials was conducted on unroasted nuts, while a second was conducted on roasted nuts. On average, roasting time was between 17-28 minutes and the temperature was between 100-112°C. The oil extraction efficiency was calculated as follows:

$$Efficiency = \frac{oil\ extracted}{oil\ in\ paste} X\ 100\ or\ y = \frac{e}{wc(1-m)} X\ 100, \qquad (2)$$

where *e* is the weight of oil extracted, *w* is the weight of paste pressed, *c* is the oil content of paste on moisture free basis, and *m* is the moisture content of the paste before moisturizing. The oil content of paste on moisture free basis was determined using a solvent extraction method (Soxhlet Apparatus). Particle size analysis was conducted by putting pressed cake through different mesh sizes of a vibrating particle size analyzer. Figures 21 and 22 below summarize the results.

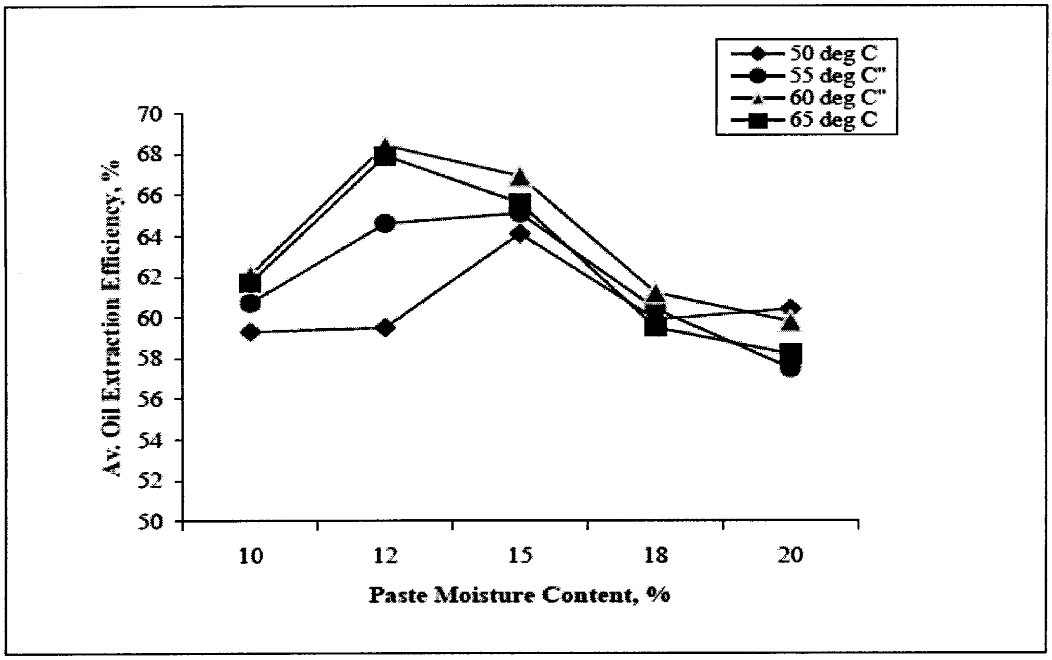


Figure 21: Oil extraction efficiency vs. paste moisture content of unroasted kernels.

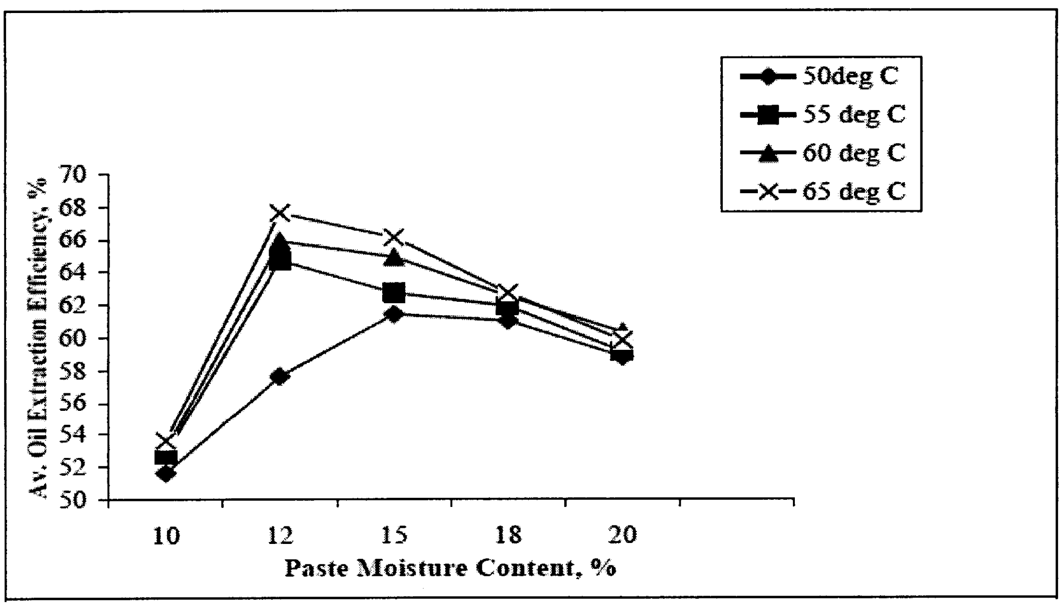


Figure 22: Oil extraction efficiency vs. Paste moisture content of roasted kernels.

The study found an optimal temperature of about 60°C, moisture content of 12% with extraction efficiency between 65.9% and 68.5%. The results also showed that the finer the paste, the higher the oil yields, and roasted kernels did not give a higher oil yield than unroasted kernels.

5. Pressing Shea Nuts

Two different presses were used in the experiments: the Instron Universal Testing Machine (UTM) and a hydraulic jack press set up in the large frame of an older non-functional screw press. The methods and observations for each press are discussed below. Unfortunately, the Instron maximum force was not high enough to fully press the ground Shea kernels, hence there are no corresponding results in Sect. 6. However, it was deemed important to outline the methods used with the Instron to provide guidance for future researchers wishing to continue these studies.

5.1 First Experimental Setup with the UTM

The Shea nuts were first compressed using an Instron UTM, shown below in Fig. 23, which recorded the reaction force versus the displacement of the piston. The oil output was collected in a pot or soaked in a napkin and measured using an Ohaus Scout Pro model SPE123 scale with a 0.001 g readability. Three configurations of cylinders were used to observe how oil escapes from the cake and cylinder while pressed. After reaching the machine's maximum force capability of 10 kN (1.02 ton) and finding that the nuts had still not reached incompressibility, another setup was used to test the affect of temperature and roasting on oil yield.

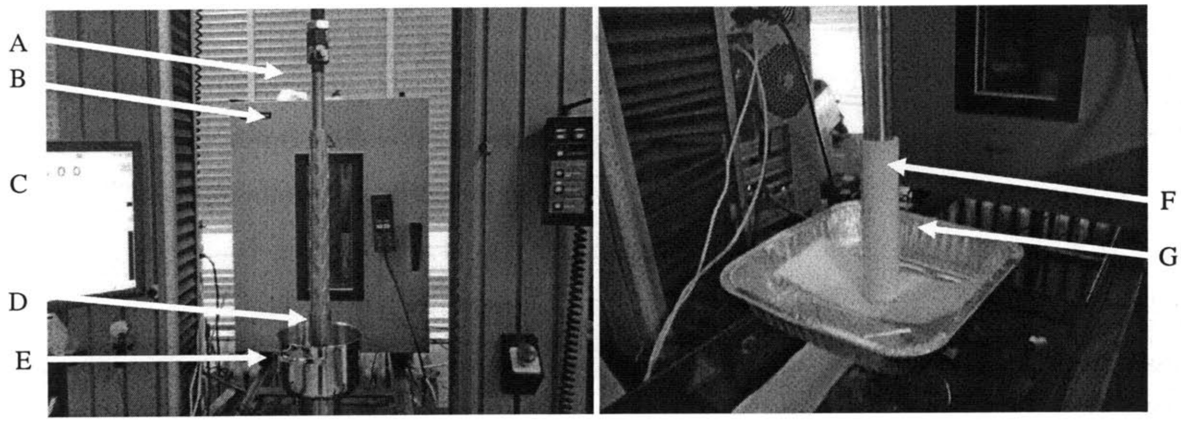


Figure 23: First experimental setup using an Instron 5560 Series from the MIT 2.002 mechanical engineering course laboratory to press crushed kernels and record the reaction force. (A) Piston (B) Well-point press chambers (C) Computer (D) Pedestal support (E) Collection bowl (F) PVC tube (G) Collection tray with napkin.

5.1.1 Universal Testing Machine Parameters

For initial attempts to collect Shea nut force-displacement data and observe the effects of pressing speed on oil yield, the Universal Testing Machine was programmed to press at speeds of 10 mm/min, 5 mm/min, 1 mm/min and 0.5 mm/min. Additionally, the machine was programmed to stop pressing at 10kN and hold, under the assumption that the force range, or peak pressure would not exceed the machine maximum of 10 kN. The force displacement data was collected on an attached computer using Instron software.

5.1.2 Observations with the Instron Machine

The experimental trials with the Instron machine to obtain force vs. displacement graphs did not give useful data. The machine's force capabilities reached maximum and the curves never reached incompressibility, while very little oil was extracted.

Moreover, these attempts brought to light several issues. First was the difficulty in cleaning the pressed Shea cake after each run. The pressed Shea cake would jam in the perforations with or without the cloth bags. Without a good way to unload the cake, it adds significant time to using the vertical hydraulic jack oil press and makes it a very user-unfriendly option. Ground Shea kernels required less pressure to produce slightly more oil than solely crushed kernels, and were easier to remove after each press, hence further trials were conducted on ground, rather than crushed, kernels. Secondly, the tests confirmed the need for heat to extract oil while pressing as hardly any oil resulted from each press without heating the pressing chamber. Heating the press chamber allows for oil extraction with less pressure input. Lastly, the machine reached its maximum safe force capacity without the force/displacement graph indicating a fully pressed state (never reaching incompressibility). Although it would be beneficial to display the graphs that demonstrate how the curves never reached incompressibility, the data was unfortunately not properly saved. Figure 24 shows a pressed cake that retained a significant amount of oil after a trial on the Instron machine.

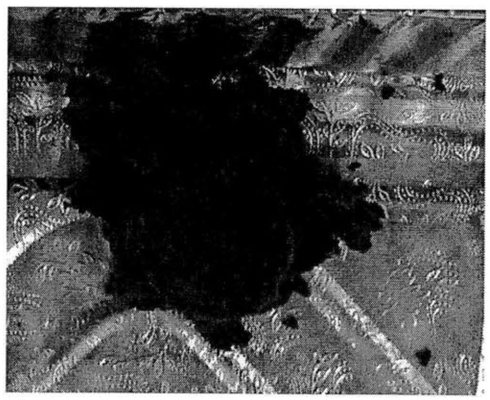


Figure 24: Shea cake with oil retention after press in Instron machine.

Patel's research discussed in Sect. 4.3 successfully used the Instron for pressing peanuts because it required less force for oil extraction. If the maximum force capability can be changed on the Instron machine and the pressing chamber heated, future attempts might yield more useful force vs. displacement data for pressing ground Shea kernels.

5.2 Final Experimental Setup

After the failed attempts to obtain measureable results with the Instron machine, an experimental setup closer to the design of the hydraulic jack press in Ghana was prepared. A 16-ton (157 kN) hydraulic jack was used to apply the axial force from below. The hydraulic jack piston was removed and replaced with a customized part that included a welded collection tray, as can be seen in Fig 25.

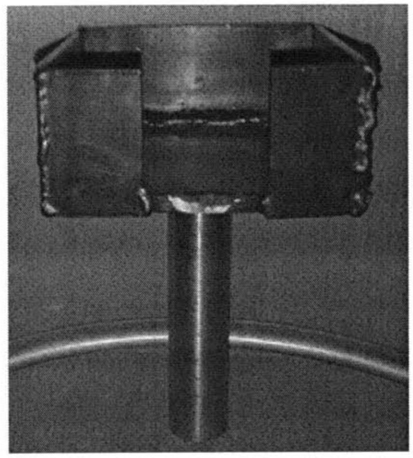


Figure 25: Customized hydraulic jack piston with welded collection tray.

A 0.127m long, 0.051 m pipe with a screw cap was used as a perforated cylinder. The perforations were made on the screw cap as well as along the circumference of the pipe about half of its length, as shown in Fig. 26. Slits were added on the bottom connecting the perforations to allow oil to seep out from beneath the cylinder while sitting on the collection tray, as shown in Fig. 26. Slits were added to the flange of the screw cap to help oil flow to the bottom of the collection tray.

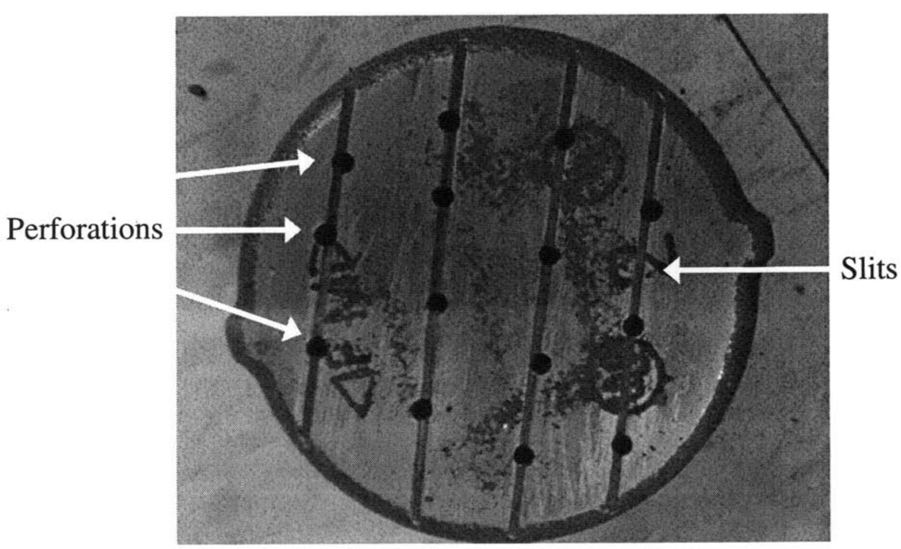


Figure 26: Picture of screw cap

A piston was fabricated with a flat top for support and to prevent slipping under high pressure in case of angular misalignment. The set up was made to fit inside the mouth of an old, unusable screw press frame. Two sets of ground Shea nuts, roasted and unroasted, were pressed in the setup shown in Fig. 27 below.

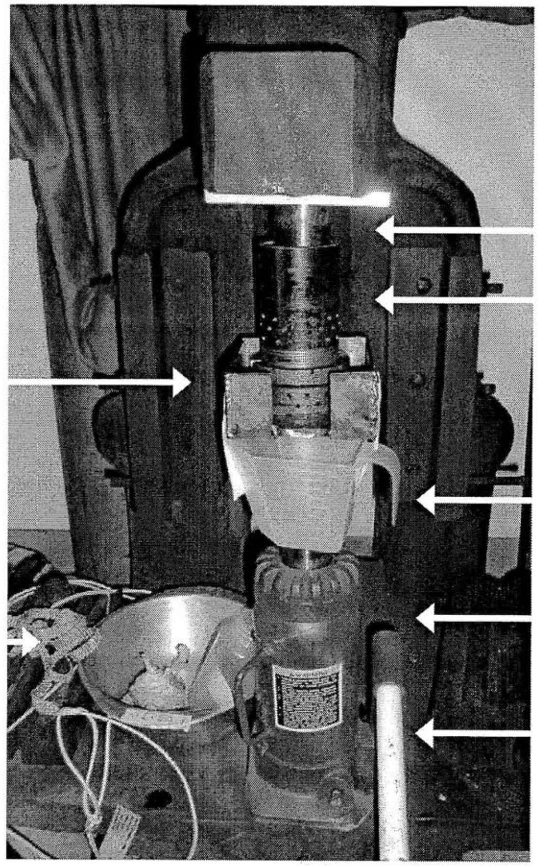


Figure 27: Second experimental setup in an old press frame, including the pipe with screw-on cap press chamber, matching piston, a 16-ton hydraulic jack with customized collection tray, and collection cup.

Before each experiment, the ground Shea nuts were weighed and tied in sections of a cloth pillowcase. An Omega FGS051-060 heat tape of about 1 m long was wrapped around the press chamber, to heat the Shea nuts in the cloth bags inside the chamber to the desired temperature for the specified trial. The temperature was monitored using a Vernier TMP-BTA temperature probe and Logger Pro 3.5.0. The piston was also heated to a similar temperature before pressing. Once the desired temperature was reached, the heat tape was removed, a collection cup taped to the tray, and the hydraulic jack operated in intervals until it was fully extended, providing the maximum force. The fully pressed position was held for a minimum of 5 minutes to allow the oil to flow. At the end of each trial, the oil was collected and any remaining oil in the collection tray was scooped into the cup. This likely resulted in small oil losses of order 2-3 gm.

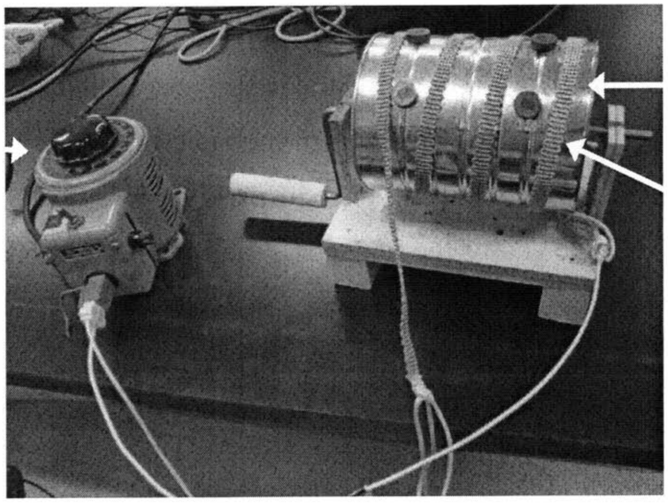


Figure 28: Prototype coffee can roaster with heat tape and variable voltage source. The coffee roasted consisted of a wooden base, metal crank with wooden handle, and magnetic sliding door.

To roast one set of the Shea nuts for testing before grinding and pressing, a portable coffee can roaster was fabricated on a wooden base, as shown in Fig. 28. An Omega FGS051-060 heat tape of about 1 m length, and variable voltage source was used to heat the coffee can to a maintained 100°C, noted as a suitable roasting temperature under the study described in Sect. 4.4.

An Ohaus Scout Pro scale, model SPE123, with a readability of 0.001 gm was used to measure the mass of the Shea nut oil produced in the second experimental setup. The collection container (a plastic measuring cup) was weighed without the Shea nuts before each trial in order to allow determination of the amount of oil from measurement of the weight of the combined mass of the cup with oil after pressing.

5.2.1 Oilseed Pressing Parameters Tested

As discussed in Sect. 3, there are numerous factors that affect the oil yield and peak pressure. The present study is concerned with roasting, heating of the nuts during the press, and pauses to allow for oil to flow. The effect of the geometry (i.e. cross-sectional area and loading height) of the loading cylinder on oil yield and peak pressure was investigated in a previous study as described in section 4.2. Consequently the trials were conducted with press temperatures ranging from 50-70°C with both roasted and unroasted ground kernels. A summary of the experimental conditions can be found in Appendix A. which tabulates the mass of Shea nuts pressed, the time paused at the end of the full press, and the resulting oil mass was collected for each trial. Oil yields were determined from equation (3):

$$\%\, Oil\, Yield = \frac{grams\ Shea\ oil}{grams\ Shea\ nuts} X\ 100. \tag{3}$$

Fig. 29 below is a photograph of unroasted (left) and roasted (right) nuts. Roasted nuts are a slightly darker brown shade than unroasted.

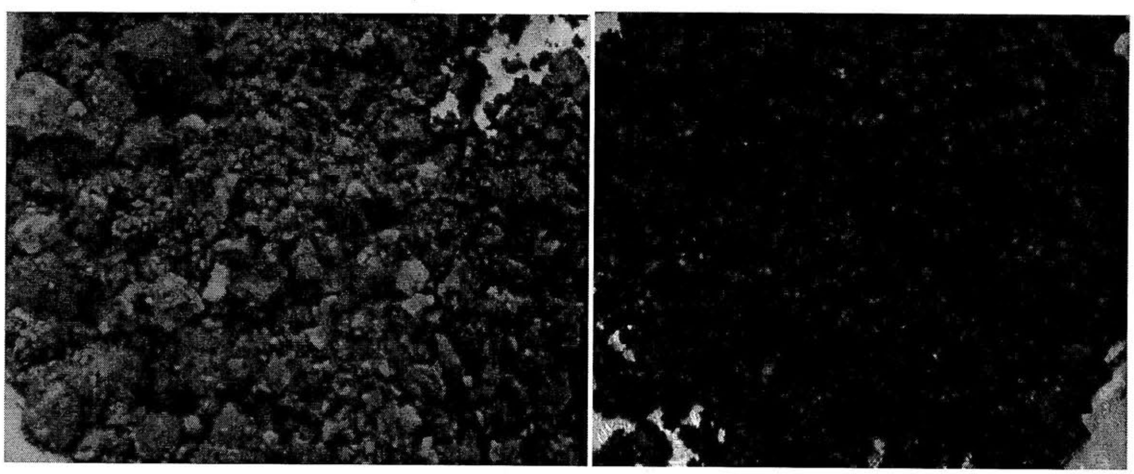
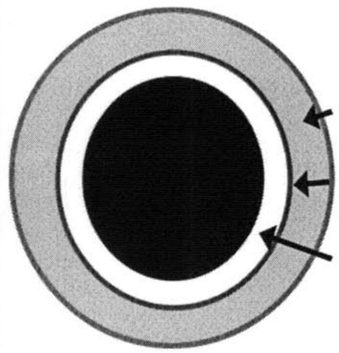
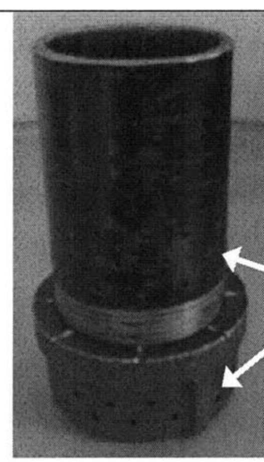


Figure 29: Unroasted nuts (left) vs. roasted nuts (right). Notice the roasted nuts are slightly darker. Both sets are ground.

5.3 Press Chamber Configurations

In order to test various design configurations, several press chambers were fabricated to press oil from the Shea nuts, as illustrated in Table 2.

Table 2: Press chamber configurations

Press chamber type	**Photograph of Press chamber**
1. Well-point with 3 layers: Oil flow through perforated circumference	 
2. PVC tubes: Open bottom	
3. Pipe with screw on cap: Perforated circumference and bottom	

The first configuration used a modified 0.025 m well point[1] with three layers: the inmost is a perforated PVC pipe; the middle layer is a fine mesh layer; the outermost is a steel pipe with large half circle perforations. The threads and point were removed to leave a 0.41 m section of perforated pipe, long enough to attain a large force and pressure range to observe. The pipe sits snugly in a groove milled into a round pedestal for the pipe, as in Fig. 30. The pedestal fits tightly in a pocket in a hole bored into a plate that sits in the oil collection pot. This configuration ensured stability and strength against the predicted high pressures that would result from the press. Additionally, it was hoped that the various layers would help filter the oil, since oil could only seep out from the perforations along the circumference while the Shea nut cake was held inside. The piston radius was reduced on the lathe until it slid smoothly without wiggle. It is about 0.48 m long, such that that after the press, it would help press out the remaining cake.

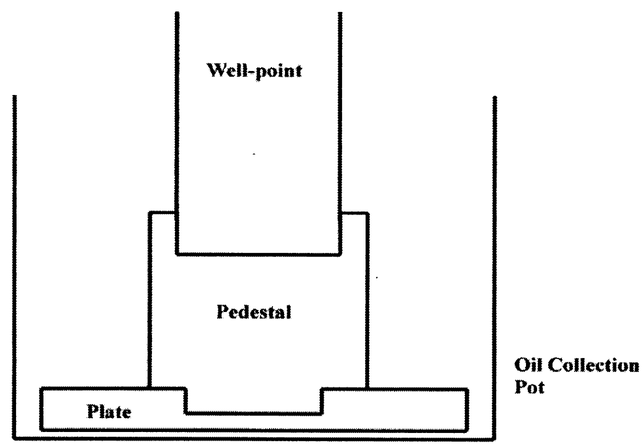


Figure 30: Well-point configuration with pedestal and plate in the oil collection pot.

The second configuration was a set of disposable 0.1524 m long 0.025 m PVC tubes with disposable tins and napkins used to soak the oil that would presumably come out from the bottom of the pressed cake. The PVC held the crushed or ground nuts and sat on a napkin in the tin. The same piston for the first configuration was used with a reduced diameter modification to fit the set of PVC pipes. This configuration cannot be used to press heated nuts because of the

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[1] A well-point is used to create driven water wells and consists of a perforated pipe encased in a hardened drive-point and a screen. The well-point is hammered into the ground with a tripod and driver. The screen filters the pumped water of sediments.

low melting point of PVC plastic (~50°C). This configuration focuses on getting force vs. displacement data without caring for collection of the oil and without needing to remove the cake. This configuration also tests for how much of the oil yield is through the bottom of the cake, allowing one to make more conclusions of how the oil released when the Shea nuts are pressed and where some of the oil losses might be.

The third setup was a cast iron pipe with a screw-on cap. The cap and circumference have holes and slits as described above (Fig. 26) to allow for oil to flow out from the most directions in comparison to the two configurations described above. This alternative however, may create more impurities in the oil, as cloth bags will be the only form of filtering during the press. This press chamber was only used for the second experimental setup.

6. Results and Discussion

This section presents two types of results gathered from the experiments described in Sect. 5. The first discusses the qualitative observations of oil flow and purity in three different press configurations. The second is a quantitative analysis of optimal pressing temperature range and the effectiveness of roasting the Shea kernels.

6.1 Qualitative Results

After testing three press-chamber configurations, several observations were made in regards to the flow of oil from the chamber and of the oil purity. It was concluded that a combination that allows for the most pathways along the circumference and base of the press chambers will help produce higher oil yields. A trade-off to consider is the added stress concentration in the press chamber from opening slits and holes in the material.

6.1.1 Press Chamber Observations

When using the well-point, the pressure tore the inner filtering screen as shown in Fig. 31 and created jamming as well as rendered the well-point unusable for measuring pure oil output. The bottommost part of the pressed cake retained some moisture.

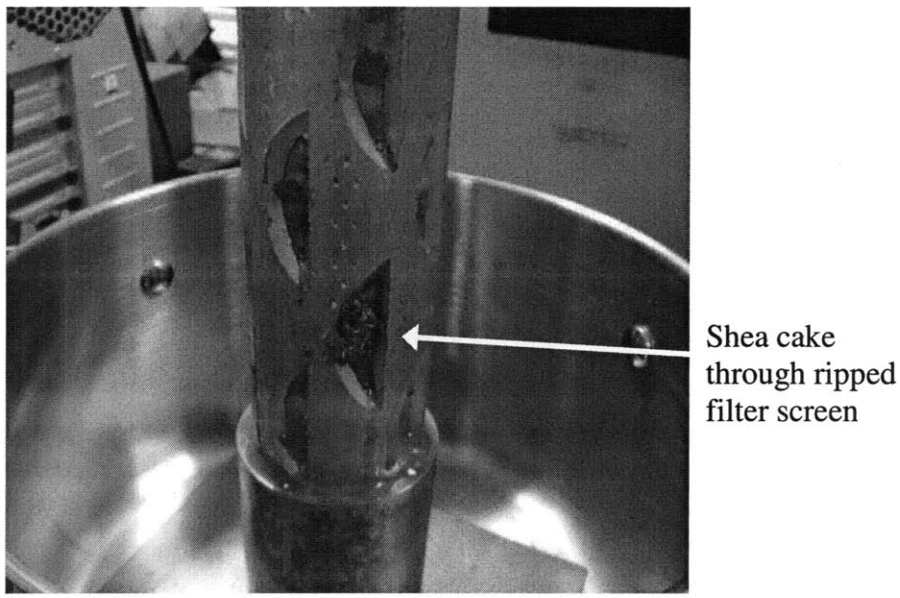

Figure 31: Well-point press chamber with oil seeping from sides. The Shea cake extruded through the ripped inner filtering screen under pressure.

When pressing with the PVC tubes, where only oil can escape from the bottom, the napkin soaked oil, as seen in Fig. 32, but much of the oil pooled at the top without any pathways to escape from the sides while the Shea was being pressed.

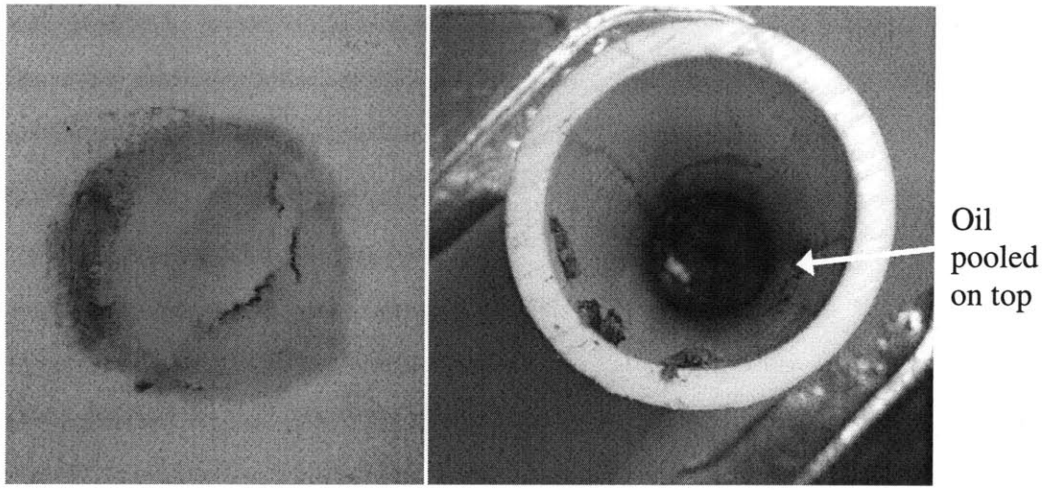

Figure 32: Oil soaked in napkin from PVC tube tests (left) Oil pooled on top with no outlets in sides of tube.

The best results were achieved using the 0.051 m pipe with screw cap that had openings along the circumference and on the base with slits to help oil seep out into the collection tray. As can be seen in Fig. 33, the resulting cake appeared very dry with this press chamber configuration and experimental setup using the 16-ton hydraulic jack (closest to current press design in Ghana).

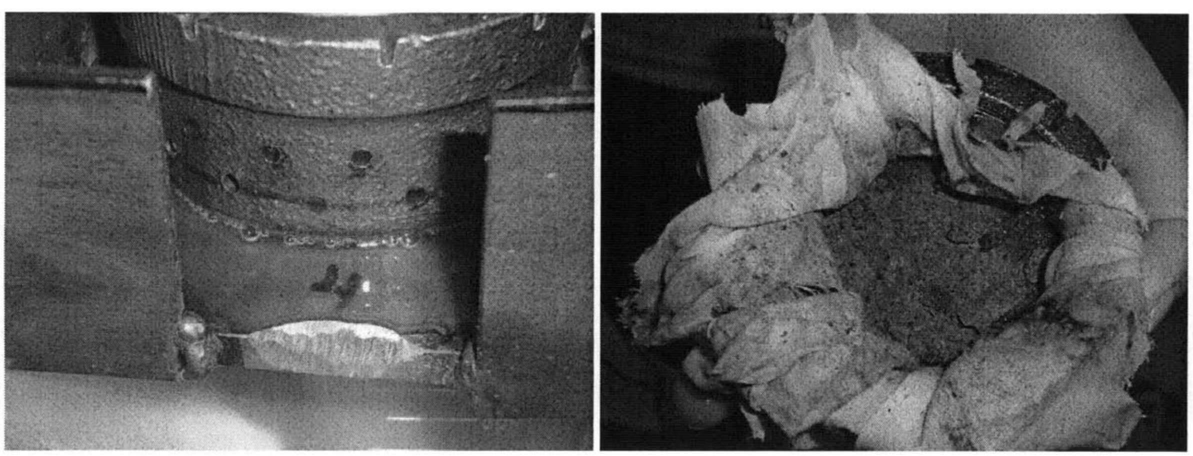

Figure 33: Oil exiting press chamber from perforations on circumference and base with slits (left). Extremely dried press cake after press with hydraulic jack and pipe (right).

6.1.2 Oil Purity

At higher temperatures, the oil tended to be a darker brown, especially for the fresh batch of roasted Shea kernels, indicating higher incidence of dissolved solids when recently ground and roasted nuts were used. The resultant oil is shown in Fig. 34.

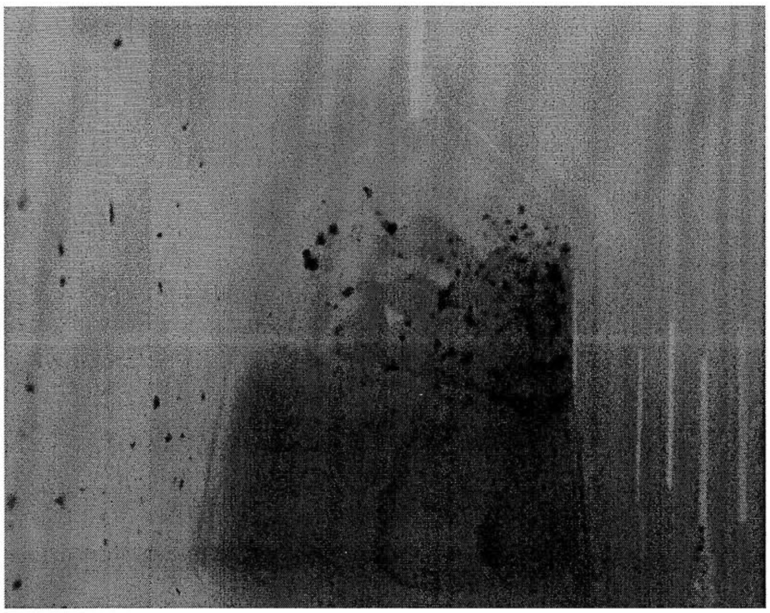

Figure 34: Oil with mixed-in and dissolved solids. This resulted most often from breaking cloth bags and with freshly ground and roasted Shea nuts (hence the darker brown color which is undesirable).

Impurities are highly undesirable and would make the resulting Shea butter unmarketable. Grayish and dark brown Shea butter indicates poor quality, and a creamy yellowish butter is best. These results indicate that post-filtering will be necessary when using the hydraulic jack for Shea oil extraction.

6.2 Optimal Temperature Range

Figure 35 shows the oil yield from unroasted and roasted Shea nuts as a function of pressing temperature. Also shown are quadratic fit lines with of R^2 of 0.99 and 0.83 as well as the 95% confidence bounds. Appendix A shows the full data chart with the temperature at press, mass of ground Shea nuts, mass of oil, and the oil yields along with qualitative observations for each trial.

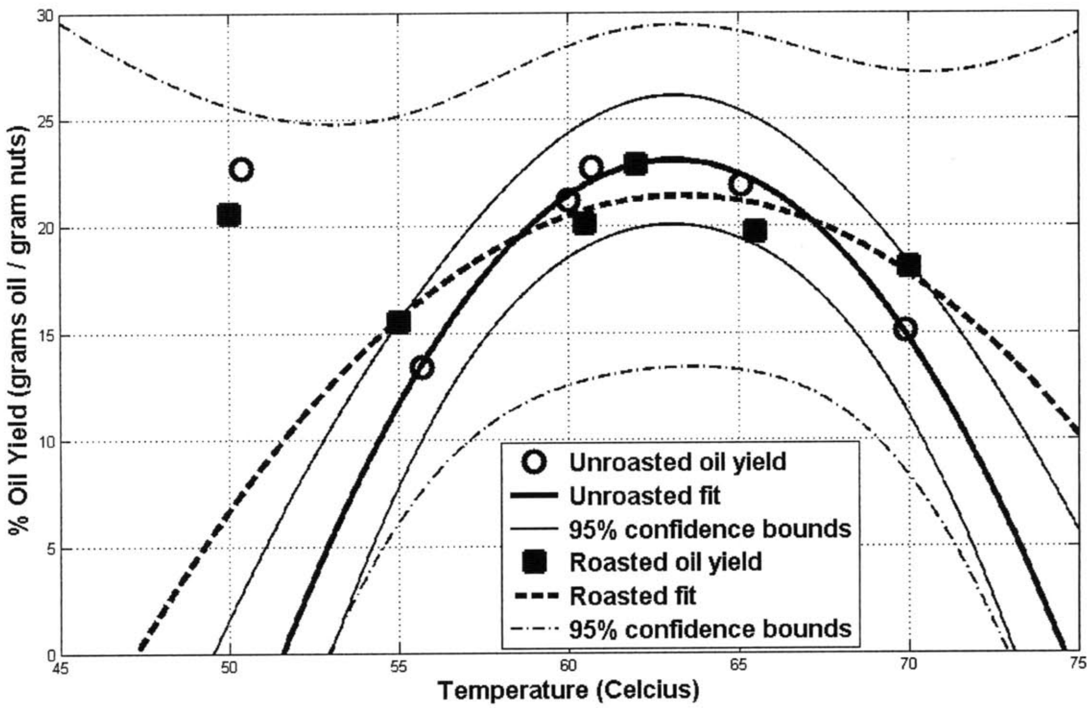

Figure 35: Percent oil yield versus temperature at press in Celsius. The models for both the unroasted and roasted data are quadratic with a R^2 of 0.99 and 0.83, respectively. The dotted lines represent the 95% confidence bounds for each fit. The 50°C data points were excluded from the fit due to errors in measurements (extruded solids dissolving into oil and falsely raising the measurement)

For both unroasted and roasted Shea kernels, the optimal temperature range for pressing is between 60-62°C according to the data, and 59-67°C according to the fits, confirming the findings in studies discussed in Sect. 4.4. At this optimal range, unroasted Shea kernels appeared to result in higher oil yields than roasted, although the error bounds of the measurements overlap.

The measurement error in the roasted oil yield was much higher than the unroasted due to contributions from impurities mostly in the forms of mixed-in Shea cake: solids dissolving in the oil output and/or the cloth breaking and the use of an older batch of crushed Shea nuts.

For unroasted nuts, the highest yields occurred at 60.7°C with (23 ± 3)%, 60.0°C with (21 ± 1)% and 65.1°C with (22 ± 2)%. However at 65.1°C, some solids mixed in with the oil, likely raising the mass measurement of the oil output (making it a seemingly a higher yield). For roasted nuts, the highest yields occurred at 62°C with (23 ± 7)% and 60.5°C with (20 ± 3)%. Some solids also mixed in and dissolved in the oil in the test at 62°C, possibly raising the perceived yield. Additionally, the unroasted ground Shea kernels tested at 60.0°C and the roasted Shea kernels tested at 60.5°C were of the older batch, contributing to slightly lower yields. The older batch was also used to test at unroasted and roasted 55°C and the roasted 50°C trials, causing lower yields.

It should also be noted that the oil extraction efficiency could be improved by repressing the cake, as discussed under the study summarized in Sect. 4.1, and by decreasing the loss of oil from the system after pressing. Oil was lost from inefficient collection. Some remained in the tray, and on the press chamber. A collection chamber with more slants to guide flow is recommended for better oil collection to achieve higher efficiencies of oil extraction.

7. Conclusions

The intention of this study was to find the effect of temperature and roasting on Shea oil yield and determine the optimal temperature range to extract Shea oil from a hydraulic jack vertical press. The study also evaluated existing oil extraction methods as well as the practicality of the hydraulic jack pressed designed in Ghana during IDDS. It was found that the optimal temperature range was about 60-62°C, confirming the studies from KNUST (Sect. 4.4) with unroasted Shea kernels producing the highest oil output. Elimination of the roasting step will reduce the time and resources (valuable firewood) consumed in the overall Shea nut oil extraction process. Furthermore it was observed that a configuration with the most pathways possible for oil to escape, while considering added stress concentrations, was best for the most oil output.

For marketable butter using a process that involves the hydraulic jack press, a post-press filtering process will be necessary to reduce resulting impurities from dissolved solids and from the equipment used. Future studies should improve the user friendliness of the press through addition of alternative manual-power methods such as a treadle; improved removal of pressed cake; and cleaning to reduce the time involved. Much time was lost in the process to the removal of the cake, cleaning after each press and preparation for the next press. There was an oil loss of about 10% compared with the traditional process. If time and labor could be significantly reduced by improving the hydraulic jack press, this option would still be a viable one in comparison to the traditional process, despite the oil loss.

Future studies should compare the economics of this press to other press designs, including oil expellers and manual screw presses. There is doubt as to whether the benefits of the press outweigh the possible monetary loss from lower oil output, initial investment, and difficulties in using the press. Another interesting future study would combine the IMC method with the use of this press and compare the results to the study conducted in KNUST with the manual screw press. Many more factors affect oil yield than could be explored in this study- such as choosing a size of press chamber and optimizing the overall design to the chamber, as well finding the best press speed and pause time for oil to flow. Nonetheless, for the cost of this press compared to other expensive options and the possibility of improving the 10% oil gap through future work, this press design might just eventually pass the test after all.

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Appendix A: Oil Yield Data

Trial	Mass of Shea nuts (g)	Roasted/Unroasted	Temperature (°C)	Time held pressed (min)	Oil mass (g)	Yield (%)	Notes
1	37.041	U	50.4	5	8.396	22.7	New batch, solids mixed
2	35.102	R	50.0	6	7.247	20.6	Old batch, solids mixed, bags broke
3	50.405	U	55.7	12	6.750	13.4	Old batch
4	38.498	R	55.0	5	5.985	15.5	Old batch
5	28.235	U	60.0	5	5.978	21.2	Old batch
6	46.099	R	60.5	5	9.724	20.1	Old batch
7	33.952	U	65.1	5	7.441	21.9	New batch, solids mixed
8	29.930	R	65.5	8	5.895	19.7	New batch, darker brown
9	36.803	U	69.9	6	5.570	15.1	New batch
10	32.242	R	70.0	7	5.824	18.1	New batch, dark brown
11	30.967	U	60.7	7	7.029	22.7	New Batch
12	40.212	R	62.0	6	9.226	22.9	New batch, solids mixed