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Optimization of the Extraction of Shea Butter from Shea Nut using Ovat Methodology

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Abstract: ***The yield of Shea butter extracted was optimized by varying kneading time, kneading temperature, and kneading speed using conventional method of varying one variable at a time (OVAT). Helical shaped impeller mounted on a variable speed Tecmix TM 1100 kneader was used to knead the Shea paste. Shea paste produced by milling crushed Shea nut was kneaded with 125% (wt) water at temperatures ranging from 10 to 35 OC for periods ranging from 0.5 to 8.7minutes. The impeller speed was varied between 260 and 1050 rpm. OVAT optimization conditions were established to be time of 5.36minutes, temperature of 15.90C, and kneading speed of 894.4rpm. The optimized Shea butter yield for these conditions was 24.04%.***

Keywords : Shea butter; kneading; optimization; yield; Temperature; Time; Speed.

I. INTRODUCTION

Shea butter is a versatile vegetable plant fat (Hee et al., 2012), yellowish in colour extracted from dried kernels of Shea nuts, a derivative seed of Shea trees. The economic value of Shea butter is massive. It is source of business for rural women in under-developed countries (Ferris & Collinson, 2001). Recently, Shea butter has gained a compelling attention from many reputable cosmetic companies in Asia, Europe and America. This has indeed created a competitive marketing atmosphere and job creation [1]. Shea butter is used by trado-pharmacetical doctor (native doctor) for treating rheumatism cough, wound, catarrh, and skin related treatments [2-3]. African local communities have also found uses and applications of Shea butter for weather-proofing roofs and soap manufacturing [1,3-4], Shea butter, in addition, it has been beneficial for moisturizer [5].

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At room temperature, Shea butter is in solid state but becomes liquid at temperature slightly above ambient. In terms of appearance, smell and quality (crude or unrefined), Shea butter exhibits wide variations depending on the geographical location, origin as well as the extraction method [6]. Omodara et al, [5] showed that Shea butter has high UV-B absorption due to triterpene esters. The component of triterpene esters includes: vitamin A (tocopherols) and phytosterols cinnamic acid. The percentage of unsaponifiable materials like alpha-spinosterol, campesterol phytosterols, beta-sitosterol, and stigma sterol and triterpenes of Shea butter are high. On the average, the fatty acid compositions of Shea butter are; palmitic acid (2.3-5.44%), oleic acid (40.71-44.48%), linoleic acid (6.0-6.41%), stearic acid (39.74-45.0%), and arachidic acid(<0.9%) [7].

Shea butter like most vegetable oils and fats consist of mixtures of triacylglycerol's, which constitute about 95% of its constituents, and a non-triacylglycerol that contains variable amounts of phosphatides, free fatty acids, unsaponifiable matter, oxidation products and other impurities. These impurities have an adverse effect on the quality of Shea butter as they have different effects on the nutritional, functional and organoleptic properties of the Shea butter [8].

Stearic, palmitic, linoleic, arachidic and oleic acids are the five major fatty acids that characterize Shea butter (Table 2.1) [7]. Oleic and stearic acid account for about 85-90% of the fatty acids composition of Shea butter. The relative proportion of both the oleic and stearic acid compositions of the fatty acids largely determines the consistency of Shea butter. For instance, the softness and hardness of Shea butter is controlled by the percentage of oleic acid and stearic acid content respectively [8].

II. MATERIALS AND METHOD

The major raw material needed is Shea nut. The equipments used for the study includes: crusher, Milling machine, Kneading equipment (variable speed Tecmix TM 1100 kneader), Stopwatch, Digital weighing Balance, Thermometer, Deep freezer, Thermostatic control Water bath, Sieving cloth, Crystal tachometer, Electric stove. The steps involve in the drying of Shea kernels are shown in figure 1 below.

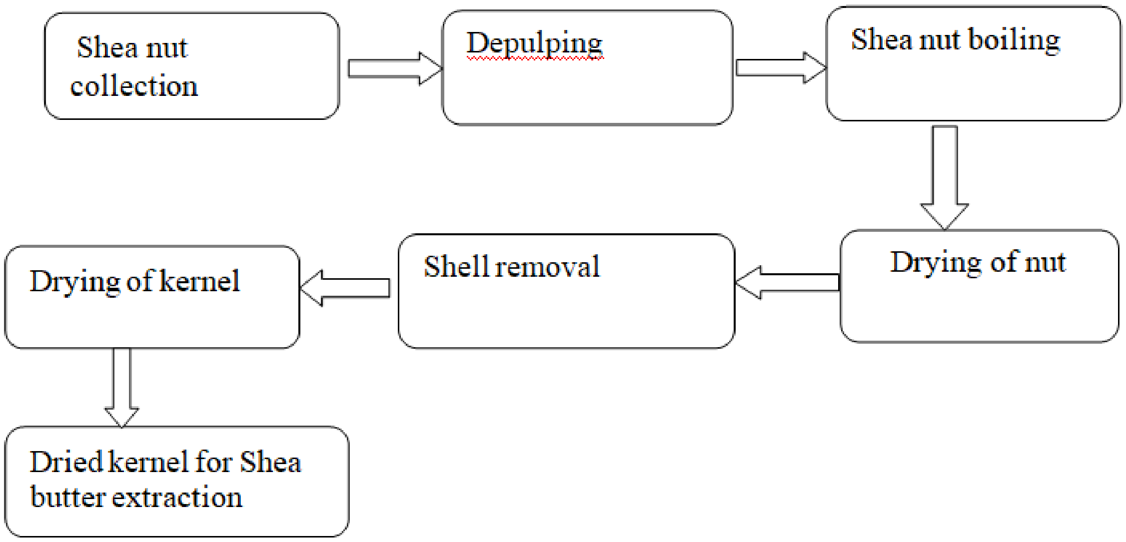

Figure 1: Drying of fresh Shea nut to obtain dried kernels.

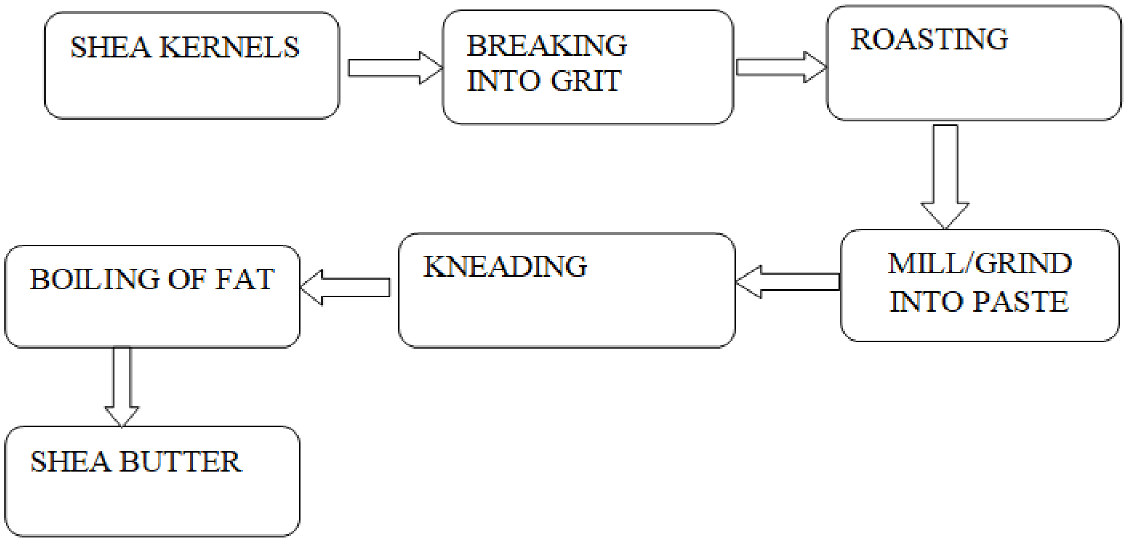

Figure 2: Processing of Shea kernels into Shea butter

De-pulping is the removal of the pulp of a fresh Shea kernel to prevent or terminate the growth of fungi. The pulp is a natural harbinger of the growth of fungi due to its high sugar content. The growth of fungi in Shea kernel decreases its oil content [2]. Boiling of Shea seed is done for the purpose of preventing seed germination. This is usually carried out immediately after the nuts have been completely de-pulped. Germination of the seed if not prevented via boiling process, will lead to the formation of free fatty acid which accounts for the bad taste and poor quality of the nut [9-11]. Traditionally, after about fifty minutes of boiling (for mild heating), ash is usually added to the nut to prevent formation of starch and further guarantee high quality of Shea butter that would be produced [5].

Drying of nuts after boiling is necessary for two major reasons: first to reduce the moisture content to at least 8% of its weight, secondly to prevent the growth of molds and fungi. If the nuts are not properly dried, it will turn black and this will adversely affect the quality and market of the nut. Breaking the nuts using mortar, stone, or any suitable hard material to crack and break the shell removes the shells of the well-dried nuts. Hands can easily remove the shell after cracking. It takes up to a week to dry the nuts depending on weather condition. Drying at this stage is highly important so as to further reduce the moisture content to about 1% of the weight of Shea nut to prevent fungi and mold growth [12]. If the nuts are not well dried before storage or the nuts are carelessly stored in a humid, damped or wetted place, they may be infested with fungi or molds or both.

The step by step method of extraction of Shea butter from Shea kernels is shown in the schematic diagram as shown above.

As shown in the figure 2 above, the step by step process of extracting Shea butter is elucidated below. The dried kernels are broken into smaller grits by nut crusher for the main purpose of creating a larger surface area needed for effective roasting process. Roasting of crushed nuts is done for the purpose of aiding/facilitating the extraction of Shea butter. Shukla [13] affirmed the possibility of achieving maximum Shea butter extraction if roasting could be done at a temperature near 1200C.

Roasting at a temperature high above 1200C can burn the nuts and this will invariably damage any Shea butter that is produced by making it unsuitable for market consideration. Milling machine is commonly used to mill the roasted nut into a fine paste, where it is impossible to get milling machine as in the typical situation in local communities, grinding is done using flat and fairly wide stone. The efficiency of the milling device used will determine to a large extent, among other variables, the yield and quality of Shea butter produced.

The paste from the milling is then mixed with water and kneaded, water is added to the paste, several times during kneading in order to make the paste soft and to maintain relative uniform temperature as well as to aid extraction. During the kneading process, two fractions are formed, a brownish watery fraction on the bottom with the crude butter appearing as a creamy mass floating on top [12]. The crude butter (emulsion) produced during kneading is scooped off, washed to remove dirt and any other unwanted item before boiling. Washing more than two times may not be desirable as it can lead to loss of taste or loss valuable vitamins. As a result of boiling, three distinctive fractions are formed: the froth that floats on the liquid oil (this is continuously skimmed off); the light yellow oil that floats on dark brown liquid; and the dark brown liquid at the bottom [12].

Evaporation is the basic unit operation used in recovering the Shea butter during boiling. Water gets boiled off (being a component with a lower boiling point as compared to Shea butter) over time leaving the Shea butter as the only liquid and the Shea cake as solid residue. The black hot oil is allowed to cool down before decanting it. Decantation is accompanying by the use of a sieving cloth so as to prevent any solid material from draining with the oil. The oil is left to cool down under ambient condition, the oil become solidified as the cools below body temperature

The time of kneading was varied as the temperature and speed were kept constant. The procedure is outlined below:

1). 5000g of Shea paste was fed into the kneading machine, and 7500cm3 of water added.

2). The experiment was run five times at 0.5mins, 2mins 4.5mins, 7mins and 8.7mins respectively while the temperature and speed at each run were kept constant at 22.50c and 900rpm respectively.

3). At the end of each run, excess water (35L) was added to the paste, and the Shea butter was allowed to float at the top of the bowl, this extracted crude butter (emulsion) is scooped out, boiled, and filtered to obtain refined Shea butter . The weight of the refined Shea butter was recorded and the yield calculated.

The procedure for investigating the effect of temperature on yield includes:

1). 5000g of Shea paste was fed into the mixer, and 7500cm3 of water added.

2). The experiment was run five times at temperature of 100C, 150C, 22.50C, 300C and 350C respectively. The time and speed at each run were kept constant at 4.5minutes and 900rpm respectively.

3). At the end of each runs, excess water (35L) was added to the paste, and the Shea butter was allowed to float at the top of the bowl, this extracted crude butter (emulsion) is scooped out, boiled, and filtered to obtain refined Shea butter. The weight of the refined Shea butter was recorded and the yield calculated.

The procedure for investigating the effect of impeller speed includes:

1). 5000g of Shea paste is fed into the mixer, and 7500cm3 of water added.

2). The experiment was run five times at different speeds of 250rpm, 400rpm, 600rpm, 900rpm and 1050rpm respectively. The time and temperature at each run were kept constant at 4.5 minutes and 22.50C respectively.

3). At the end of each runs, excess water (35L) was added to the paste, and the Shea butter was allowed to float at the top of the bowl, this extracted crude butter (emulsion) is scooped out, boiled, and filtered to obtain refined Shea butter. The weight of the refined Shea butter was recorded and the yield calculated.

III. RESULTS AND DISCUSSION

The determination of the kneading speed (in revolution per minute) using photo/contact tachometer was done to know the actual rotational speed of the kneading impeller, the different rotational speeds of the kneader powered by variable speed electric motor (1100watt capacity) were measured using photo/contact tachometer. The speed was determined by operating the regulator of the variable speed electric motor while the tachometer sensor contacts the crystal lining attached to the rotating impeller and the measured value is shown on the liquid crystal display of tachometer. (See table 1 below)

Table 1: Determination of speed of kneader in RPM using crystal tachometer

Selector speed	Speed (rpm)
1	250
2	400
3	600
4	800
5	900
6	1050

Table 2: Effect of time of kneading on yield of Shea butter.

Kneading Time (min)	Yield (%)	Extraction Temperature (^oC)	Kneading Speed (rpm)
0.5	14.2	22.5	900
2	18.20	22.5	900
4.5	23.91	22.5	900
7	23.68	22.5	900
8.7	23.70	22.5	900

Table 2 below shows the effect of time of kneading on yield of Shea butter at constant temperature 22.5 ^oC and speed 900rpm. Figure 3 shows the extraction oil yield with time at constant temperature (22.5^OC) and speed (900rpm). The oil yield increased linearly within 1-4 minutes kneading time. Beyond 5 minutes, it was observed that no significant increase was noticed. This show that though the kneading time is important in the oil yield. The optimization technique would be more accurate at kneading time below 4 minutes.

Table 3 below illustrates the effect of temperature on Shea butter yield at constant time 4.5mins and speed 900rpm; (see appendix A) for detailed calculation. Figure 4 shows the variation of the extraction oil yield with temperature at constant temperature (22.5^0C) and speed (900rpm). The parabolic shape of the graph depicts that at temperature 22.5^0C, the optimization tool would be inactive.

Table 4 below shows the effect of speed on yield of Shea butter at constant time 4.5mins and temperature 22.5 ^OC. Figure 5 show the variation of the extraction oil yield with speed at constant temperature (22.5^OC) and speed (900rpm). The results in figure 5 show that the kneading speed is very vital for the optimization technique. Hence, kneading speed is the most active parameter for optimizing the yield of oil i.e. using the traditional method.

The optimization of the oil yield in kneading time, temperature and kneading speed is shown in figures 6, 7 & respectively. Figure 6 show that increasing kneading time 1& 2, the optimum may not exceed 4 minutes. The highest oil yield at given kneading time span between 3 and 4 minutes. Figure 7 shows the dual event at highest temperature increase. When temperature is

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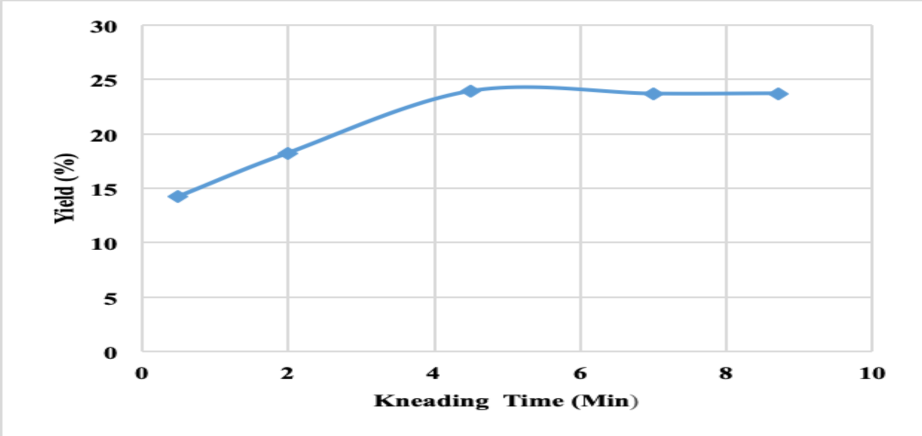

Figure 3: Variation of the extraction oil yield with time at constant temperature (22.5^{O}C) and speed (900rpm)

Table 3: Effect of kneading temperature on yield of Shea butter.

Extraction Temperature (°C)	**Yield (%)**	**Kneading Time (min)**	**Kneading Speed (rpm)**
10	17.20	4.5	900
15	21.68	4.5	900
22.5	23.91	4.5	900
30	22.90	4.5	900
35	18.70	4.5	900

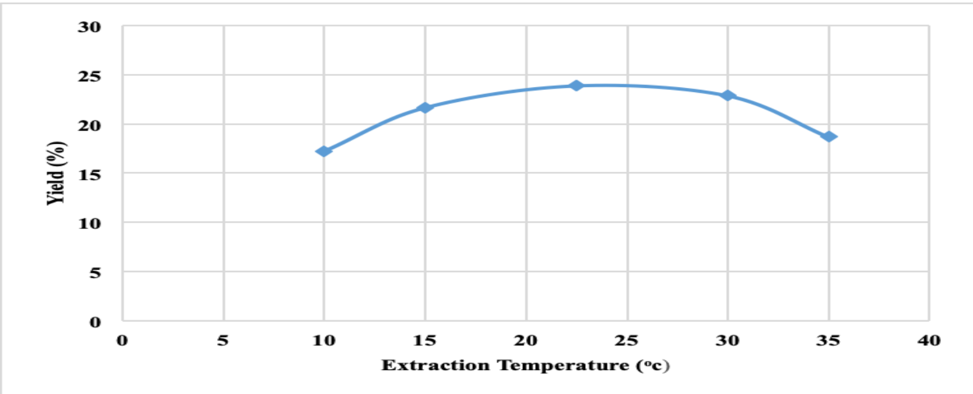

Figure 4: Variation of the extraction oil yield with temperature at constant temperature (22.5^{0}C) and speed (900rpm)

Table 4: Effect of speed of kneading on yield of Shea butter.

Kneading Speed (rpm)	Yield (%)	Time of kneading (min)	Temperature (°C)
250	15.78	4.5	22.5

400	16.40	4.5	22.5
600	17.45	4.5	22.5
900	23.91	4.5	22.5
1050	23.80	4.5	22.5

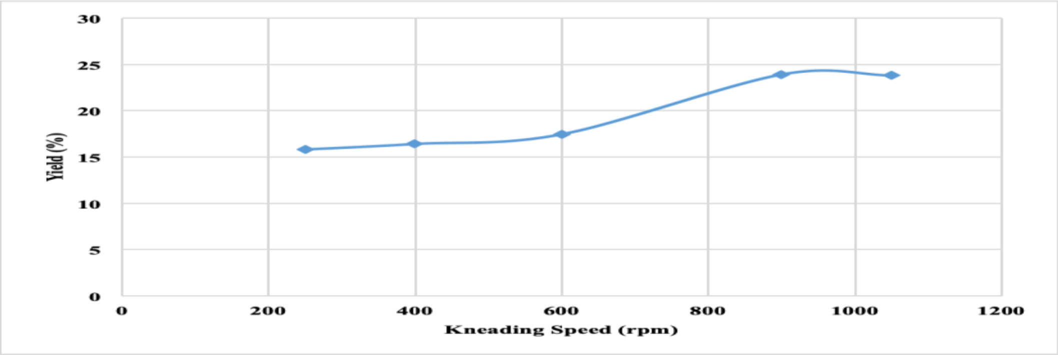

Figure 5: Variation of the extraction oil yield with speed at constant temperature (22.5^{O}C) and speed (900rpm)

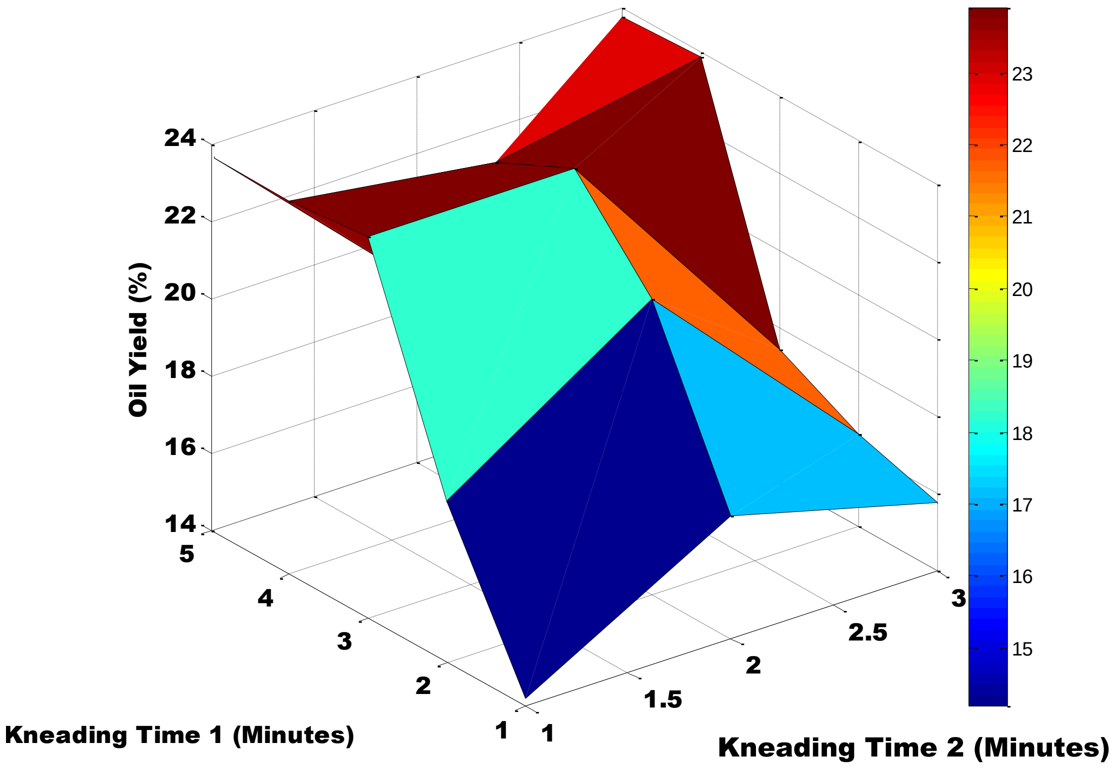

Figure 6: Optimization of kneading time to enhance oil yield increase

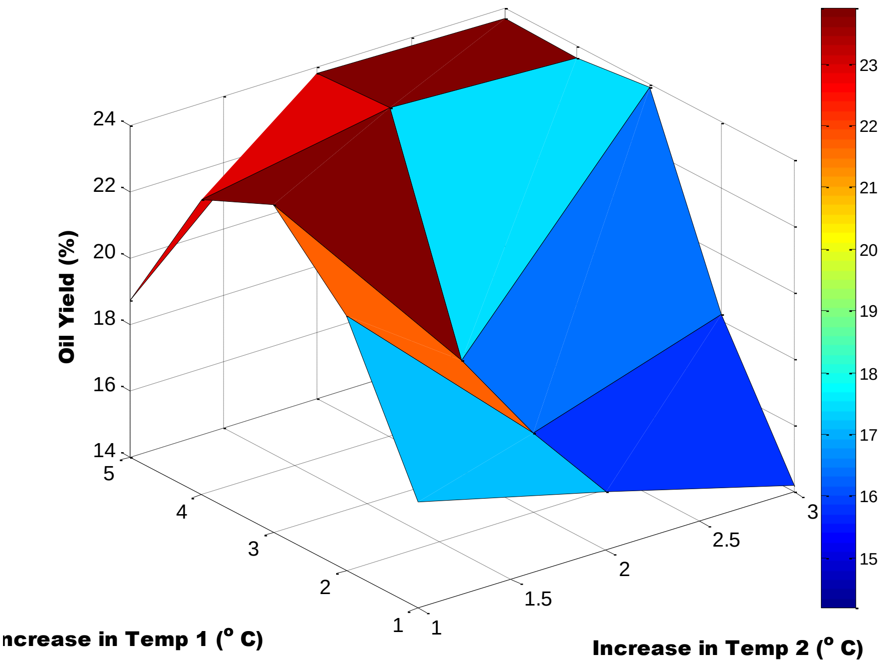

Figure 7: Optimization of temperature increase to enhance oil yield

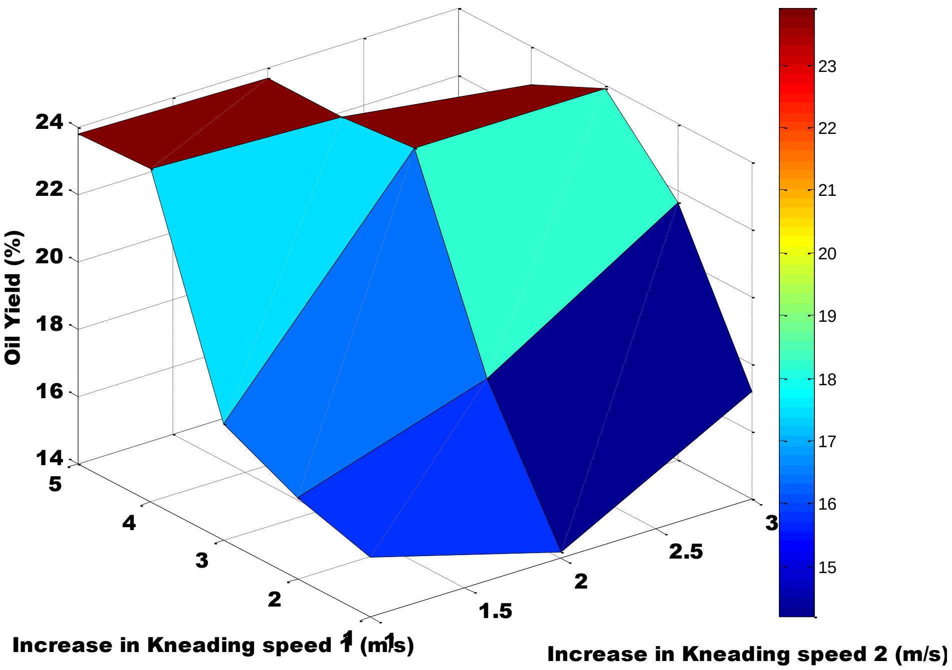

Figure 8: Optimization of kneading speed increase to enhance oil yield

Between 0 and 2 ^{O}C (on the x-axis) the system is thermal equilibrium unstable hence, n significant rise or increase in oil yield. At beyond 2 ^{O}C the system is at thermal equilibrium, hence an increase in oil yield. Figure 8 show the dual event at highest kneading speed. When kneading speed is between 2 and 3 m/s (on the x-axis) the system will be in equilibrium that initiates an increase in oil yield. When it is increased beyond 2 m/s, the system becomes thermally unstable, hence the highest yield. Therefore, the optimization of kneading speed and temperature show that when the system is at equilibrium, the parameters are inversely proportional to each other.

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IV. CONCLUSION

The findings in this work can be summarized in the following statements;

i. The yield of Shea butter depended on the three main factors: kneading time, Speed of kneading and kneading temperature).
ii. OVAT optimization conditions were established to be time of 5.36minutes, temperature of 15.9^0C, and kneading speed of 894.4rpm.
iii. The optimized Shea butter yield for these conditions was 24.04%.
iv. At equilibrium, the kneading speed and temperature are inversely proportional to each other

Further works should consider statistical method of optimization. Also, the thermodynamics and kinetics of the Shea butter extraction process is recommended for further research.

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