Asian Research Journal of Agriculture
1(1): 1-13, 2016, Article no.ARJA.27513

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Effects of Extraction Method and Geographical Location on the Physico-chemical Properties of Shea (*Vitellaria paradoxa*) Butter

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Authors' contributions

This work was carried out in collaboration between all authors. Author EAS designed the study, wrote the protocol and the first draft of the manuscript. Authors PAA and SA identified the plants and reviewed the experimental design and all drafts of the manuscript. Author GO managed the laboratory analyses. Author EAS performed the statistical analysis. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ARJA/2016/27513
Editor(s):
(1) Marco Aurelio Cristancho, National Center for Coffee Research, Chinchiná, Caldas, Colombia.

Original Research Article

Received 6th June 2016
Accepted 10th July 2016
Published 19th July 2016

ABSTRACT

Aim: To determine the effects of extraction technology and geographical location on the quality of shea butter.
Study Design: Data for physico-chemical characteristics were entered into Micro soft Excel spread sheet and summarized into mean and standard deviations. Analysis of Variance (ANOVA) was carried out to assess the variation between the parameters. All analyses were carried out in triplicates. Duncan's Multiple Range Test was used to compare mean variance. Significance was accepted at 5% level of probability.
Place and Duration of Study: The study took place in selected villages in the Upper East, Upper West and the Northern regions of Ghana between August, 2015 and February, 2016.
Methodology: Oil samples from the chemical (C), mechanical (M) and the traditional (T) extraction methods (EM) and those from different shea butter extraction villages across the north of Ghana

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were evaluated to determine their effects on the physicochemical properties of shea butter. All analyses were carried out in triplicates and Duncan's Multiple Range Test used to compare mean difference. Significance was accepted at 5% level of probability.

Results: The mean oil yield, saponification, iodine, acid, free fatty acid values were (50.04±3.35%; 40.21±7.21%, 39.09±2.46%), (160.79±1.50; 162.15±40, 193±8.58 mgKOH/g), (49.18±2.83; 49.58±1.39, 54.78±12.88 gI_2/100g), (9.77±1.75; 12±0.27, 13.765±1.10 mgKOH/g) and (5.42±0.17; 4.69±0.04, 7.61±0.35 mg/KOH/g) for the CEM, MEM and TEM respectively. While the mean specific gravity, refractive index and peroxide values were (0.97±0.00; 0.92±0.02, 0.88±0.01), (1.46±0.00; 1.45±0.01, 1.47±0.00) and (2.25±0.15; 2.80±0.16, 3.55±0.30) respectively. The mean oil yield, saponification, and iodine values were (43.08±2.75%; 45.87±1.25%), (39.62±1.40%; 39.02±1.16%), (53.27±2.40%; 50.26±1.44%), (155.80±9.46; 127.50±5.96 mgKOH/g), (163.63±2.66; 155.45±1.30 mgKOH/g), (201.39±2.78; 193.29±3.59 mgKOH/g), (46.84±2.06; 43.93±1.47 gI_2/100g), (39.19±0.99; 53.96±4.87 gI_2/100 g), (66.19±1.52; 47.46±0.97 gI_2/100g) for oil samples from (Jonga; Kpongo) in the Upper West, (Doba; Pusunamongo) in the Upper East and (Savelugu; Tantuani) in the Northern region of Ghana respectively. The acid value, specific gravity, refractive index and peroxide values were (9.60±1.11; 12.53±1.17 mgKOH/g), (15.46±1.00; 16.47±1.26 mgKOH/g), (12.81±0.90; 11.57±1.02 mgKOH/g), (0.85±0.16; 0.94±0.01), (0.98±0.01; 0.92±0.01), (0.88±0.02; 0.88±0.01), (1.46±0.01; 1.48±0.01), (1.52±0.11; 1.42±0.01), (1.47±0.01; 1.46±0.01), (2.67±0.05; 3.42±0.18 mEqKOH/g), (2.59±0.06; 2.65±0.02 mEqKOH/g) and (2.84±0.06; 2.26±0.02 mEqKOH/g) respectively.

Conclusion: The MEM technology had values almost mid-way between CEM and TEM and therefore yielded butter of superior quality than the other two technologies and should therefore be encouraged even if at a smaller scale. Geographical effect on the quality of shea butter revealed that kernels from the Northern region produced good quality shea butter, followed by those from the Upper West and finally to the Upper East regions. The results showed significant differences in the oil samples extracted by the different extraction methods and from different geographic locations but all fell within the acceptable ranges for edible vegetables oils.

Keywords: Shea butter; physico-chemical; extraction; properties.

1. INTRODUCTION

Shea butter is the fat content of the kernel of shea nut (*Vitellaria paradoxa*) which grows naturally in the wild and uncultivated state in most parts of Africa. The fat is used as edible oil and for raw material in the production of soaps, pomade, drugs and medicinal ointments [1]. The tree starts flowering in early November, with picking and gathering of fruits lasting from April to August every year. Shea fruit is green in colour with a fleshy edible pulp which contains protein and carbohydrates, and is very sweet [2]. The nuts sold on the International market are harvested from village tree populations in several West African countries [3].

Shea butter is the most important product from the shea tree [4] and it is used for the preparation of sauce, frying and baking in addition to being a cosmetic and traditional medicine in many rural areas [5]. Shea butter is important in the food, cosmetic and pharmaceutical industries. A report by United State Agency for International Development [6] indicated that technologies that have been used for extracting vegetable oil including shea butter are traditional boiling, mechanical pressing and solvent extraction. However, for centuries, shea butter has been processed by indigenous traditional boiling method which has been described as labour intensive [7]. This has made the quality of indigenous traditionally extracted shea butter variable [8]. Due to this, improved methods such as mechanical pressing are being adopted in many African countries. Frank et al. [9] attributed the variation of the fatty acid composition of the butter to its geographical source.

Variations in the physico-chemical compositions have been reported in different countries [10,11]. These variations have been attributed to environmental factors such as climate, temperature, soil fertility; maturation period; agronomic practices and genetics. With the increasing global demand for shea oil, characterization of physico-chemical properties of shea oil originating from Ghana is essential to improve its marketing and utilization. It was in this regard that this study was conducted to assess the physico-chemical characteristics of shea butter as affected by processing method

and geographical location in some selected shea growing districts in Ghana to determine benchmarks for further research on quality, commercialisation and value addition.

2. MATERIALS AND METHODS

2.1 Sampling

Six different samples were collected from (Jonga and Kpongo) in the Upper West Region, (Doba and Pusunamongo) in the Upper East Region and (Savelugu and Tantuani) in the Northern Region where the crop grows widely.

2.2 Sample Preparation

The fruits were sun-dried and broken to obtain the nuts, which were subsequently sun-dried again and further shelled to obtain the kernels. The dry nuts were shelled manually using a wooden mallet to obtain shea kernels that were dried. The dry kernels were ground into powder, packed in a low dense polyethylene (LDPE) bag and stored under the same condition till the solvent extraction completed [5].

2.3 Oil Extraction

2.3.1 Chemical extraction

Solvent system is mainly used in laboratory experiment although it is sometimes used for commercial extraction in developed countries. According to [8], this method is not usually used in domestic and commercial shea butter extraction due to the high costs involved, environmental problems and lack of technical skills in developing countries.

The oil was extracted with the aid of soxhlet extractor. 300 ml of normal hexane was poured into a round-bottomed flask. A 100 g batch of the sample was weighed, wrapped in filter paper and then inserted into the centre of the extractor. The soxhlet was heated at 60°C for 6 hours. When the solvent was boiling, the vapour rose through the vertical tube into the condenser at the top. Liquid condensed and dripped into the filter paper thimble in the centre which contains the solid sample to be extracted. The extract seeped through the pores of the thimble and fills the siphon tube where it flows down back into the round-bottomed flask. This was allowed to continue for 6 hours. The sample was removed from the tube, dried in an oven and cooled in the desiccators and then re-weighed to determine the amount of oil extracted. The resulting extract containing the oil was heated to recover the solvent from the oil at the end of the extraction. The extracted oil samples were stored in a refrigerator at 4°C until analysis was completed.

2.3.2 Mechanical expressing

An expeller press is a screw-type machine that presses oil seeds through a caged barrel-like cavity. Raw materials enter one side of the press and waste products exit the other side. The machine uses friction and continuous pressure from the rotating screws which moved and compressed the seed material. The oil seeped through small openings that did not allow seed fiber solids to pass through. Afterward, the pressed seeds are formed into a hardened cake, which is removed from the machine. Pressure involved in expeller pressing creates heat in the range of 60–99°C. The method was developed to improve the efficiency of production of shea butter since traditional boiling method was found to be labour intensive and wasteful [7]. The oil was collected using a beaker. The weight of oil was obtained as the difference between the weight of beaker with oil and the mass of empty beaker.

2.3.3 Traditional extraction

Shea kernels were crushed, roasted and ground into paste which was then kneaded by hand with addition of water to separate the fat. The fatty component was removed by scooping with the hand, into a separate container, clarified and crystallized. Kneading was the most crucial step which determines the yield of the final product. In the clarification and crystallization phase, the washed cream was heated in a big pot. The clear oil formed was collected with a ladle into a smaller pot, clarified and poured into a clean, enameled basins and left to cool overnight. The shea butter is then transferred into calabashes and stored in the refrigerator. Fig. 1 is a flow chart of the traditional method of shea butter extraction.

2.4 Determination of Physico-chemical Properties

Standard analyses were carried out on the oil extracted to determine the physic-chemical properties.

2.4.1 Determination of percentage oil yield

The weight of extracted oil was expressed as a percentage of the weight of the dry mass sample as in Equation 1.

$$Oil\ Yield = \frac{wt\ of\ oil\ extracted}{wt\ of\ sample} \times 100 \quad (1)$$

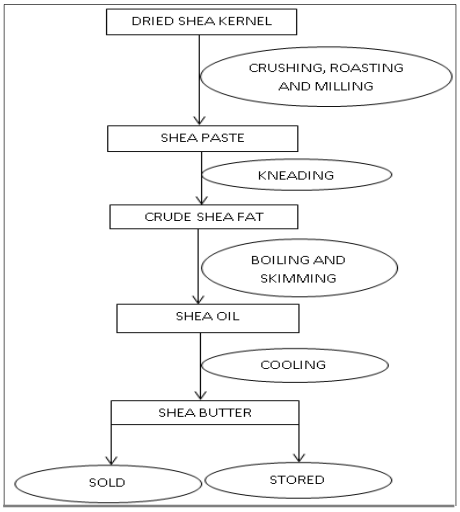

Fig. 1. Flow chart of traditional oil extraction

2.4.2 Determination of saponification value

0.5 g of oil sample was weighed and transferred into a clean dry round bottom flask. 50 ml of 0.5M alcoholic NaOH was weighed out and added to the oil. To the round bottom flask, was a fixed condenser and the contents were refluxed for about 30 mins. The content of the flask was cooled and titrated with standard HCl. A blank test was run in the same way without oil sample. This was then titrated against 0.5 m HCl. The saponification value was calculated using Equation 2 [12].

$$Saponification\ Value = \frac{56.1N(V2-V1)}{W} \quad (2)$$

Where;

N = Normality of HCl
V_2 = Titre value for the blank run
V_1 = Titre value for the oil
W = Weight of oil used

2.4.3 Determination of iodine value

The fat was melted at 70°C and 0.2 g of the oil was weighed into a 500 ml flask and dissolved in 15 ml of carbon tetrachloride. 25 ml of Wijs solution was then dispensed using a pipette into the flask containing the sample. The flask was stoppered, swirled to ensure complete mixing and left in the dark for 30 minutes at room temperature. After which 20 ml of 10% KI solution was added, followed by 150 ml of distilled water. The mixture was titrated with 0.1N $Na_2S_2O_3$ solution using 1.5 ml of starch indicator solution. The blank was run in the same way without the oil sample. The iodine value was determined using Equation 3 [12].

$$IodineValue = \frac{12.69\ (V2-V1)\times N}{W} \quad (3)$$

Where;

w =Weight of oil sample used (g)
N=Normality of the Sodium thiosulphate Sodium
V_1= Volume of $Na_2S_2O_3$ used
V_2= Volume of $Na_2S_2O_3$ used in blank
N = Normality of Na_2S2O_3 (0.1N),

2.4.4 Determination of peroxide value

Five grams (5 g) of the fat was weighed into a 250 ml conical flask with a glass stopper. 30 mL of 3:2 v/v glacial acetic acid-chloroform solvent was added and swirled to dissolve the sample. 0.5 mL of saturated KI solution was added. The solution was left in the dark with occasional shaking for exactly 1 min, and 30 mL of distilled water added immediately. The mixture was titrated with 0.1N sodium thiosulphate using 0.5 mL of starch indicator solution. A blank was also performed at the same time. The test was done in triplicate. The peroxide value was calculated using Equation 4, [12].

$$Peroxide\ Value = \frac{1000(V1-V2)\times N}{W} \quad (4)$$

Where;

N = normality of $Na_2S_2O_3$ solution,
V_1 = volume (ml) of $Na_2S_2O_3$ solution used in test,
V_2 = volume (ml) of $Na_2S_2O_3$ solution used in blank,
W = weight of oil sample.

2.4.5 Determination of acid value

5 g of oil sample was weighed and transferred into 250 ml conical flask. 50 ml of neutral solvent was added and 3 drops of phenolphthalein

indicator was added. This was immediately titrated using standard (0.1 N) sodium hydroxide (NaOH). The end point was the appearance of a permanent pink colour. The procedure was repeated thrice and the average end point obtained. The acid value was then calculated using Equation 5 by [13].

$$Acid\ \boldsymbol{Value} = \frac{56.1NV}{W} \quad (5)$$

Where;

N is the normality of NaOH
V is the volume of NaOH used in ml
W is the weight of the oil sample used in g
Mass of oil sample

2.4.6 Determination of the free fatty acids

To 20 ml of ethanol:diethyl ether (1:1 v/v) mixture, 2 ml of 1% phenolphthalein solution was added and the mixture was neutralised using 0.10M NaOH solution. Then 5 g of each oil sample was added to the neutralized mixture and titrated against 0.10M NaOH solution with constant shaking until a pink colour developed and persisted for 15 minutes. The titre values were used to obtain the free fatty acid value [14]. The free fatty acid value was determined by Equation 6.

$$\boldsymbol{FFA, as\ Oleic}\ (\%) = \frac{28.2VN}{W} \quad (6)$$

Where;

N = normality of NaOH solution,
v = volume (ml) of NaOH solution,
W = weight of oil sample.

2.4.7 Determination of specific gravity

The specific gravity was determined using an empty 10 ml specific gravity bottle. The bottle was placed in a water bath maintained at 25°C and filled with distilled water. It was removed, wiped dry and weighed. The bottle was emptied, dried and placed in a water bath at 60°C and allowed to attain a temperature of 60°C for about 30 minutes. The bottle was then refilled with the melted fat sample. It was then cleaned and wiped completely dry and weighed. The specific gravity was calculated using Equation 7.

$$\boldsymbol{Specific\ Gravity} = \frac{\boldsymbol{Weight\ of\ oil}}{\boldsymbol{Weight\ of\ equal\ volume\ of\ water}} \quad (7)$$

2.4.8 Determination of refractive index

The fat sample was melted at 60°C and several drops placed on the lower prism of an Abbe refractometer (which was also adjusted to the same temperature as the sample. The prisms were closed and tightened firmly with the screw head, ensuring that the sample came to the same temperature with the instrument. The instrument was adjusted until the most distinct reading possible was obtained and the refractive index read.

2.5 Data Analysis

Data for physico-chemical characteristics were entered into Microsoft Excel spread sheet and summarized into mean and standard deviations. Analysis of Variance (ANOVA) was carried out to assess the variation between the parameters [15]. All analyses were carried out in triplicates. Duncan's Multiple Range Test was used to compare mean variance. Significance was accepted at 5% level of probability following Steel and Torric [16] procedures.

3. RESULTS AND DISCUSSION

3.1 Effect of Extraction Method on the Physicochemical Composition of Shea Oil

The results of the effect of extraction method on the physicochemical properties of shea oil samples are presented in Table 1. From the results, yield of oil from the CEM, MEM and TEM methods ranged between 47.67-52.41%, 35.11-45.30% and 37.35-40.83% with mean values of 50.04±3.35%, 40.21±7.21% and 39.09±2.46% respectively. Chemical extraction has higher extraction output than the other two methods. This could be due to the effect of the chemical (n-hexane) which dissolves and drains completely the fat contained in the paste. MEM is also more efficient than TEM because of the high pressure and temperature the paste is subjected to forcing the fat out of the cells. But this does not completely express all the fat as traces of the fat remains in the caked and can therefore be treated with a chemical to recover the remaining fat. The difference in oil yield among the three extraction methods was not significant (P=0.05).

High saponification values of fats and oils are due to the predominantly high proportion of shorter carbon chain lengths of the fatty

acids [13]. The Saponification value ranged between 159.29-162.30, 158.15-166.20 and 184.00-201.40 mgKOH/g with mean values of 160.79±1.50, 162.15±40 and 193±8.58 mgKOH/g for CEM, MEM and TEM respectively. The S.V. of TEM oil (193±8.58 mg KOH/g of oil) was significantly higher (P=0.05) than CEM and MEM but he S.V for CEM and MEM however were not significantly different.

The iodine value measures the degree of unsaturation of an oil or fat, by determining the amount of iodine, in grams, that is taken up by 100 g of the oil. The iodine value is useful in predicting the drying property of oils and was found to range between 47.18-51.18, 48.60-50.56 and 45.67-63.89 gI_2/100 g with mean values of 49.18±2083, 49.58±1.39 and 54.78±12.88 gI_2/100 g for the CEM, MEM and TEM respectively. There was no significant difference (P=0.05) in the I.V. for all the extraction methods. All oils extracted by the three methods could be classified as non-drying oils, since their iodine values were lower than 100 [17]. The low iodine values recorded for the non-drying and semi-drying oils could be of significance in the manufacture of leather, candles, lubricants and hydraulic brake fluids, as reported by Adelaja [18]. The I.V. is also an index for assessing the ability of oil to undergo oxidation and rancidity. The higher the iodine value, the more reactive, less stable and more susceptible it is to oxidation and rancidity.

Acid value is an indicator for edibility of oil and suitability for industrial use. The acid value ranged between 8.02-11.52, 11.70-12.22 and 12.67-14.86 with mean values of 9.77±1.75, 12±0.27 and 13.77±1.10 mgKOH/g for the CEM, MEM and TEM respectively. This suggests that the extracted oil samples are suitable for edible and industrial purposes and are also in accordance with the report of [19,20]. The acid values were highest for the MEM followed by TEM and then to CEM. However, there was no significant variation in acid value among all the three extraction methods (P=0.05). The high acid value of 13.77±1.10 exhibited by TEM compared to CEM of 9.77±1.75 mgKOH/g could be due to either post-harvest handling practices of shea oil or hydrolysis of triglycerides in the shea oil due to the water processes used in the extraction. Post-harvest practices such as harvesting; drying and storage have been reported to be related to increase of the fatty acid in shea oil [5,6,21].

The free fatty acid ranged between 7.26-7.96, 4.65-4.73 and 5.25-5.59 respectively with mean values of 7.61±0.35, 4.69±0.04 and 5.42±0.17 mg/KOH/g for the CEM, MEM and TEM respectively. There was a significant variation in the free fatty acid values of CEM (7.61±0.35) shea oil from those of MEM (4.69±0.04) and TEM (5.42±0.17 mg/KOH/g) (P=0.05). The low free fatty acid maybe an advantage in terms of human consumption [22,23] and suggests that the oil may have a long shelved life [24]. According to [25], specific gravity is commonly used in conjunction with other indices to assess the purity of oil. Specific gravity ranged between 0.96-0.97, 0.90-0.94 and 0.87-0.89 with mean values of 0.97±0.00, 0.92±0.02 and 0.88±0.01 for the CEM, MEM and TEM respectively.

There were no significant differences in the specific gravity of shea oil between MEM and CEM and MEM and TEM (P=0.05). But significant differences were observed between CEM and TEM (P=0.05). The result showed that the oil is less dense than water and therefore would be useful in body cream production as it will make the oil flow and spread easily on the skin. The values are almost similar to those of some well-known edible oil like soya beans (0.916), corn oils (0.921), cottonseed (0.916) and sunflower oils (0.918) [26]. Akinhanm et al. [27] reported 0.962 in a similar assessment of physicochemical properties of cashew nut oil.

Refractive index is an important characteristic which determine the degree of saturation or unsaturation of fats and oil. The index generally indicates the structural properties such as average molecular mass and degree of unsaturation of the fatty acids of oils and fats. The index ranged between 1.45-1.46, 1.44-1.46 and 1.46-1.47 with mean values of 1.46±0.00, 1.45±0.01, 1.47±0.00 for the CEM, MEM and TEM respectively. There was no significant difference in the R.I. among the extraction methods (P=0.05). The almost similar refractive index values for the CEM, MEM and TEM suggest that all the shea oil samples had similar average fatty acid chain lengths and degrees of unsaturation [28].

According to Kaul et al. [29], presence of peroxide has been reported to indicate an increase in iodine value due to oxidative hydrolysis. Peroxide value ranged between 2.10-2.40, 2.65-2.94 and 3.25-3.85 with mean values of 2.25±0.15, 2.795±0.16 and 3.55±0.30 mEqKOH/g for the CEM, MEM and TEM respectively. There was no variation in P.V. between (MEM and CEM) and (MEM and TEM). However, significant difference existed between

Table 1. Variation of Physicochemical properties of shea oil as affected by extraction method

Physicochemical property	Extraction method								
	Chemical (CEM)			Mechanical (MEM)			Traditional (TEM)		
	Min. value	Mean value	Max. value	Min. value	Mean value	Max value	Min. value	Mean value	Max. value
Oil yield (%)	47.67	50.04±3.35a	52.41	35.11	40.21±7.21a	45.30	37.35	39.09±2.46a	40.83
Saponification value (mgKOH/g)	159.29	160.79±1.50b	162.30	158.15	162.15±40b	166.20	184.00	193±8.58a	201.40
Iodine value gI_2/100 g	47.18	49.18±2.83a	51.18	48.60	49.58±1.39a	50.56	45.67	54.78±12.88a	63.89
Acid value (mgKOH/g)	8.02	9.77±1.75a	11.52	11.70	12±0.27a	12.22	12.67	13.765±1.10a	14.86
Free fatty acid (mg/KOH/g)	7.26	7.61±0.35a	7.96	4.65	4.69±0.04b	4.73	5.25	5.42±0.17b	5.59
Specific gravity	0.96	0.97±0.00a	0.97	0.90	0.92±0.02ab	0.94	0.87	0.88±0.01c	0.89
Refractive index	1.45	1.46±0.00a	1.46	1.44	1.45±0.01a	1.46	1.46	1.47±0.00a	1.47
Peroxide value (mEqKOH/g)	2.10	2.25±0.15c	2.40	2.65	2.80±0.16ab	2.94	3.25	3.55±0.30a	3.85

Results are means for triplicate determinations ±standard deviation. Means with the same letter in the same row are not significantly different based on Duncan Multiple Range Test (P=0.05)

(CEM and TEM) (P=0.05). The increase in peroxide value could be due to oxidative hydrolysis reaction during the extraction processes. Boiling with water during the traditional extraction method could have caused oxidative hydrolysis leading to formation of peroxides, a reason for the highest peroxide value. The figure is an index of rancidity, thus the low peroxide values of the oils indicate a good resistance to peroxidation during storage. Rancid oils have very high peroxide value [30]. These values are far below the maximum acceptable value of 10 mEqKOH/g set by the Codex Alimenterius Commission for groundnuts [31].

3.2 Effect of Geographical Location on the Physicochemical Composition of Shea Oil

The results of the effect of geographical location on the physicochemical composition of shea oil are presented in Figs. 2a and 2b. The mean oil yield from the different geographical locations were (43.08±2.75%; 45.87±1.25%), (39.62±1.40%; 39.02±1.16%) and (53.27±2.40%; 50.26±1.44%) for oil from (Jonga; Kpongo) in the Upper West, (Doba; Pusunamongo) in the Upper East and (Savelugu; Tantuani) in the Northern regions respectively. Differences in the O.Y. content of oil from the various villages are simplified as: O.Y: Pus=Dob<Jon= Kpo<Sav=Tan, (P=0.05). This means that, there was no significant difference in oil yield between (Pus.; Dob.), (Jon.; Kpo.) and (Sav.; Tan.) while significant difference existed between (Dob.; Pus.), (Jon.; Kpo.) and (Sav.; Tan.) (P=0.05). There was no significant variation in intra-regional shea oil yield while significant differences occurred in inter-regional oil yield (P=0.05). The average shea oil yield content above 40% corresponds with values reported by [2,5,10,32]. The differences in the shea oil yield could be due to environmental influence and genetic variation [5], geographical location and other agronomic factors [11]. Oil yield from the Northern region was highest followed by oil from the Upper West region, and the least from the Upper East region. This could be due to variation in the climatic conditions in these regions.

The mean saponification value of samples from the Upper West Region (Jon.; Kpo.), Upper East Region (Dob.; Pus.) and Northern Region (Sav.; and Tan.) were (155.80±9.46; 127.50±5.96), (163.63±2.66; 155.45±1.30) and (201.39±2.78; 193.29±3.59 mgKOH/g) respectively. Differences in the S.V. content of oil from the various villages are simplified as: S.V: Kpo<Pus=Jon =Dob <Tan =Sav, (P=0.05). There was no difference in the saponification value among Pus., Jon., Dob but significant difference existed between (Kpo., Tan. and Sav. There was no difference between Tan. and Sav. (P=0.05). These values were lower than the reported saponification values for soya bean, groundnut, cotton, sun flower and olive [30,33]. Similar values were reported by [5,34]. The high saponification value obtained indicates that it can be useful in the production of liquid soap [35].

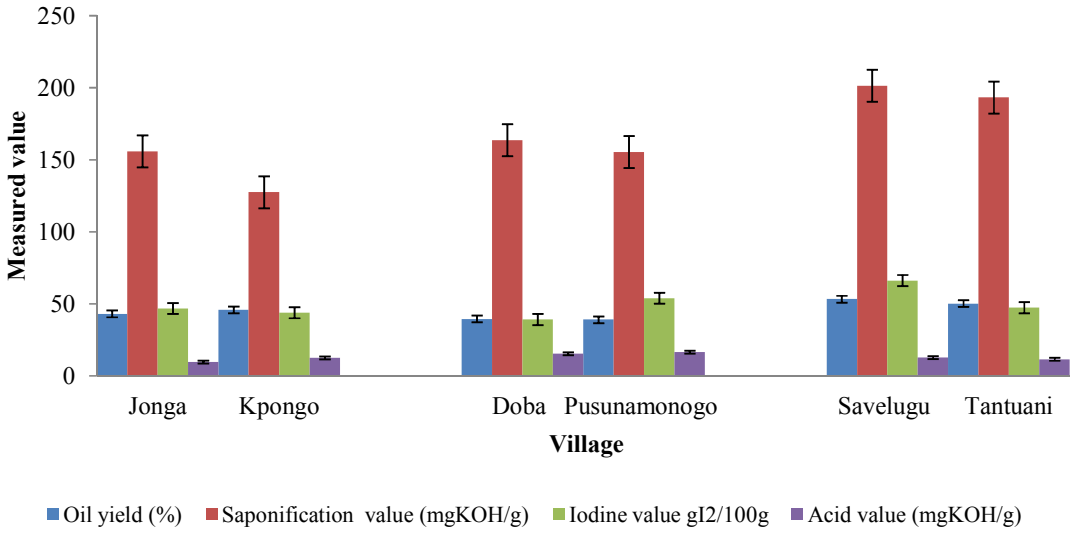

Fig. 2a. Regional variation in physico-chemical properties of shea oil. Bars represent standard mean errors

Note: Results are values of chemical extraction method

The iodine values for samples from (Jon.; Kpo.), (Doba; Pus.) and (Sav.; Tan.) were (46.84±2.06; 43.93±1.47), (39.19±0.99; 53.96±4.87) and (66.19±1.52; 47.46±0.97 gI_2/100g) respectively. Differences in the I.V. content of oil from the various villages are simplified as: I.V: Kpo<Sav=Jon=Tan<Dob<Pus, (P=0.05). There were no significant differences in the I.V. of Sav., Jon., and Tan., but significant difference existed between (Kpo.; Dob.) and Pus. The iodine value of shea obtained is lower than values for most vegetable oils [36]. The value is very much higher than 38.50±0.67% and 23.25±0.02% reported by Oladimeji et al. [37] and Ozcan et al. [38] for Hausa melon seed and fluted pumpkin seed respectively. The low I.V. however makes the oil unsuitable for paint making as it is non-drying oil.

The acid values were (9.60±1.11; 12.53±1.17), (15.46±1.00; 16.47±1.26) and (12.81±0.90; 11.57±1.02 mgKOH/g) for samples from (Jon.; Kpo.); (Dob.; Pus.) and (Sav.; Tan.) respectively. Differences in the A.V. content of oil from the various villages are simplified as: A.V: Jon<Tan=Kpo=Sav<Dob=Pus (P=0.05). There were no differences between Tan. Kpo., Sav., but difference in A.V was observed within A.V. from Jon., Dob., and Pus. However, there was no significant difference between Dod. and Pus., (P=0.05). The acid values reported for seed oils of Pumpkin, A. *muricata* and *P. armeniaca* L varieties are 0.39 [39], 14.2 [40], and 0.41-0.93 mgKOH/g [41] respectively.

The mean free fatty acid of oil samples from the Upper West (Jon.; Kpo.), Upper East (Dob.; Pus.) and Northern (Sav.; Tan.) regions were (6.90±1.54; 7.18±0.22), (4.48±1.16; 4.79±1.07) and (5.53±0.94; 5.76±0.43 mg/KOH/g respectively. Differences between FFA content of oil from the various villages is simplified as: FFA: Dob<Pus<Sav≤6<Tan<Jon<Kpo,(P=0.05). There were no significant differences in the free fatty acid values of samples from Dob., Pus., Sav., Tan. Also, no differences were observed in the FFA values of samples from Sav., Tan., Jon. and Kpo. No significant difference was observed between samples from (Sav. and Tan.), but significant differences were observed between (Jon.; Kpo.) and (Dob.; Pus.), (P=0.05).The FFA makes the oil a good source of raw materials for industries [42]. 1.68 and 10.7 mgKOH/g acid values were reported for almond [43] and cashew nut [27] oils respectively. The acid values of ≤10 mg/KOH/g confirmed the edibility of the oil as well as its stability to rancidity.

The mean specific gravity from the oil from (Jon.; Kpo.), (Dob.; Pus.) and (Sav.; Tan.) were (0.85±0.16; 0.94±0.01), (0.98±0.01; 0.92±0.01) and (0.88±0.02; 0.88±0.01) respectively. Differences in S.G. of oil from the various villages are simplified as: S.G: Jon=Tan=Sav= Pus=Kpo=Dob, (P=0.05). The S.G. values fell within the range of values reported for *P. macrophylla* (0.89), *Treculia africana* (0.81), *Telferia occidentalis* (0.83) and *C. nucifera* (0.86) [44]. There was no significant difference in the S.G values for all the oil samples (P=0.05). This means that, the S.G. value is not different between and within regions.

The mean refractive index from the oil samples from the Upper West (Jon.; Kpo.), Upper East (Dob.; Pus.) and Northern (Sav.; Tan.) regions were (1.46±0.01; 1.48±0.01), (1.52±0.11; 1.42±0.01) and (1.47±0.01; 1.46±0.01) respectively. Differences in R.I. content of oil from the various villages are simplified as: R.I: Pus <Jon=Tan=Sav=Kpo<Dob, (P=0.05).

There were no differences in the R.I. of samples from Jon., Tan., Sav., Kpo. However, they were significantly different from samples from Pus. and Dob (P=0.05). These values were comparable to those reported for cashew nut oil (1.458) [27], *Bischofia javanica* seed oil (1.4863), [45], *P. armeniaca* L. varieties seed oils (1.4655-14.790), [41] and walnut cultivars kernel oil (1.534-1.537), [38]. Pure oils have marked ranges of refractive index and density; thus the degree of variation of typical oil from its true value may indicate its relative purity [39].

The mean peroxide value from the oil from the Upper West (Jon.; Kpo.), Upper East (Dob.; Pus.) and Northern (Sav.; Tan.) regions were (2.67±0.05; 3.42±0.18), (2.59±0.06; 2.65±0.02) and (2.84±0.06; 2.26±0.02 mEqKOH/g) respectively. Differences in P.V. content of oil from the various villages are simplified as: P.V: Tan<Dob=Pus= Jon<5Sav<Kpo, (P=0.05) There were no significant differences in P.V. of samples from Dob., Pus, Jon. But samples from Tan., Sav.,Kpo are all significantly different from Dob., Pus and Jon. The P.Vs. are similar to those reported by [5 and 35]. The P.V. is an index of rancidity, thus the low peroxide value obtained indicates a good resistance of the shea oil to peroxidation during storage. The low peroxide value is an indication that the oil does not contain

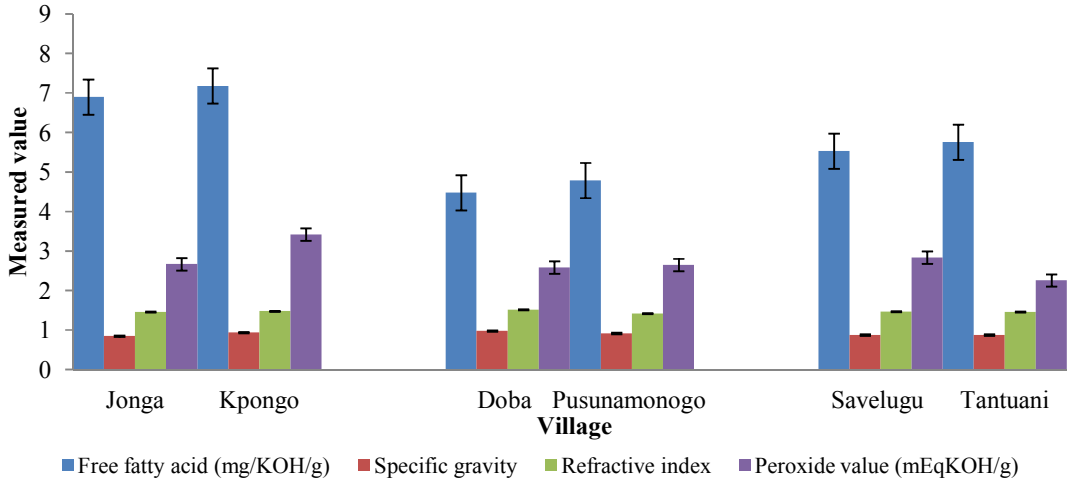

Fig. 2b. Regional Variation in physico-chemical properties of shea oil. Bars represent standard mean errors

Note: Values of chemical extraction method

much of trace elements (especially copper) and moisture which normally accelerates auto-oxidation [46]. The values are within the permitted maximum peroxide value (≤10 mEqKOH/g).

4. CONCLUSIONS

The results of the physico-chemical investigation of the oil extracted shea butter compared well with those reported by other investigators. Also, the high oil content of the shea butter extracted by the chemical method suggests that, commercial extraction of shea butter using solvents will be a very viable option as compared to the traditional method which is not only arduous but requires huge volumes of water and firewood. It was noted that mechanical expression of shea kernels, does not only alleviates time consuming process but also improves the fat output. The oil yield of mechanical expressed oil was between 40.83% and 45.30% while that of the traditional method was between 35.11% and 37.35%. The chemical extraction had the highest oil yield, of between (47.67 to 52.41%). Beside the high oil yield, CEM technology proved to be excellent in iodine, acid and specific gravity values, but with the least saponification value. Therefore commercial extraction of sheabutter by this technology appears to be viable on large scale production. The TEM technology yielded the highest saponification, iodine, free fatty acid, refractive index and peroxide values with least values in oil yield and specific gravity. The MEM technology had values almost mid-way between CEM and TEM and therefore yielded butter of superior quality than the other two technologies and should therefore be encouraged even if at a smaller scale. Geographical effect on the quality of shea butter revealed that kernels from the Northern region produced good quality shea butter, followed by those from the Upper West and finally to the Upper East regions.

Though there were variations in the physico-chemical characteristics of the shea butter extracted by the different methods, the values were within limits of other edible vegetable oils. The physico-chemical characteristics exhibited by shea oil samples from the different shea zones of Ghana make it a possible raw material for use in cosmetics (creams and lotions), soap, and food processing (as edible vegetable oil), in bakery and confectionery sectors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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