KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF FOOD SCIENCE AND TECHNOLOGY

FACULTY OF BIOSCIENCES

COLLEGE OF SCIENCE

EXTRACTION AND CHARACTERIZATION OF *Borassus aethiopum* KERNEL OIL

BY

STANLEY BANSAH

SEPTEMBER, 2018

Extraction and Characterization of *Borassus aethiopum* Fruit Kernel Oil

By

Stanley Bansah BTech Science Laboratory Technology (Hons.)

A thesis submitted to the Department of Food Science and Technology,

Kwame Nkrumah University of Science and Technology in partial

fulfilment of the requirements for the degree

Master of Science in Food Quality Management

Faculty of Biosciences,

College of Science

SEPTEMBER, 2018

CERTIFICATION

I hereby declare that this submission is my own work towards the Master of Science in Food Quality Management and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgment has been made in the text.

Stanley Bansah ....

Student name Signature Date

Certified by Supervisor:

Dr. Jacob K. Agbenorhevi ....

Signature Date

Certified by Head of Department:

Dr. (Mrs.) Faustina Dufie Wireko Manu ....

Signature Date

ABSTRACT

Borassus aethiopum (African Palmyra palm) fruits are underutilized but have currently received a great attention in the search for alternative food sources to supplement the current food demands of the increasing world population. *Borassus aethiopum* fruits flour and other products have been produced successfully in previous works. However, the oil yield and characterization of oil from *B. aethiopum kernel* had not been evaluated. The main objective of this study therefore, was to extract and characterize the oil from *B. aethiopum* kernel. The fruit nuts were manually cracked with a machete to obtain the kernels. The kernels were chopped into smaller pieces, dried and milled using the hammer mill. Oil extraction was carried out using the Soxhlet apparatus with petroleum ether as the organic solvent. The physicochemical properties, oil yield and four fatty acids were determined by standard procedures. The results indicated an oil yield of 1.56%, a peroxide value of 4 9 . 8 5 ± 0.17 meqO_2/Kg, iodine value of 167.00 ± 2.70 mg I_2/g, saponification value of 196.69 ± 0.51 mgKOH/g and FFA of 9.56 ± 0.17%. Also, 6-methyl laurate was the highest among the four detected fatty acids in *B. aethiopum* kernel oil. Based on the yield obtained, commercial production of *B.*

aethiopum fruit oil may not be economical.

ACKNOWLEDGEMENT

I would first of all extend my greatest appreciation to God for the sustenance of life throughout the pursuance of this Master‟s degree. Secondly, I thank my thesis supervisor, Dr. Jacob Agbenorhevi for his support in providing technical advice to aid the progress of this study. To all laboratory technicians who supported me immensely with the laboratory analysis, I say God richly bless you.

Finally, I also express my deepest appreciation to my parents – Mr. Fabian Bansah and Mrs Edna Bansah, my wife - Mrs Eunice Bansah and all my siblings. Without their unfailing support and encouragement, I would not have come this far.

DEDICATION

This thesis is dedicated to my children Stanley Kweku Bansah and Edna Kukua Bansah.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1.0 Introduction

Palmyra palm (*Borassus aethiopum* Mart) grows in desolate lands inside the vast geographical region from Western Africa to Eastern Indonesia (Agbo and Simard, 1992). The palmyra tree is very beneficial for the populace within the axial regions of Côte d'Ivoire. As a source of food (sap, fruits and immature shoots), over 88 % of the palm tree is utilized for the wellbeing of the general public in these regions. (Waziri *et al*., 2010). Majority of the palm fruits are not exploited and usually left in the field to deteriorate (Ali *et al*., 2010). In remote areas, after a period of six (6) to eight (8) weeks of cultivation, undeveloped shoots of palmyra are obtained and consumed as food (Kouamé, 1992; Ali *et al*., 2010). The palm is part of the *Arecaceae* family in which the species of socioeconomic significance are *Borassus aethiopum* Mart (Madagascar and Africa), *Borassus sundaicus* Becc (Indonesia), as well as *Borassus flabellifer* L. (Asia, India and Sri Lanka) (Agbo and Simard, 1992).

Averagely, three (3) shoots usually develop from a single palmyra fruit. According to Malumba *et al.* (2011), „Fallen parts of the fruit normally reproduce the palmyra palm plant whilst the other portion is collected by the natives for food usage. African Palmyra palm tree can be useful in value addition to crops, by employing inventive technologies, including decrease in losses after harvest, thereby enhancing food security, agricultural sustainability and good environmental practices (Beddington, 2010). Tubers of Palmyra serve as valuable source of starch for the indigenes where the plant thrives. The tubers are cooked before consumption and could serves as replacement for various sources of starch (Barminas *et al.*, 2008).

Research by Ali *et al*., (2010) indicated that flesh of the fruit is a great source of fiber, minerals, sugars, vitamins A and C. *Borassus aethiopum* fruits have also been shown to be used for syrups that improve the sensory properties (taste and colour) of foods (Adzinyo *et al*., 2015). Also, it has been established that *Borassus aethiopum* fruits could be used in the production of pectin at industrial scale (Assoi *et al*., 2014). The fruits have been found to have mineral constituents such as sodium, potassium, iron and calcium (Niamké *et al.*, 2013; Arthur, 2018).

According to the study of Abe-Inge *et al*., (2018), „The *Borassus aethiopum* fruits have a great potential in flour production for the pastry industry. Although several research works have been conducted on the *Borassus aethiopum* fruits, little has been done on the fruit kernel. Therefore, the aim of this project was to extract and investigate the quality of *Borassus aethiopum* fruit kernel oil.

1.1 Problem Statement

Borassus aethiopum fruits are underutilized (Ali *et al.*, 2010; Siaw *et al*., 2014) and characterization of oil from *Borassus aethiopum* kernels for food applications have not been evaluated. Also the growing population of the world demands alternative food sources to supplement the already existing food commodities in meeting the potential increase in food demand.

1.2 Justification

Value addition to underutilized African Palmyra palm fruits will gradually reduce postharvest losses, contribute to food security as well as reduce the over dependence on palm oil from other varieties of palm fruits.

Extraction of African Palmyra palm fruit kernel oils with comparable oil characteristics will serve as an alternative source of oil for domestic and industrial purposes. There is also the possibility of commercially refining it.

1.3 Aim

The aim of this project was to extract and characterize oil from *Borassus aethiopum* kernel.

1.3.1 Specific objectives

i. To determine oil yield from *Borassus aethiopum* kernel.

ii. To determine the acid value, free fatty acid (FFA) content, iodine value, saponification value and peroxide value of *Borassus aethiopum* kernel oil.

iii. To determine fatty acid composition of *Borassus aethiopum* kernel oil.

CHAPTER TWO

2.0 Literature Review

2.1 African Palmyra Palm (*Borassus aethiopum*)

2.1.1 Origin

The Palmyra palm tree (otherwise called the sugar palm or toddy palm) is a dioecious plant in Africa (Mollet, 1999; Ariyasena *et al*., 2001). They develop normally from Senegal to the Central African Republic (Ali *et al*., 2010). They are likewise found in South Asia (Sri Lanka and India) and in addition South East Asia (Cambodia, Indonesia, Malaysia, Vietnam, Myanmar and Thialand). The class *Borassus* is one of the broadly dispersed individuals from *Palmae*. It is generally developed in tropical dry or wet climatic areas. Having an extensive variety of taxon, the three most paramount commercial species are *Borassus flabellifer* L, commonly found in the seaside regions of Southeast Asia including India, the *Borassus aethiopum* Mart discovered in Africa and the *Borassus sundaicus* normally confined to zones inside Indonesia (Davis and Johnson, 1987).

2.1.2 Characteristics and Benefits of *Borassus aethiopum*

Because of its noteworthy incentive to the neighbourhood populaces in the regions where it is found, the *Borassus* palm is generally alluded to as the tree of life. It has almost 800 application which encompasses nourishment, drink, fibre, therapeutic and timber (Arulraj and Augustine, 2008). By-products like palm sugar and gur (molasses) are additionally made from the juices that are extricated from the storage compartment of the *Borassus aethiopum* (Sandya *et al*., 2010). In tropical parts of India, the juvenile delicate delicious seed nuts are utilized as beverages amid the sweltering summer

(Sandhya *et al*., 2010).

It function as food (fruit, sap, immature shoots) (Waziri *et al*., 2010), as building material (the stem and leafage) (Akinniyi *et al*., 2000). The delicate orange mesocarp mash of the mature fruit of the Palmyra is sugary, generally thick and eatable. It is known to contain copious amount of Vitamin A and C. Additionally, they are recognized to contain bitter compounds called flabelliferrins that are steroidal saponins in nature (Sandhya *et al*., 2010). Other means of application of the Palmyra to the general public are extraction of palm wine which represent a part in their eating as well as growth. The ready organic product mash can likewise be incorporated into delicate refreshments such as jams, toffees and other candy parlor (Das and Das, 2003). Notwithstanding, the commercialization of these products is laborious. Because of this, more than 60% of the yearly fruit yield is lost during storage and furthermore in the fields (Ali *et al*., 2010). A noteworthy reason behind the underutilization of the Borassus fruit is the detachment of the mash from the fibre and in addition the unpleasant compounds that arise in the fruit (Jan *et al*., 1994). The *Borassus* plant parts are known to have numerous medical advantages, for example, in the treatment of secondary syphilis, pyrosis, liver and spleen augmentation. It is utilized locally as a stimulant and as a diuretic and antiphlogistic substance. The organic products are likewise known to be soothing, purgative and Spanish fly in nature (Jan *et al*., 1994). Because of its noteworthy incentive to the neighbourhood populaces in the regions where it is found, the *Borassus* palm is generally alluded to as the tree of life. It has almost 800 applications which encompasses nourishment, drink, fibre, therapeutic and timber (Arulraj and Augustine, 2008). By-products like palm sugar and gur (molasses) are additionally made from the juices that are extracted from the storage compartment of the *Borassus aethiopum* tree (Sandya *et al*., 2010).

In tropical parts of India, the juvenile delicate delicious seed nuts are utilized as beverages amid the sweltering summer (Sandhya *et al*., 2010). It functions as food (fruit, sap, immature shoots) (Waziri *et al*., 2010), as building material (the stem and leafage) (Akinniyi *et al*., 2000). The delicate orange mesocarp mash of the mature fruit of the Palmyra is sugary, generally thick and eatable. It is known to contain copious amount of Vitamin A and C. Additionally, they are recognized to contain bitter compounds called flabelliferrins that are steroidal saponins in nature (Sandhya *et al*., 2010). Other means of application of the Palmyra to the general public are extraction of palm wine which represent a part in their eating as well as growth. The ready organic product mash can likewise be incorporated into delicate refreshments such as jams, toffees and other candy products (Das and Das, 2003). Notwithstanding, the commercialization of these products is laborious. Because of this more than 60% of the yearly fruit yield is lost during storage and furthermore in the fields (Ali *et al*., 2010). A noteworthy reason behind the underutilization of the *Borassus aethiopum* fruit is the detachment of the mash from the fibre and in addition the unpleasant compounds that arise in the fruit (Jan *et al*., 1994). The *Borassus aethiopum* plant parts are known to be of numerous medical advantages, for example, treatment of secondary syphilis, pyrosis, liver and spleen augmentation. It is utilized locally as a stimulant, for diuretic and antiphlogistic purposes. The organic products are likewise known to be soothing, purgative and Spanish fly in nature (Jan *et al*., 1994).

Figure. 2.0: African palmyra palm trees (left photo) and fruits (right)

http://www.palmpedia.net/wiki/Borassus_aethiopum

Ali *et al*. (2010) investigated the nutrient content and morphological characteristics of ready Palmyra natural fruit gathered from different areas in Cameroun and discovered huge deviation in the physicochemical properties of the different fruits. Effort has thus been made to transform the fruit into different items, for example oil, spread and toffee.

2.1 Genus *Borassus*

Borassus or the palmyra palm is the taxonic group containing six groups of fan looking palm trees. The six species comprise *Borassus aethiopum, Borassus akeassii, Borassus flabellifer, Borassus heineanus, Borassus madagascariensis* and *Borassus sambiranensis* (Bayton, 2007). *Borassus aethiopum* is indigene to the tropical parts of Africa. *Borassus akeassii* is mostly found in West Africa. *Borassus heineanus* is indigenous to New Guinea and its surroundings areas. *Borassus flabellifer* is located in the southern parts of Asia and *Borassus madagascariensis* and *Borassus sambiranensis* is indigenous to Madagascar (Bayton, 2007). They develop normally from Senegal to the Central African Republic and additionally located in Sri Lanka, India likewise South East Asia, Cambodia, Indonesia, Malaysia, Vietnam, Myanmar and Thailand. It is the

national fruit of the Cambodians (Davis and Johnson, 1987, Ali *et al*., 2010). They are usually grown in tropical dry or wet climatic areas.

The African palmyra palm tree can grow up to 30 meters high with long fan shaped leaves which extend to 2-3 meters in length (Fig 2.1 and 2.2). The trunks of these palms are very firm and robust. The plants are dioecious with male and female blossoms on different plants; fertilization is by both breeze and insect. The blossoms are little in thickly bunched spikes. Male blooms are less than 1 cm long and in semi-circular groups, sandwiched between coriaceous bract in some sort of cernuous catkin (Figure 2.3) while the female blossoms are 3-5 cm wide, in the form of globe and solitary (Fig.2.4). The fruits are 15-25 cm wide, they are generally spherical and have about 1-3 vast seeds (Fig.2.5 and 2.6). Based on the type of species, the colour of the fruit may be dark to umber and orange in nature. The stringy mash is redolent and luscious to taste and each of the seed is enveloped in a woody endocarp.

Figure 2.1: *Borassus flabellifer* plant

Source:
http://www1.biologie.unihamburg.de/bonline/library/palms/borassus_flabellifer_juv.J PG

Figure 2.2: *Borassus flabellifer* fruits (unripe)

Source:
http://www1.biologie.unihamburg.de/bonline/library/palms/borassus_flabellifer_juv.J PG

Figure 2.3: Male flowers of the *Borassus flabellifer*

Source:
http://www1.biologie.unihamburg.de/bonline/library/palms/borassus_flabellifer_juv.J PG

Figure 2.4: Female flowers of the *Borassus flabellifer*

Source:
http://www1.biologie.unihamburg.de/bonline/library/palms/borassus_flabellifer_juv.J PG

Figure 2.5: *Borassus flabellifer* fruits

Source:http://world-crops.com/wordpress/wp-content/uploads/202-Borassus- flabellifer-Asian Palmyra-palm.jpg

Figure 2.6: *Borassus* seeds

Source:http://world-crops.com/wordpress/wp-content/uploads/202-Borassus- flabellifer-Asian Palmyra-palm.jpg

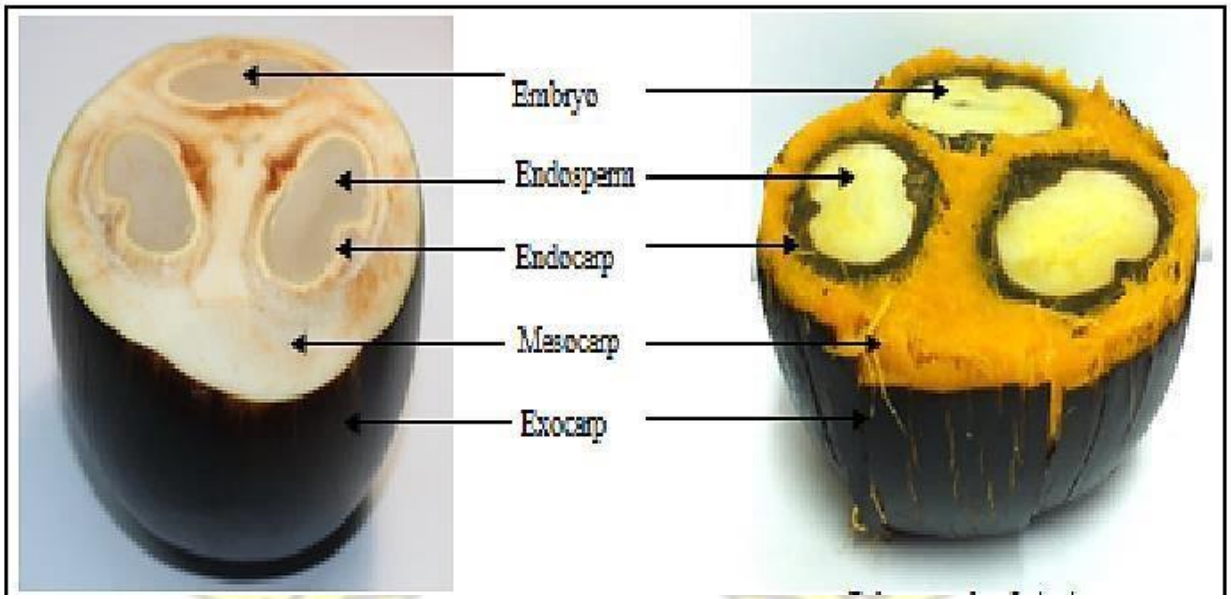

Figure 2.7: Diagram of a cut section of the *Borassus aethiopum* fruit

Source:
https://www.researchgate.net/profile/Maneesri_Jaruwan/publication/302584085

2.2 *Borassus aethiopum* in Ghana

In the woodlands of Ghana, wood from non-conventional sources like the palmae species including *Borassus aethiopum* are copious. It is utilized as a raw material in Ghana's wood industry (Siaw *et al*., 2014) for construction works including building of local bridges in the rural areas. It serves as raw material for both the furniture and development enterprises. It is likewise utilized in medicine, food and drink industries as well as production of industrial materials. Ripe *Borassus aethiopum* fruits are consumed either fresh or boiled with porridge or corn in the rural parts of Ghana and many rural areas of Africa (Ali *et al*., 2010; Siaw *et al*., 2014). Young leaves of *B.aethiopum* are also use in making hand-woven local fans.

2.3 Palm Kernel Oil

Oil is a term used to describe organic-liquids that are somewhat less viscous in nature. Fatty, mineral, essential and silicone oils may be differentiated on the basis of their chemical make-up (Anaekwe, 2011). Oils derived from the kernel of the palm fruits are termed „palm kernel oil" and are eatable and palatable (Hartley, 1997). Oil from palm kernel has a white to yellowish colour and is obtained from a vegetable source. They are semi sold at room temperature (Anaekwe, 2011). It has extraordinary advantages both domestically and industrially. It is known that no part of the palm tree is unusable. After processing palm fruits to obtain palm oil the shelled item remained can be separated to acquire two items being the nut and the shells which are all of economic significance. The shell is used as a raw material for fuel and furthermore utilized to make roads in remote regions. Shells are also used as a means of sustenance to the general population in the society. It can likewise be pulverized and transformed to generate palm oil as well as the cake (Anaekwe, 2011). According to Poku (2002), „Oil from palm kernel at room

temperature is semi-solid and highly saturated compared to palm oil.‟ Palm kernel oil saturation can be compared to that of coconut oil. It is known to be exceptionally steady at high cooking temperature making it the most effective to use when cooking commercially. It has a good shelf life compared to various vegetable oils and rich in lauric acid (Poku, 2002). Although individuals often use them conversely, oil from palm kernel is different from that of palm. Both oils vary in their composition as well as their attributes. Palm kernel oil comprises nearly 45% - 48% by weight of oil whose attributes vary from palm oil yet are like coconut oil (Gbasonuzo *et al*., 2012). Lauric acid (C12, 48%), myristic acid (C14.16%) and oleic acid (C18.15%) are the major fatty acids present in palm kernel oil.

2.3.1 Benefits of Palm Kernel Oil

Due to the similitude of the attributes and chemical component of palm kernel oil to that of coconut oil both oils have similar importance in the food industries as well as other industries (Oyinalala *et al*., 2004). Oils such as palm kernel oil as well as fractionated and hydrogenated products are usually used solely or mixed with different oils to make substitute like cocoa butter. Likewise, it is utilized in the production of fats for confectionery products, to mimic whipping cream, ice cream, cake icing, sharp-liquefying cream and other nourishment products (Bredeson, 1983). It is aromatic and generate an appealing physical attributes to bakery goods such as bread. Palm kernel oil is utilized in the production of chocolate and utilized at home for cooking different kinds of diet. It can also be added to petrol and diesel as well as applied in the production of biodiesel to be a source of fuel for vehicles that use diesel.

In the neighbourhood setting, palm kernel oil can serve as fuel for lightening local lamps thereby reducing cost (Shaver, 2005). Oils from palm kernel likewise is vital in

the soap industry because of high lauric acid content which aids fast lathering. Soaps with 15% laurate are said to be effective for lathering during usage (Bachmann, 2005). Palm kernel oil also find use in the pharmaceutical companies where they are utilized to manufacture suppositories because of their hardness and quick melting abilities. It can likewise be utilized to manufacture other non-food items, for example beautifying agents, candles, glue and lubricating substances for machine and plastic items and printing inks (Butcher, 2005).

2.4 Methods of oil extraction

The process used to separate oils is dependent on the kind of available raw material (Harris, 1995). Raw materials can be categorized in terms of the plant parts that have fat or oil which comprises the kernel as well as bean and nut or the palm fruit. The fundamental distinction among the various materials is the amount of water contained in them. Raw materials that have reduced moisture present are beans, seeds as well as nuts which have undergone drying. Those raw materials that are processed wet include olive fruits likewise palm fruits and coconuts. Large and small scale extraction of oil utilizes nuts, seeds and fruits that have appreciable amount of edible oil. Seeds such as maize could contain edible oil however the amount may be little for commercial processing. Nonetheless, not all fruits as well as seeds that have high amount of oil are edible because some have substances that are toxic and poisonous with unappealing aroma. This type of oils are utilized in the manufacture of paints, varnishes and other products (Ataga *et al.*, 1993). Cost of production, recovery of oil as well as quality of product influence the type of method to employ (Ataga *et al.*, 1993).

The oil extraction process involves the sieving of bunches of fresh fruit, sterilization, followed by threshing to free the fruit. The next stage involves mashing the fruit and

then pressing to generate the palm oil, treatment to purify, subsequent packaging and storage of oil. Refining of crude oil involves expulsion of the products generated due to hydrolysis and oxidation as well as colour and flavour. When refining is complete, oil may be separated into the solid component and liquid portion using thermo- mechanical processes at appropriate cooling as well as crystallization and filtrations conditions. The fluid portion known as olein is utilized widely as cooking oil in tropical climates, competing well with the more costly oils made from corn, groundnut as well as sunflower oil. Strict quality control from the reception of the fruit to extraction of the kernel is vital to ensure oil produce as well as by-products generated are of good quality (Poku, 1998).

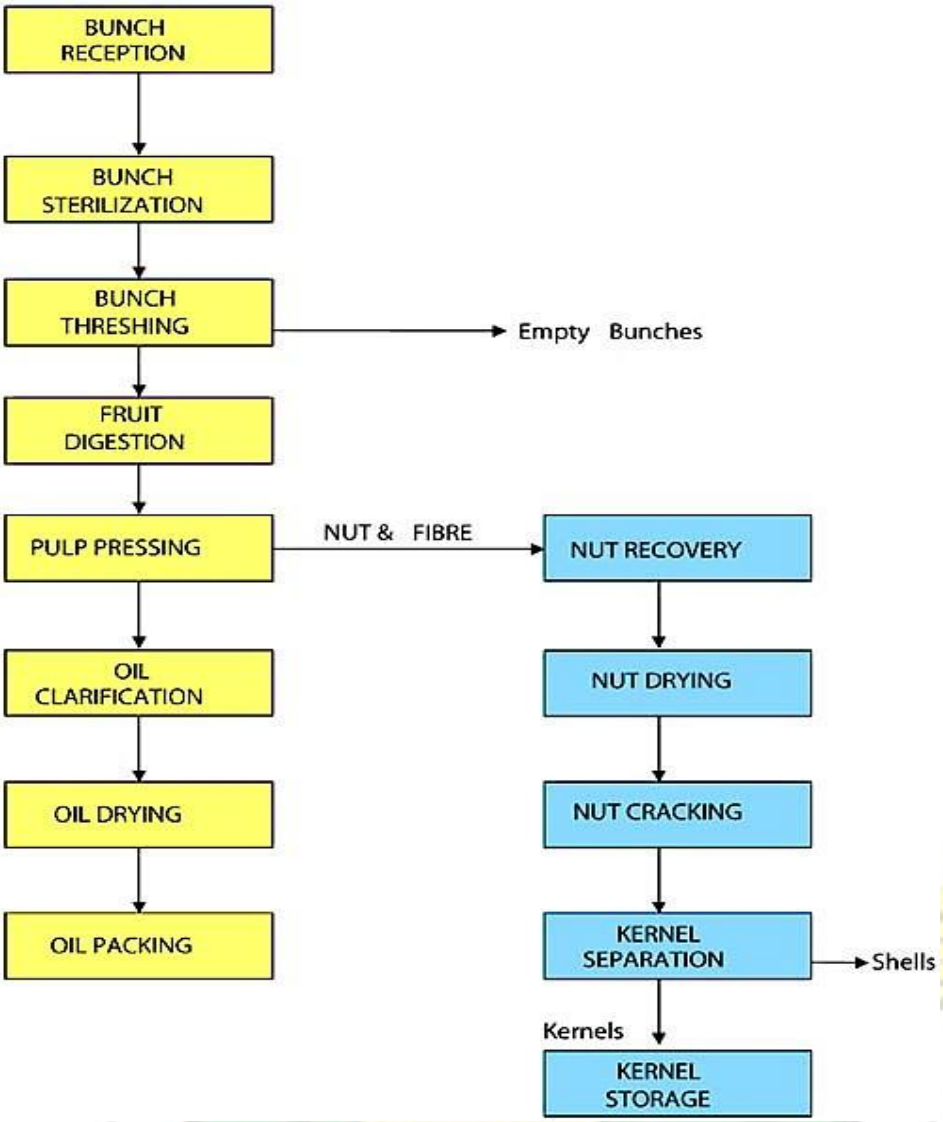

Figure 2.8: General flow chart in palm oil extraction

Source: FAO Agricultural Services Bulletin, 148, (2002).

2.4.1 Traditional method of oil extraction

Traditional means of palm kernel oil extraction is generally the native method which is referred to as thermal extraction (Hartley, 1998). It employs low-pressure techniques and also displacement of water (Cornelius, 1983).

The main processes in this method of extraction comprise of pre-extraction treatment which involves heat application. Gbasouzor *et al*., (2012) indicated the following method involved in thermal extraction of oil from palm kernel;

1. Pre-extraction treatment of kernel nut: This stage helps facilitates the main extraction process and generally involves the use of heat.

2. De-shelling and Cleaning: The thermal method begins with shelling of the palm nuts. This is carried out by application of stones to break the nuts thereby isolating the shell from the kernel simultaneously. The application of cracking stations for cracking nuts has taken dominancy over manual breaking of nuts. This gives a mixture of nuts and shells which can then be manually isolated. The isolation of the shell-kernel is normally done in clay bath made of water and clay. The traditional method utilizes the density of clay likewise the shells sink whiles the kernels which are lighter are moved on top of the mixture. The portions of kernel are then scooped from the surface of the blend into a container. At this point, the kernels are washed with clean water and dried.
Occasionally, the shells are removed from the bath and disposed.

3. Heat treatment and size reduction: During heat treatment the kernels are normally heated. Portion of the kernels that are roasted are pulverized in a grinder to obtain a paste.

4. Oil extraction: The main oil extraction is carried out at this point. Little amount of water is mixed with the paste and heated while stirring in order to displace the palm kernels on top of the mixture. Sporadically, displaced oil is taken off the surface. This process is known to have an estimated rate of extraction of about 20% - 40% (UNIFEM, 1987).

There are other methods that have been categorized as traditional methods of palm kernel oil extraction. In the second method, palm kernels are roasted at a very high temperature until the point when oil begins exuding out of the nut (Addo Consultants, 1989). Other method of oil extraction which does not involve heat has been stated by Irvine (1970). In this process, kernel nuts are left overnight in water and grounded in a mortar. Paste generated is heated with water to separate oil on top of the mixture. Occasionally, the oil is removed and heated till it dries. Nonetheless, these two methods of extraction are observed to be ineffective compared to the first method of extraction.

Pounding (digestion) and oil expression are the most laborious and essential tasks in traditional oil extraction. Small-scale processing, the most difficult aspect include digestion and the breaking of the oil-bearing cells of the fruit mesocarp.

2.4.2 Mechanical method of oil extraction

With regards to the extraction of vegetable oils using the mechanical method, the key extraction technique employed is the screw press (Gbasouzor *et al*. 2012). This technique of vegetable oil extraction is adopted in most unindustrialized countries and can be used in small vegetable oil processing facilities and large one alike. In order to ease the extraction of oil, complex and advanced machineries are currently being developed. The mechanisms involved in the mechanical extraction method are categorized into three steps:

1. Preliminary operations/Pre-treatment of raw materials (nuts)
2. Screw pressing
3. Clarification of oil

1a. Preliminary operations/Pre-treatment: Thorough pre-treatment of nuts prior to extraction is the foremost stage and very critical in mechanical oil extraction as it increases the efficiency of the extraction. Cleaning and Size Reduction: regarding pre-treatment of raw materials for the extraction, cleaning is done so as to eliminate the contaminants such as wood chippings, stones, glass pieces and debris which could limit the mechanical effectiveness of the screw press. In most oil extraction facilities, there are magnetic separators which help in the removal of metallic contaminants as well as vibration screens which eliminate non-metallic contaminants such as stones, glass pieces, wood chippings and sand. After thorough cleaning of the kernels, they are cracked into smaller pieces with the aid of a swinging hammer grinder or breaker roll grinder. The reduction in size of the kernels promotes flaking due to an increased surface area (Gbasouzor *et al*., 2012).

1b. Flaking: After size reduction, the kernel fragments are fed into a roller mill which breaks down the cell walls of the kernel pieces. This process is well-known as flaking and the end-product at this point is known as flakes. According to Tang and Teoh (1995), "The flakes usually have thickness ranging from 0.25 to 0.45 millimetres.

1c. Steam Conditioning: In this step, the kernel flakes are moved to a heap cooker for steam conditioning to occur. This is a very important step due to the fact that;

i. It prevents an increase in Free Fatty Acids by stopping enzymatic reactions. This is useful as it reduces the viscosity of the extracted oil.

ii. It continues with the breakdown of kernel cell walls initiated at the flaking stage.

iii. It aids in adjusting the moisture content of the kernel meal to an ideal level.

In series of five separate sections, the kernel meal moves from one section to another. The kernel meal is stirred vigorously at every section. There are steam trays for heating the cookers and occasionally, steam is transferred into each section as and when needed. At this point, the significant variables include time of retention, temperature and moisture content. As indicated in the work done by Tang and Teoh (1995), palm kernel meals are mostly cooked to a moisture content of 3 % at a temperature of 104 – 110 °C.

2. *Screw Pressing*: After steam-conditioning of kernel meal, the meal is fed into a screw press bit by bit. A screw press is made up of a cage which has an episodic helical thread inside. The thread functions by revolving within the cage. The cage also has perforations through which the kernel meal is forced through via the action of the helical thread. As it moves through the cage, the kernel meal is compressed. This process makes oil to ooze out through the cage‟s perforations. The oiled cake is forced out though the bottom opening. Water is repetitively circulated around the warm–shaft to cool it whilst the cage is externally cooled using cooled oil. The cooling helps in checking extremely high temperatures which may affect the quality of the extracted oil and the cake (Ataga *et al*., 1993).

3. Oil *Clarification*: The extracted oil is crude - it contains certain undesirable constituents. To improve the quality and acceptability of the palm kernel oil, these undesirable constituents have to be removed. The crude oil is usually stored in a reservoir and thereafter, pumped to a coarse screen that is constantly revolving. This ensures that all the large-sized undesired particles in the crude oil are removed. The screened oil is then passed through a filter press to remove all small remnant of the undesirable particles. This process gives a clear oil before it is stored in a tank (Gbasouzor *et al*., 2012).

There are some disadvantages associated with the mechanical method of oil extraction which include wear and tear of machinery, cost of utilizing electricity and unavoidable maintenance expenses (David and Vincent, 1980). Another disadvantage is that the method is time-consuming - the length of operation is usually from there (3) to six (6) hours. The need for special equipment with skilled labour and the incomplete recovery of compounds that are more water soluble and less volatile are also demerits that cannot be overlooked in using this method (Lam *et al*., 1986).

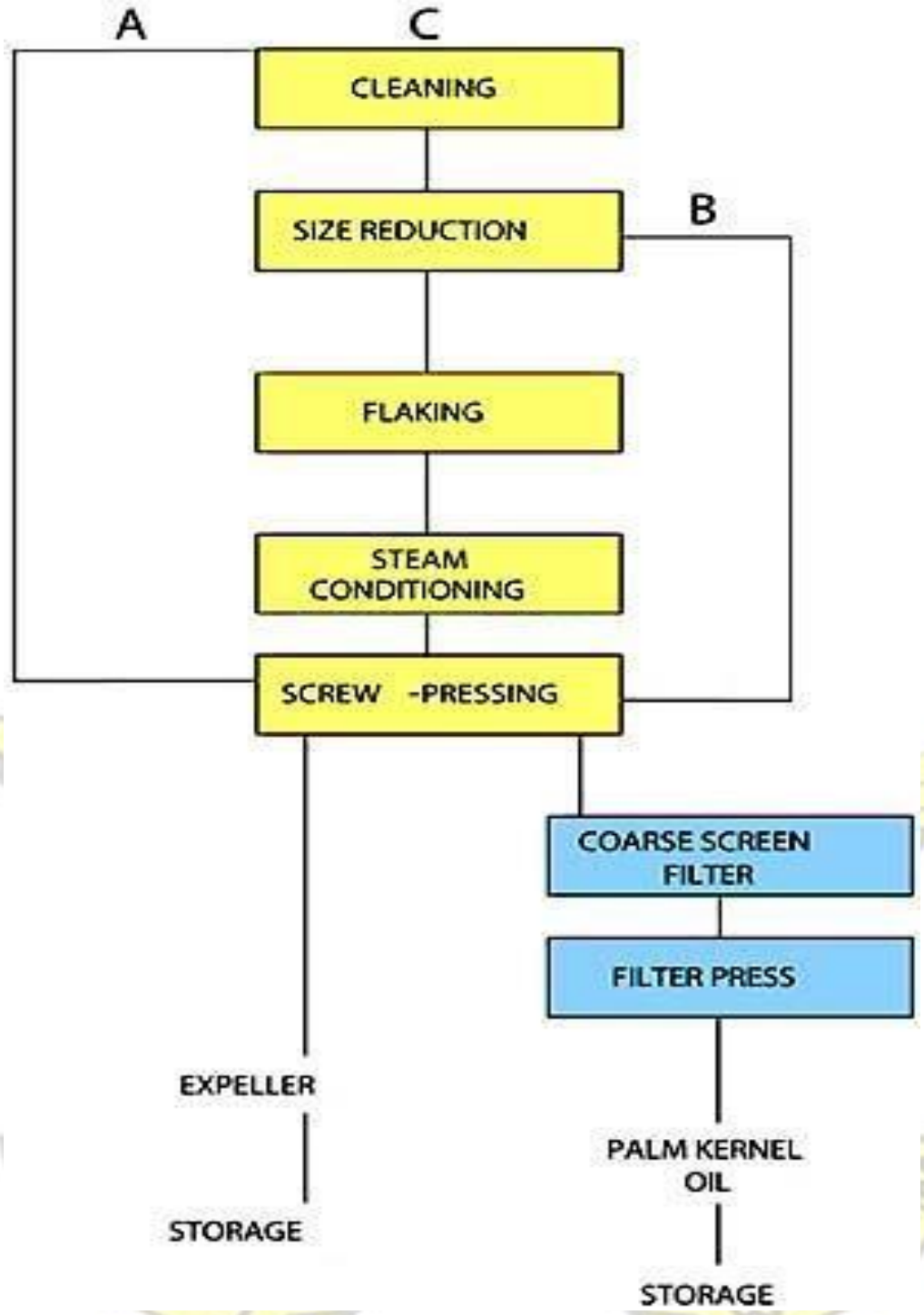

Figure 2.9: Mechanical extraction of oil

Source: FAO Agricultural services bulletin, 148, (2002).

2.4.3 Solvent extraction of oil

Unlike the mechanical extraction method by which screw press is used, the solvent extraction method uses an extruder and organic solvent. With the solvent extraction method, relatively higher volumes of oil with better quality is extracted. There is also retention of the protein content of the oil extract. For larger volumes of oil extraction, a solvent extraction plant is recommended. The processes involved in solvent extraction are categorized into three steps:

1. Pre-treatment of kernel
2. Oil extraction using solvent
3. Recovery of solvent from oil extract and kernel meal

Kernels are pre-processed and treated in a multiple stage counter-current process with a solvent until the remaining oil content is decreased to the lowest possible amount. The oil-solvent mixture is then separated through distillation. Whiles the crude oil is stored in a tank and ready for refinery, the recovered solvent is recycled into the extraction process. From recent research findings, it is recommended that alternative methods of extraction are in demand by the vegetable oil production industry. With the conventional solvent extraction method, the common organic solvents used include menthol, petroleum ether, dimethyl sulfoxide, acetone, ethanol, ethyl acetate, methanol and hexane (Braddock, 1999). Over the years, health concerns have been raised about the safety of these solvents used in oil extraction. More research works are conducted in the search for safer and more efficient extraction solvents and mechanisms. Supercritical carbon-dioxide (SC-CO_2) and liquefied dimethyl ether (DME) are receiving increased attention as the ideal extraction solvents due to their desirable physicochemical properties. Supercritical carbon-dioxide extraction has shown high selectivity and the

prospect of fractionating the components on the basis of pressure and temperature control (Sato, 1995). Dimethyl ether has also been updated as a synthetic fuel useful in both liquid and gaseous states (Fast *et al*., 2009; Lee *et al*., 2009 and Cho *et al*., 2009).

2.4.3.1 Method of solvent extraction of oil

Two storage tanks, for water and oil respectively are connected in series (Figure 2.10). Among the two storage tanks, one is for solvent containment and also an extraction column whereas the other is for containment and receipt of the solvent mixture. The collection container can vary in size depending on the expected volume of oil to be extracted. The pre-processed samples are fed into the extraction column and glass beads are packed at the upper and bottom ends of the column. The solvent in the first tank is controlled at a set temperature in the water bath to obtain a saturated vapour pressure. The solvent is cooled down to room temperature after it has been supplied to the extraction column. A long tube which joins tank 1 to the extraction column is used. The solvent is able to flow into the extraction column due to the pressure difference between tank 1 and the column. Afterwards, the solvent is allowed some minutes to evaporate by opening the pressure reducing valves in the extractor collector (tank 2).

All the oil extracts are collected in tank 2 (shown in Figure 2.10) (Hoshino, 2014).

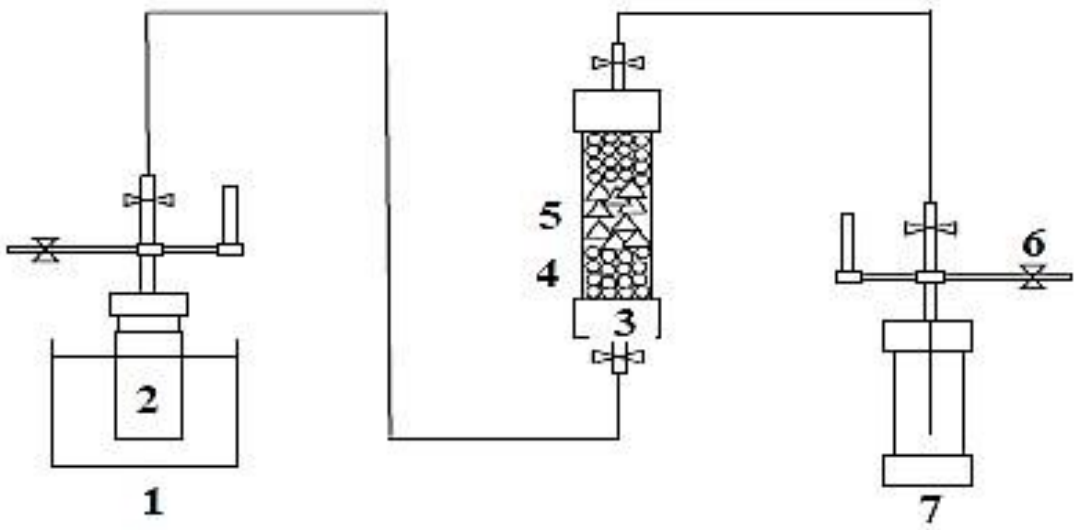

Figure 2.10: Solvent extraction apparatus. 1. Water bath 2. Solvent (tank A) 3. Extraction column 4. Glass beads 5. Test samples 6. Pressure reducing valves 7. Extract collector (tank B)

Source: (Hoshino, 2014).

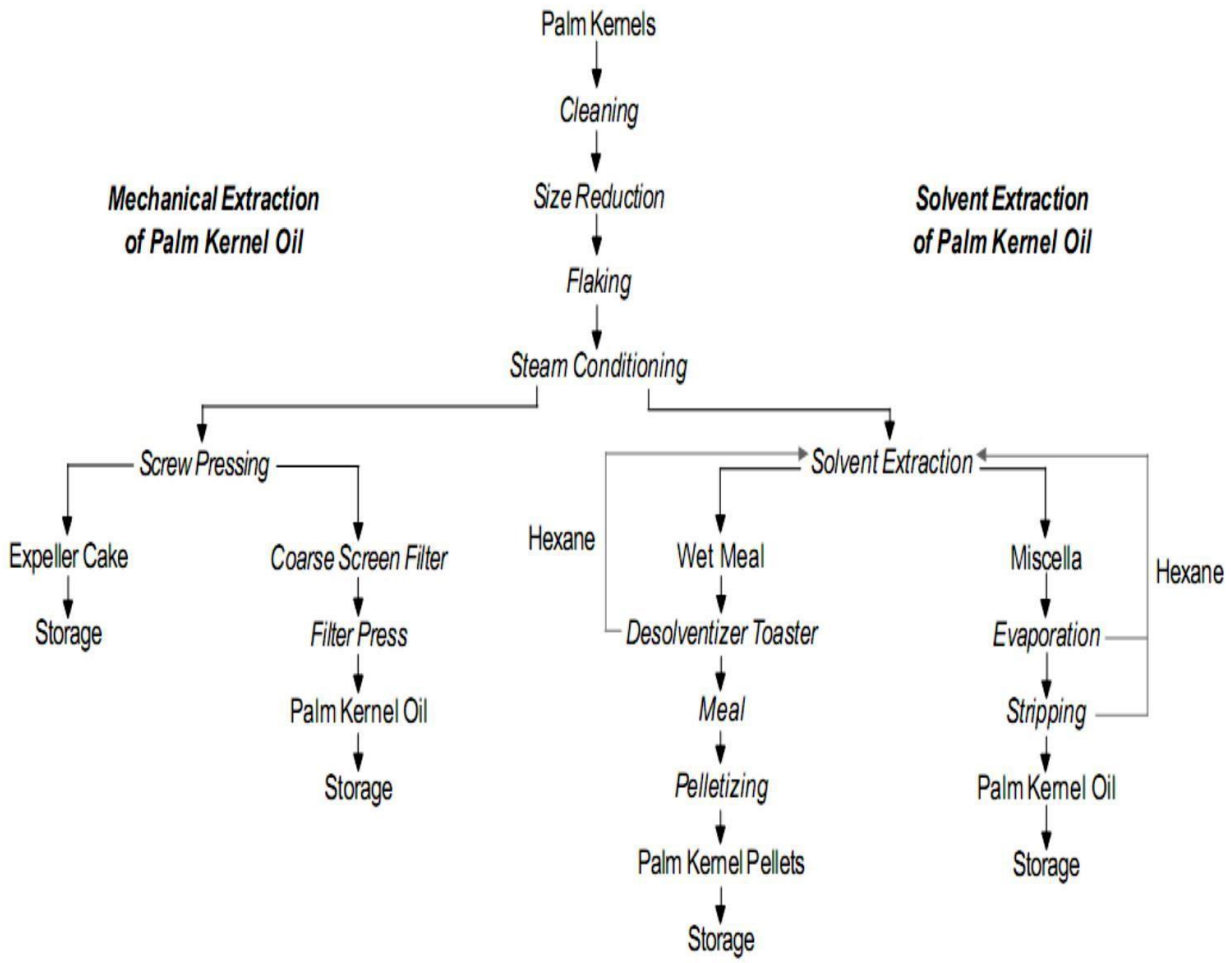

Figure 2.11: Mechanical and solvent extraction of kernel oil

Source: Hishamuddin (2002)

Table 2.1: Differences between the traditional and solvent method of oil extraction

	Traditional method	Solvent extraction
Weight of raw material	480.0 kg	480.0 kg
Percentage of oil recovery	42.0	47.2
Weight of Oil extracted	410.0 kg	472.0 kg
Weight of Burning loss	10.0 kg	Nil
Weight of Oil lost in doc	60.0 kg	8.0 kg

Source: Cheng (2011)

2.5 Characterization of *Borassus aethiopum Oil*

2.5.1 Phytochemical and antimicrobial properties

Work done by Duddukuri *et al*. (2011) indicated the antimicrobial activity of oil extracted from the soft seed coat of *Borassus flabellifer* Linn. Globally, studies on ethno-medicinal plants are been conducted for the discovery of new biochemical compounds and properties with potent antimicrobial activity. The effect of antibacterial potential was established against two Gram positive bacteria and two Gram-negative bacteria: *Staphyloccoccus aureus* and *Bacillus subtilis*, and *Escherichia coli* and *Klebsiella pneumoniae* respectively. A minimum inhibitory concentration was reported ranged between 3.12 to 6.25 mg/ml.

Work done by Alamelumangai *et al.* (2014) have also shown the phytochemical evaluation and antimicrobial activity of *Borassus flabellifer* against some human pathogenic microbes. The study indicated the presence of tannins, saponin, glycosides, flavonoids and terpenoids as the phytochemical extracts of the kernel.

The zone of inhibition using solvent extraction from methanol varied from 16 to 23 mm and that of ethanol varied from and 14 to 23 mm. The aqueous extracts differed from 10 to 15 mm at a concentration of 50 mg/ml. Among all the microbes that were tested, *Bacillus subtilis* and *Aspergillus brasiliensis* exhibited relatively higher rate of susceptibility to the extracts. The conclusion of the study was that the presence of phytochemicals may account for the antimicrobial activities against some bacteria and yeasts cells.

2.5.2 Nutritive Value of *Borassus aethiopum* Fruits

Studies conducted by Ali *et al*. (2010c) revealed that *B. aethiopum* fruits have sugar content greater than 0.22 g, 0.04 g of crude protein and a significant amount of ascorbic acid. Similar studies by Vijayakumari *et al*. (2014) also indicated 0.225 g of total sugars, 0.0124 g of proteins and 0.016 mg of ascorbic acid. *B. aethiopum* fruits have also been found to be a good source of fats and carbohydrates. Mineral analysis of the fruit showed composition of potassium, sodium, calcium, zinc, magnesium, and iron (Arunachalam *et al*., 2011). Table 2.2 below highlights the nutritional composition of the fruit sap.

Table 2.2 Nutritional composition of Palmyra sap

Nutrient	Quantity
Reduced sugar (g/100)	0.96
Nitrogen (g/100)	0.056
Phosphorus (g/100)	0.14
Vitamin B1 (IU)	3.9

Source: Davis and Johnson (1987).

2.5.3 Antioxidant properties

Antioxidant activity (in vitro) was assessed using different assays: 2, 2‟ azinobis (3-ethylbenzothiozoline- 6-sulfonic acid) disodium salt assay, 2, 2-diphenylpicryl-1-picrylhydrazyl (DPPH) radical scavenging, phospho-molybdenum reduction assay, ferric reducing antioxidant power (FRAP) assay, metal chelating activity and hydroxyl radical scavenging activity. The results pointed out that the seed embryo of the plant possesses macro, micro nutrients and antioxidant properties as well as nutraceuticals potential for malnutrition treatment. Antioxidants are involved in oxidation-reduction reactions in which one reaction species is reduced at the cost of the oxidation of another antioxidant. They are explained as reductants and inactivation of oxidants by reductants.

The benefits of antioxidants in human metabolism cannot be disregarded. They are much needed for scavenging and preventing reactive oxygen compounds from forming in the body. Reactive oxygen compounds formed in the body can prompt serious injuries to the body cells. The antioxidants scavenge these compounds to prevent their harmful reactions. Antioxidants are known to also repair some damages done to the body (Halliwell, 1996). The antioxidant potential of various seed embryo extracts were estimated from their ability to reduce TPTZ-Fe (III) complex to TPTZ- Fe (II) complex. The results were expressed as concentration of substance having ferric- TPTZ reducing ability corresponding to that of 1 mmol concentration of Fe (II). According to Arunachalam *et al*. (2011), "Methanol extract of seed embryo (863.8 mmol Fe (II)/mg extract) recorded relatively higher antioxidant activity among the various solvent extracts that were studied.

2.6 Preservation of extracted oils

The underlying principles of oil extract preservation include the damage or inhibition of enzymatic actions, the removal of water from the extracted oils, correct packaging and storage. Enzymes are complex biochemical substances which when present in a solution, cause fermentation and chemical changes to other substances without undergoing any change in itself. During the stage of sterilization when processing using heat, action of enzymes in raw food materials are generally stopped together with the influence of microbial contaminants. As much as possible, the removal of water is also needful in preventing microbial activity and proliferation. Oils with lower moisture content therefore have longer shelf life. The elimination of much water from the oils as well as proper packaging and storage conditions also prevent the onset of rancidity (Ahmad *et al*., 2014).

CHAPTER THREE

3.0 Methodology

3.1 Source of Sample and Sample Preparation

African fan palm (*Borassus aethiopum*) fruits were sampled from Congo 3, a village in the Sekyere Central District in the Ashanti Region of Ghana. The fruits were manually depulped to obtain the kernel. The kernels were manually cracked using a machete to obtain the seed kernel which was further chopped into smaller pieces for hot air oven drying (60°C, 72 h). The dried seed kernels were milled into smaller particles (≤ 425 microns) using the hammer mill.

3.2 Oil Extraction and Oil Yield Determination

A total of 600 g of the milled seed kernel was extracted in batches of 50g using the Soxhlet extraction method. Fifty grams (50g) of the milled seed kernel was weighed into a thimble and placed in the extraction chamber of the Soxhlet extractor. Petroleum ether (200ml) was poured into the flat bottomed flask, assembled with the extraction chamber and the condenser whiles heated on a heating mantle. The set up was allowed to run for 24 h after which the solvent was evaporated to obtain oil extracts. The oil extracts in all the 12 flat bottomed flasks from the 12 different set ups were rinsed twice with petroleum ether and then transferred in bits into a pre-weighed flat bottomed flask. The solvent was evaporated from the oil extract. The yield of oil was expressed as follows;

$$\% \text{ Oil Yield} = \frac{(\text{Wt of Oil+Flask}) - \text{Wt of Empty Flask}}{\text{Total Weight of Seed Kernel}} \times 100$$

3.3 Determination of Some Physicochemical Properties

3.3.1 Determination of Acid Value (AV) and Percentage Free Fatty Acid (FFA)

Approximately 0.5g of *B. aethiopum* kernel oil sample was weighed directly into a 250ml conical flask using the electronic analytical balance. Twenty-five millilitres of neutralised ethanol was mixed with the samples and carefully swirled to obtain a uniform mixture. Two (2) drops of 5% phenolphthalein solution was added. The obtained mixture was gently heated on a hot plate coupled with gentle swirling until the oil extract was completely dissolved. The mixture was cooled for 5 min and titrated against

0.1N KOH. The endpoint was noted as the first stable pinkish colour observed. The AV and %FFA were calculated as follows:

$$\text{AV (mg KOH/g)} = \frac{\text{ml of KOH X Normality of Base X 56}}{\text{Weight of Sample}}$$

$$\% \text{ FFA} = \text{Acid Value} \times 0.503$$

3.3.2 Determination of Peroxide Value

Approximately 0.5g of *B. aethiopum* kernel oil was weighed directly into a 250ml conical flask and was mixed with 30 millilitres of acetic acid-chloroform solution (1.5: 1). The flasks were covered with aluminium foil, swirled and warmed carefully on a hot plate until complete dissolution of the oil extract sample. Using a 1 millilitre pastuer pipette, 0.5 millilitres of saturated KI solution was added. The flasks were covered with aluminium foil and swirled for about 1 min. Immediately 30 millilitres of distilled H_2O

was added. The mixture was shaken vigorously to ensure the liberation of iodine from the chloroformic layer. The obtained mixture was titrated against 0.1N sodium

thiosulfate until the initial colour lightened. Then 1ml of starch indicator was added.

The titration was continued until the blue-black colour in the upper layer disappeared. The procedure was repeated (excluding the oil extract sample) for the blank. The PV of *Borassus aethiopum* kernel oil was expressed as follows;

$$\text{Peroxide Value (milliEq}O_2\text{/g)} = \frac{\text{(Vb-Vs) X Normality of Sodium Thiosulphate X 1000}}{\text{Weight of Sample}}$$

3.3.3 Determination of Saponification Value

About 0.5g of *B. aethiopum* kernel oil was weighed into a 250ml flat bottomed flask. Twenty-five millilitres (25ml) of alcoholic KOH (0.5N) was added. The mixture in the flask was assembled with a reflux condenser and heated on a heating mantle with occasional shaking for 30 mins. While the solution was still hot, 3 drops of 5% phenolphthalein solution (indicator) were added. The pink coloured solution obtained was then titrated against 0.5N HCl until it became colourless. The procedure was repeated but without the oil extract for the blank. Saponification value was calculated using the following formula;

$$\text{Saponification Value} = \frac{\text{56.1 (Vb-Vs) X Normality of HCL}}{\text{Weight of Sample}}$$

3.3.4 Determination of Iodine Value

About 0.5g of *B. aethiopum* kernel oil extract was weighed directly into a 250 millilitres conical flask and 10 millilitres of chloroform was added. Then 30 millilitres of Hanus

solution was added. The flask was completely covered with Para film and left 30 min with intermittent manual shaking. Ten millilitres of 15% potassium iodide solution was added and manually shaken to ensure uniform mixing. Hundred millilitres (100ml) of distilled water was added.

The mixture was titrated against 0.1N sodium thiosulfate solution until a yellowish colour was observed. Then 2 drops of starch indicator were added. The titration continued until the blue-black colour disappeared. The titre of thiosulfate used was noted. The blank titre was obtained by repeating the above procedure but without the oil extract sample. The iodine value of *B. aethiopum* kernel oil was expressed as follows;

$$\text{Iodine Value } (mgI_2/g) = \frac{(Vb-Vs) \times \text{Normality of Sodium Thiosulphate} \times 1.27 \times 100}{\text{Weight of Sample}}$$

3.3.5 Determination Ester Value and Glycerine

The ester and percentage glycerine were calculated using the following formulae;

Ester Value (mg KOH/g) = Saponification Value – Acid Value

% Glycerine = EVx0.054664

3.3.6 Determination of Fatty Acid Composition Using Gas Chromatogram

About 0.1g of *B. aethiopum* kernel oil sample was weighed into a falcon tube, 2ml of absolute hexane was added using a Pasteur pipette. The sample was vortexed for about 2 min to ensure uniform mixing. Two millilitres of 2M KOH was added to the resultant solution using a micropipette, the mixture was manually shaken vigorously for 5 min and allowed to separate. The obtained sample (methylated sample) was injected into the GC system (Shimadzu, Japan) with flame ionising detectors (FID) for the fatty acid methyl esters identification and quantification. The obtained peaks for the *B. aethiopum* oil sample were compared to standard peaks for identification.

CHAPTER FOUR

4.0 Results and Discussion

4.1 Oil Yield

As shown in Table 4.1, the oil yield for *B. aethiopum* fruit kernel was 1.56 ± 0.01 %. This value was recorded for the crude oil extract obtained. Hence a lower yield may be obtained after refining. This value indicates that extraction of oil from *B. aethiopum* kernel is not economically viable.

4.2 Physicochemical Properties of *Borassus aethiopum* Kernel Oil

Table 4.1 below indicates the physicochemical properties of crude *Borassus aethiopum* kernel oil. The iodine, saponification and ester values were similar to previous values reported for other vegetable oils. However, peroxide, free fatty acid and acid values were quite high. This could be attributed to the unrefined nature of the oil observed in the study by Mohdaly *et al*. (2017) where unrefined soybean and cotton seed oils recorded higher PV, AV and FFA contents than the refined oils.

Peroxide value (PV) is a measure of the level of deterioration of oils during storage or processing. Since it also the measures the susceptibility of oils to deteriorative oxidative rancidity reactions, PV could also indicate the quality and stability of oils (Ekwu and Nwagu, 2004; Mohdaly *et al*., 2017). High peroxide values therefore indicate poor resistance of the oil to rancidity reactions during processing and storage. The PV of *Borassus aethiopum* kernel oils was 49.85 ± 0.17 meqO_2/kg fat. The high peroxide value could be due to the unrefined nature as well as a high degree of unsaturation of *Borassus aethiopum* kernel oil and could be reduced by refining and hydrogenation

(Abdel-Gawad *et al*., 2015; Mohdaly *et al*., 2017).

Saponification value is a measure of the soap forming ability of oils. High saponification values indicate high soap forming ability and vice versa. The saponification value (SV)

of *B. aethiopum* oil was found to be 196.69 ± 0.51 mg KOH/g fat. This value was lower than 230-254 mg KOH/g fat and 248-265 mg KOH/g fat but similar to 190 - 209 mg KOH/g fat specified by Codex Alimentarius Commission (2009) for palm kernel oil, coconut oil and palm oil respectively. The crude *B. aethiopum* kernel oil however was higher than 172.99 mg KOH/g fat and 180.78 mg KOH/g fat reported for crude soybean and cottonseed oils respectively (Mohdaly *et al*., 2017). The high saponification of *B. aethiopum* kernel oil indicates its high soap forming ability hence its potential usefulness in soap making.

Table 4.1: Physicochemical properties and yield of crude *Borassus aethiopum* kernel oil

Parameter	Value
Peroxide Value (milliEqO_2/kg)	49.85 ± 0.17
Iodine Value (mg I_2/g)	167.00 ± 2.70
Acid Value (mg KOH/g)	24.30 ± 0.37
Saponification Value (mg KOH/g)	196.69 ± 0.51
Free Fatty Acid (%)	10.97 ± 0.17
Glycerine (%)	9.56 ± 0.05
Ester Value (mg KOH/g)	174.89 ± 0.84
Yield (%)	1.56 ± 0.01

Ester value is a measure of the amount of KOH required to saponify all the esters in 1g of oil. Ester value of *B. aethiopum* fruit kernel oil was 174.89 ± 0.84 mg KOH/g fat and

was very similar to the 174.67 ± 0.11 mg KOH/g fat and close to 171.18 ± 2.46 mg KOH/g fat reported for crude cottonseed and soybean oils respectively (Mohdaly *et al*., 2017).

The rate of rancidification in oil due to oxidative degradation also depends on the levels of free fatty acid (FFA) and acid value (AV) prior to the degradation reactions. The free fatty acid content of oil is directly proportional to its acid value hence the higher the acid value of a vegetable oil, the higher its percentage free fatty acid as deduced from Mohdaly *et al*. (2017). Free fatty acids act as pro-oxidants in oxidative degradation reactions leading to undesirable flavour in oils (Ghazani *et al*., 2013). Hence the high free fatty acid content (10.97%) and acid value (24.30 mg KOH/g) of *B. aethiopum* fruit kernel oil indicates its potential poor stability during storage. To reduce the FFA levels of *B. aethiopum* fruit kernel oil and improve its storability as well as quality for consumption, deodorization processes could be used (Onyema and Ibe, 2016).

Iodine value is a measure of the degree of unsaturation of fats and oils. Since oils with high levels of unsaturation are susceptible to oxidative rancidity (Mohdaly *et al*., 2017), iodine value could be used to predict the stability of oils. According to Perkin (1992), oxidative deterioration in fats and oils during storage causes a decrease in the iodine value of oils and an increase in the saturation of oils. Iodine value also allows for the qualitative determination of the overall unsaturation of lipids (Asuquo *et al*., 2012). The iodine value of *B. aethiopum* fruit kernel oil was 167.00 ± 2.70 mg I_2/g fat. This value was higher than the 67.00 ± 0.06 reported by Dari (2009) for soybean oil. The high iodine value of *B. aethiopum* indicated its susceptibility to oxidative damage especially during storage under undesirable conditions.

Table 4.2: Fatty acid methyl esters in crude *B. aethiopum* fruit kernel oil

Fatty acid methyl ester	Concentration (ppm)
6-methyl laurate	1.76± 0.00
7-methyl tridecanoate	0.000± 0.00
8-methyl myristate	0.048± 0.00
9-methyl pentadecanoate	0.001± 0.00

4.3 Fatty acid methyl ester composition of crude *B. aethiopum* fruit kernel oil.

As shown in Table 4.2, among the identified and quantified fatty acids, 6-methyl laurate was the most dominant with a concentration that reached 1.764 ppm. The fatty acid methyl ester that was detected at the least concentration was 7-methyl tridecanoate (0.000), with 9-methyl pentadecanoate giving the second least concentration (0.001).

The relatively high 6-methyl laurate content indicated *B. aethiopum* fruit kernel oil has antimicrobial properties. According to a study conducted by Ugbogu *et al*. (2006), where the inhibitory effects of different palm kernel oils were investigated, it was revealed that palm kernel oil with the highest lauric acid content showed the highest inhibition effects on *Staphylococcus aureus*, *Streptococcus sp*. and *Candida albicans*.

It has also been reported that high lauric acid containing oils promote growth of hair and provide skin protection against pathogenic infections (Kabara, 1990; Enig, 1998). The fatty acid composition of *B. aethiopum* fruit kernel oil indicated its potential in hair food formulations hence in the cosmetics industry as well.

CHAPTER FIVE

5.0 Conclusion and Recommendation

5.1 Conclusion

The oil yield of *B. aethiopum* fruit kernel was low (1.56%) and may not be suitable for commercial production. The oil also had high peroxide value, FFA and acid value. However, *B. aethiopum* fruit kernel oil had high saponification value suitable for soap production. The fatty acid profile also indicated *B. aethiopum* kernel oil contained relatively high levels of lauric acid hence could be used in the formulation of hair foods and development of antimicrobial agents.

5.2 Recommendation

Further studies should be carried out to investigate;

- The quality characteristics of refined *B. aethiopum* fruit kernel oil.
- The complete fatty acid composition of both crude and refined *B. aethiopum* fruit kernel oil.
- The antioxidant and antimicrobial properties of both crude and refined *B. aethiopum* kernel oil.

REFERENCES

Abdel-Gawad, I. A., Hamed, E. M., Zidan, M. A., Shain, A. A. (2015). Fatty Acid Composition and Quality Characteristic of Some Vegetable Oils Used in Making Commercial Imitation Cheese in Egypt. *J Nutr Food Sci*, 5: 380.

Abe-Inge**,** V., Agbenorhevi, J.K., Kpodo, F.M. and Adzinyo, O.A. (2018). Effect of different drying techniques on quality characteristics of African palmyra palm (*Borassus aethiopum*) fruit flour. *Food Research*, 2 (4): 331 – 339.

Addo Consultants (1989). A study of the oil palm industry in Ghana. Addo Consultants, Opeibea House, Accra.

Adzinyo, O. A., Kpodo, F. M., Asimah, V. K. and Asante-Dornyinah, D. (2015). Sensory and Physicochemical Characteristics of Naturally Flavoured *Borassus*

aethiopum Syrups for Food Applications. *Food Science and Quality Management*, 45: 109-113.

Agbo, N. Z. G. and Simard, R. (1992). Characteristics of juice from Palmyrah palm (*Borassus aethiopum*) fruit. *Plant Foods for Human Nutrition* (Formerly *Qualitas plantarum*), 42(1):55-70.

Ahmad, S., Alimon, A., Kasim, A., Mohd N., Mohd, H., Samsudin, A. A. (2014). Improving Nutritional Values of Palm Kernel Cake (PKC) as Poultry Feeds: A Review. *Malaysian Journal of Animal Science*. 17. 1-18.

Akinniyi, J.A., Waziri, M. and Usman, H.S., (2000). Study of the androgen contents of *Borassus aethiopum mart*. Unimaid research report. Pp.20-28.

Alamelumangai, M., Dhanalakshmi, J., Mathumitha, M., Saranya R. R., Muthukumaran, P., Nachimuthu, S. (2014). In vitro studies on phytochemical evaluation and antimicrobial activity of Borassus flabellifer Linn against some human pathogens. *Asian Pacific journal of tropical medicine*. 7S1. S182-5. 10.1016/S1995-7645(14)60228-5.

Ali, A., Alhadji, D., Tchiegang, C. and Saïdou, C. (2010). Physico-chemical properties of Palmyra palm (*Borassus aethiopum* Mart.) fruits from Northern Cameroon. *African Journal of Food Science*, 4(3): 115-119.

Ali, A., Djibrilla, A., Clergé, T. and Clément, S., (2010). Physico-chemical properties of palmyra palm (*Borassusaethiopummart.*) fruits from Northern Cameroon. *African Journal of Foods Science*, 4(3):115-119.

Ali, A., Fadimatou, B., Tchiegang, C., Saidou, C., and Mohamadou B, A. (2010c). Drying the African Palm tree (*Borassus aethiopum*) fruits in view of producing edible flour. *Journal of food technology*, 8(5): 211-216.

Anaekwe, E. N. (2011) Business Development Consultant http://farriconsultingng.blogspot.com/2010/04/buying-and-selling-of-palm-kernel-nuts.html. Accessed 21/10/2018.

Ariyasena, D. D. (2001). The Diversity, Bioactivity and structural studies on the flabelliferins of palmyrah (*Borassus flabellifer* L.) fruit pulp. M.Phil. Thesis, University of Sri Jayewardenepura, Sri Lanka. pp. 12-26.

Arthur, C. (2018). Evaluation of the Mineral Composition, Antioxidant Properties, Phytochemical and Anti-nutrient Composition of African Palmyra Palm (*Borassus aethiopum*) Fruit Flour. MSc. Thesis (Published), Kwame Nkrumah University of Science and Technology, Ghana.

Arulraj, S., Augustine, B. J. (2008). Underutilized palms. In: Peter KV (ed) Underutilized and underexploited horticultural crops, Vol. 3. New India Publishing Agency, New Delhi, pp. 415–429.

Arunachalam K., Saravanan S, and Parimelazhagan T. (2011). Nutritional Analysis and Antioxidant Activity of Palmyrah (Borassus flabellifer L.) Seed Embryo for Potential Use as Food Source. *Food Sci. Biotechnol*. 20(1): 143-149 DOI 10.1007/s10068-011-0020-y

Assoi, S., Konan, K., Walker, L.T., Holser, R., Agbo, G.N., Dodo, H., Wicker, L. (2014). Functionality and yield of pectin extracted from Palmyra palm (*Borassus aethiopum* Mart) fruit. *LWT -Food Science and Technology*.

Asuquo, J. E., Anusiem, A.C.I., Etim, E. E. (2012). Extraction and characterization of rubber seed oil. *Int. J. Mod. Chem.*, 1 (3): 109–115.

Ataga, D. O., Ilechie, C. O., and Omoti, U. (1993). Small-scale Palm Oil Processing Technology in Nigeria. Paper presented to BUROTROP-AFOPDA Seminar on Small and Medium Scale Palm and Coconut Technologies, Accra, Ghana.

Bachmann, J. (2005). Oilseed Processing for Small-Scale Producers. National Sustainable Agriculture Information Service. http://attra.ncat.org/attrapub/oilseed.html

Barminas, J.T., Onen, A.I., Williams, E.T., Zaruwa, M.Z., Mamuru, S.A., & Haggai, D. (2008). Studies on functional properties of starch from fresh germinating nuts of giginya (*Borassus aethiopum*) palm. *Food Hydrocolloids*, 22: 298–304.

Bayton, R. P. (2007). A revision of *Borassus* L. (*Arecaceae*). *Kew Bulletin*. 62: 561– 586.

Beddington, J. (2010). Global food demand and the sustainable intensification of agriculture. *Phil. Trans. R. Soc. B.*, 61-71.

Braddock R., J. (1999) Handbook of citrus by-products and processing technology. Willy Inter Science, New York.

Bredeson, D. K. (1983). Mechanical Oil Extraction. Journal of the American Oil Chemists' Society. 60; (2): 211-213.

Butcher, D. (2005). Pedal Powered Generator. David Butcher's Personal Page. http://www.losgatos.ca.us/davidbu/pedgen.html

Cheng, H. T. (2011). The Palm Oil Industry in Malaysia; from seed to frying pan. Prepared for WWF Switzerland by TEOH Cheng Hai, Hon. Advisor, Plantation Agriculture, WWF.

Cho, W., Song, T., Mitsos, A., McKinnon, J. T., Ko G. H. (2009). Optimal design and operation of a natural gas tri-reforming reactor for DME synthesis. *Catal Today*, 139: 261-267.

Codex Alimentarius Commission. (2009). Codex standard for named vegetable oils – "Codex Stan 210-1999" Food and Agricultural Organization of the United Nations and the World Health Organization.

Cornelius, J.A. (1983). Processing of oil palm fruit and its products. *Tropical Product Institute.* G. 149

Dari, L. (2009). Effect of Different Solvents on the Extraction of Soya Bean Oil. MSc. Thesis (Published), Kwame Nkrumah University of Science and Technology, Ghana. pg.44

Das, B. C. and Das, S. N. (2003). Cultivation of minor fruits. India: Kalyani Publishers; 2003.

David, J., and Vincent, L. (1980). Extraction of Vegetable oils and fats. In: *"Fats and Oils: Chemistry and Technology"* (R.J. Hamilton and A. Bhati, eds.), Applied Science Publishers, pp. 123–134.

Davis, T. A. and Johnson, D.V. (1987). Current utilization and further development of the palmyra palm (*Borassus flabellifer* L., Arecaceae) in Tamil Nadu State, India. *Economic Botany* 41(2):247-266

Duddukuri, G. R., Sastry, N. Y., Kaladhar, D., Rao K. K., Chaitanya, K., (2011). In vitro Antibacterial activity of Organic Solvent seed coat extracts of *Borassus flabellifer Biosciences, Biotechnology Research Asia*.

Ekwu, F.C., Nwagu, A., 2004. Effect of processing on the quality of cashew nut oils. *J. Sci. Agric. Food Tech. Environ,* 4:105–110.

Enig, M. G. (1998). Lauric oils as antimicrobial agents. In nutrients and foods in AIDS (Waston, R. ed.) CRC Press London 81 – 97.

Fast, G., Kuhn, D., Class, A. G., Maas, U. (2009). Auto-ignition during in stationary jet evolution of dimethyl ether (DME) in a high-pressure atmosphere. Combust Flame 156: 200-213.

Ghazani, S. M., Garcia-Llatas, G. and Marangoni, A. G. (2013). Minor constituents in canola oil processed by traditional and minimal refining methods. *J. American Oil Chemists' Society*, 90: 743-756.

Gbasouzor, A. I, Okeke, A. C, Chima, L. O. (2012). A Plant Design for Mechanical Extraction of Nmanu Aki (Palm Kernel Oil) Using Complete Pre-treatment Process: *Proceedings of the World Congress on Engineering and Computer Science* 2012 Vol II.WCECS 2012, October 24-26, 2012, San Francisco, USA.

Halliwell, B. (1996). Antioxidants in human health and disease. *Annual Review Nutrition*, 16, 33-50. https://doi.org/10.1146/annurev.nu.16.070196.000341

Harris, R. (1995). A Survey of Palm Oil and Palm Kernel Extraction Equipment manufactured in Europe, Central and West Africa and Latin America. Final Technical Report on FAO Project GCP/INT/588/CFC.

Hartley, C. W. S. (1988). The Oil Palm. Third edition. John Wiley & Sons Inc., New York. p. 19-21.

Hishamuddin, M. A. (2002). Malaysian palm kernel cake as animal feed. Malaysian Palm Oil Board. Palm Oil Developments. http://bepi.mpob.gov.my/images/area/2013/Area_summary.pdf

Hoshino, R. W., Machmudah, S., Kanda, H., Goto, M. (2014). Simultaneous Extraction of Water and Essential Oils from Citrus Leaves and Peels Using Liquefied Dimethyl Ether. *J Nutr Food Sci* 4:301. doi: 10.4172/2155-9600.1000301. http://www.etawau.com/OilPalm/Elaeisguineens.htm

Irvine, F.R (1970). West African Agriculture- London Oxford University Press, 3rd Ed.

Jan, E. R., Nikawala, J. K., Goonaratne, J. and Theivendirarajah, K. (1994). Studies on the bitter principle and debittering of palmyrah fruit pulp. *Journal of Science of Food and Agriculture*; 65:185-189.

Kabara, J. J. (1990). Lauric oils and health benefits in Pharmacological effects of lipids (3) (Kabara J.J. ed.) *AOCS Press London*, 120 – 130.

Kouame, D. (1992). Le palmier rônier (*Borassus aethiopum* Mart.) Etude de la microflore de la pulpe et de la fermentation alcoolique du jus de fruit de rônier. Thèse Université de Cocody, FAST.

Lam, K. C., Nickerson, G. B., Deinzer, Max, L. (1986). A rapid solvent extraction method for hop essential oils. *Journal of Agriculture and food chemistry*, 34 (1): 63-66.

Lee, M. C, Seo, S. B, Chung, J. H, Joo, Y. J, Ahn, D. H. (2009). Industrial gas turbine combustion performance test of DME to use as an alternative fuel for power generation. 88: 657-662.

Malumba, P., Sébastien, J., Claude, D., Thaddée, M., (2011). Structure de l‟amidon de maïs et principaux phénomènes impliqués dans sa modification thermique. *Biotechnol. Agron. Soc. Environ.*, 15(2).1-12.

Mohdaly, A. A., Seliem, K. A., Maher, A., El-Hassan, A. and Mahmoud, A. A. T. (2017). Effect of Refining Process on the Quality Characteristics of Soybean and Cotton seed Oils. *International Journal of Current Microbiology and Applied Sciences*, 6 (1): 207-222.

Mollet, M., (1999) L‟utilisation durable des palmiers *Borassus aethiopum*, *Elaeis guineensis* et *Raphia hookeri* pour l‟extraction de vin de palme en Côte d‟Ivoire. Eschborn 1999. N° de la série du TÖB FTWF-12f. Deutsche Gasellschaftfür tecnische zusammenarbeit (GTZ) GMbHPostfach 5180, D-65726 Eschborn. République Fédérale „Allemagne. 69p.

Niamké, A. M., Saki S. J., Sea T. B., Pierre E., Olivier, K. C., Georges N. A., Djaman, J. A. (2013). Physicochemical Characterization, Enzymatic and Rheology of the Flour of Young Shoots of Palmyra (*Borassus aethiopum* Mart.). *Asian Journal of Science and Technology*, 4(10): 036-047.

Onyema, C. and Ibe, K. (2016). Effects of Refining Processes on the Physicochemical Properties of Some Selected Vegetable Oils. *American Chemical Sci. J.*, 12(4): 1-7.

Oyinlala A, Ojo A, Adekoya LO. (2004). Development of a laboratory model screw press for peanut oil expression. *Journal of Food Engineering*, 64(2): 217-227.

Perkin, E.G. (1992). Effect of lipid oxidation on oil and food quality in deep frying. In: Angels, A.J.S. (Ed.), Lipid Oxidation in Food, Chapter 18, ACS Symposium Series no. 500 ACS, *American Chemical Society*, Washington DC, pp. 310–321.

Poku, K. (1998). Oil Palm Smallholder Development: Processing Technology Mission Report presented on FAO Project TCP/MLW/6612

Poku, K. (2002), Small-scale palm oil processing in Africa, Food and Agriculture Organisation of the UN, Rome.

Sandhya, S., Sudhakar, K., David Banji, Vinod, K. R., Aradhana,R. (2010).

Pharmacognostic characterization of *Borassus flabellifer* leaf. *J Advanced Pharmac Res*, 1(2):88–96.

Sato, M., Goto, M., Hirose, T. (1995). Fractional extraction with supercritical carbon dioxide for the removal of terpenes from citrus oil. *Ind Eng Chem Res*, 34: 3941-3946.

Shaver, M. (2005). Bicycle Powered Generator. Matt Shaver's Home Page. http://users.erols.com/mshaver/bikegen.html

Siaw**,** D. E. K. A., Asamoah, E. F. and Baidoe, G. A. (2014).The stock and socio-economic uses of *Borassus aethiopum* in Abrimasu Forest Reserve of Mampong Forest District. *JENRM*, 1(3):148-155.

Tang, S. T. and Teoh, P. K. (1995). Palm Kernel Oil Extraction – The Malaysian Experience. Paper presented to the World Conference on Processing of Palm, Palm Kernel, and Coconut Oils, Kuala Lumpur, *Malaysia Journal of the American Oil Chemists' Society*, 62(2): 255-255.

Ugbogu, O.C., Onyeagba, R. A., Chigbu, O. A. (2006). Lauric acid content and inhibitory effect of palm kernel oil on two bacterial isolates and *Candida albicans*. *African Journal of Biotechnology*, 5 (11): 1045-1047.

United Nations Development Fund for Women (UNIFEM). (1987). Food Cycle Technology Source Books. Oil Extraction. UNIFEM N.Y. USA.

Vijayakumari, Vengaiah P. C. and Kiranmayi P. (2014). Physiochemical and functional characteristics of powder prepared from palmyra fruit pulp. *International Journal of Current Microbiology and Applied Science*, 3(9):352-356.

Waziri, M., Akinniyi, J. A., Salako, A. A. (2010). Toxicity of Acetone Extract of *Muruchi*, the shoot of *Borassus aethiopum* mart. *European Journal of Scientific Research*, 41(1): 6 -12.