EFFECTS OF PROCESSING METHODS ON THE QUALITY OF PALM OIL IN GHANA

BY

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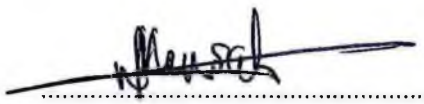
DECLARATION

This thesis is my own work produced from research undertaken under the supervision of Professor George S. Ayernor.



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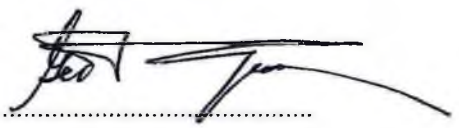

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PROFESSOR G. S. AYERNOR

(SUPERVISOR)

DEDICATION

This work is dedicated to my father Mr. I. Y. Mensah, my mother Mrs. Mary Mensah and all my brothers and sisters.

ABSTRACT

Palm oil samples from GOPDC, TOPP and two traditional methods (*Kyembe* and *Bedo*) were analysed using the following quality indices: moisture content, refractive index, percentage FFA, peroxide value and TBA value. They were examined with regards to the determination of the effect of industrial processing methods on the quality of palm oil; the effect of traditional processing methods on the quality of palm oil; the relative efficacy of the processes in the production of good quality crude palm oil.

Processing altered significantly better the physical indices of quality (moisture content, refractive index) in all the processes (GOPDC, TOPP, Kyembe and Bedo). There was no significant alterations in the chemical indices of quality in all the processes except in FFA for TOPP, which produced significant differences in the percent FFA, which ranged from 2.34 percent to 2.66 percent.

Using their final stages of processing (storage tank stage for industrial processes; and "frying" stage for *Kyembe* and boiling stage for *Bedo*) the industrial methods produced significantly better quality palm oil than the traditional methods with regards to moisture content (industrial processes 2.40 percent; traditional processes, 5.32 percent P.O.V. (industrial processes 2.94m Eq/Kg, traditional processes, 3.05m Eq/Kg) TBA values (industrial processes, 0.14; traditional processes 0.16).

It was recommended that traditional processors be informed as to the effect of certain practices they engage in on the quality of their oil; traditional methods of processing palm oil in the palm oil producing zones be researched into; and the refined, bleached and deodorised method be included in a future study to bring the whole study to its logical conclusion.

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CHAPTER ONE

1.0 INTRODUCTION

There is no gain saying that palm oil as a vegetable oil which now ranks second to soybean as far as total world production is concerned, cannot be easily replaced; since, fats and oils are the most essential nutrient of both human and animal diets. Fats provide the most concentrated energy (9 k cal/g) of any foodstuff, supply essential fatty acids, serve as carriers for fat-soluble vitamins, make foods more palatable and contribute towards feelings of satiety after eating (Shukla, 1994)

The versatility of palm oil has been enhanced ever since the discovery of hydrogenation at the beginning of the century (Norman, 1903). New methods of processing are being brought to bear on the processing of palm oil. Current techniques include biomodification (use of lipase for modifying palm oil and its fractions by interesterification), bioconversion (the use of enzymes and microbial cells in manufacturing useful products), and molecular distillation.

Choosing one method of processing is by no means a simple one; it should be an informed decision, with a full recognition of all the factors at stake. Refined, bleached and deodorized oil is stripped of carotenoids, a vital nutrients in a tropical country like Ghana, but that is a recommended process by other standards. Should we accept that as it is? Or, palm oil is a vital source of vitamin, so the stripping of the carotenoids should not be of primary importance as far as quality is concerned?

The characteristics of a finished product, in most cases, depends on the processing techniques applied; these processes are also subject to technical and cost limitations. Also, product specifications and standards are usually a

compromise between the requirements of the market and the issues raised above.

Traditional processing is also now undergoing changes; mechanisation being superimposed on this area of processing; the implications and ramifications are by no means simple.

Furthermore, there is an aggressive search for improved and alternative sources of fats and oils. Nuts and tropical fruits are aggressively being researched as alternative sources of edible oils, and research is going on with the view of obtaining oils from tropical fruits and vegetable (Woodrof, 1994; Kamel and Kakuda 1994). Also engaging the interest of research scientists is the task of obtaining oils from forest products. Still yet, scientists are exploring the use of unconventional sources such yeast, moulds and bacteria (Ratledge, 1994) for alternatives. Other oils which may compete with palm oils are those from okra, six varieties of which were shown to have seeds containing 22 percent oil above average. The separated kennels contained 41 – 56 percent protein and a similar amount of oil (Telek and Martin, 1981). This is indeed very promising, since the separated glyceride structure was found to be similar to cottonseed oil (Crossley *et al.,* 1951).

There is also a search for new oil seed crops with more advantageous oil composition which has lead to the development of commerically acceptable crops, among whom are *Limanthes, Sapium.* Also linoleic acid content of manioc *Manihot utilisma,* from Nigeria contains 70 percent linoleic acid (Shukla, 1992).

Any of these research findings could cause ripples in the oils and fats industry which could render thousands of workers who depend on the oils and fats for a living, jobless. Thus, research in this area should not be layed to rest since the outlook is rapidly changing

Nutritional concerns also add to the complexity of the scenario; it is among

the areas that drive research in the palm oil industry. Saturated fatty acids, for example, are suspected of increasing the risk of cardiovascular diseases. Other substances associated with palm oil such as phospholipids are essential in that they help as structural components of cellular membranes. Omega–6–polyunsaturated fats, stimulate the growth of tumors of breast to a significantly greater extent than diets in either saturated, mono-unsaturated or Omega–3–polyunsaturated fatty acids (Carroll and Khor, 1971; Cohen, 1987). The products of oxidized fats and oils, palm oil inclusive, have been implicated in various steps of the atherosclerotic process (Duthie, 1989). Also storage and usage of palm oil may introduce undesirable or harmful materials.

Quality is also a rapidly changing phenomenon (Synder, 1994). Issues bordering on the quality of palm oil should engage the attention of food scientists in Ghana so that palm oil produced in Ghana is not classified as sub-standard. This will certainly have very wide implications and ramifications since the products which have palm oil as constituents are many and various. There is currently an ongoing debate in the U.S.A, to the effect, that products of trans-fatty acids should be clearly labelled to distinguish between trans-free fatty acids and trans-fatty acids. The effect of trans-fatty acids on humans is well documented; to a large extent it does not have a positive effect (Santhiapillai, 1995; Kalyana, 1993; Troisi *et. al., 1992*). This labelling may sway the market in favour of palm oil products, which can simulate margarine minus its negative effect trans-fatty acids. We as a nation, should stand at the frontiers of research, willing and able to make use of the wide market this will open. This we can, however, only do if our products are up to scratch, as far as meeting international standards is concerned.

The major fats and oils used in Ghana are palm oil, palm kernel oil, coconut

oil, shea butter, groundnut oil, cocoa butter, sunflower oil and cottonseed oil. Of all the fats and oils produced in Ghana, palm oil is a very important one. This is because of the role it plays in the diet of Ghanaians and also because of the sheer volume of it produced annually. Ministry of Food and Agriculture (MOFA, undated) reports that in the 1994/95 season, 600,000 metric tonnes of Fresh Free Bunch (FFB) of palm fruits were produced by large-scale production centres alone, 400,000 of which went into palm oil production. As compared to 300,000 metric tonnes of cocoa, 109,000 metric tonnes of copra, about seven and a half-metric tonnes of sheanut; all of which are oil-bearing crops.

It was estimated by the Ministry of Food and Agriculture of Ghana (MOFA, undated) that 100,000 metric tonnes of palm oil is produced annually and 20,000 metric tonnes of refined, bleached and deodorized palm oil is imported to Ghana annually. The palm oil industry in Ghana is by no means a dispensable one in the gamut of fats and oils industry in Ghana.

Barnes (1924), however, stated:

> native methods of palm oil manufacture as practised in West Africa are such as would be expected to yield a low grade product of more or less as high acid content, unpleasant flavour due to the development of rancidity, and poor appearance caused by the presence of water and foreign matter. These native processes can undoubtedly be modified and improved to lead to the production of purer oil; but they are primitive and wasteful for in the best of them 40 percent or more of the oil in the pulp is irretrievably lost.

This statement is true to a certain extent and 75 years after this statement was made (when we are left with a few months to the next millenium) other writers have made similar statements. Kordylas (1990) has expressed the view that traditional processing of palm oil in West Africa has an efficiency of only 40 percent not- withstanding the fact that the potential for palm oil production in

this region is enormous; it is, therefore, important that the techniques employed are carefully studied and improvements made.

Chandrasekharan and Kalyana (1998), also agrees with the fact that the market for palm oil is very large. He estimates that palm oil makes up 17 percent of the total world oil production of 95million tonnes, but, in terms of its share of the world's traded oils and fats, it has captured nearly 36 percent.

The issues raised above coupled with the fact that there is a growing demand for palm oil of good quality makes the study of traditional processing of palm oil side by side the industrial processing of palm oil in Ghana of the utmost importance.

Basically, there are two methods of processing palm oil, the traditional and the industrial. Within these two major methods, there are widespread variations. They all apply physical means in processing to obtain crude oil. Chemicals are used if they have to go through the refining, bleaching and deodorizing (RBD) stages. Weiss (1983) has detailed the various stages of processing fats and oils, which generally applies to palm oil as well. These processes may alter significantly the quality of the palm oil; each may be determined by the quality indices which are basically chemical or physical in nature. For example RBD reduces the level of carotenes in palm oil. The study will, therefore, be of immense help to the country as a whole and the palm oil industry in particular.

1.1 Objectives of the Study

The main objective of the study is to determine the effects of processing methods in Ghana on the quality of palm oil to form the basis of Quality Control in the palm oil processing industry.

The specific objectives are:

a) To determine the effects of industrial processing methods on the quality of palm oil.

b) To determine the effects of traditional processing methods on the quality of palm oil

c) To determine the relative efficacy of the processes in the production of good quality crude palm oil.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 PALM OIL – AN IMPORTANT VEGETABLE OIL

Oil palm (*Elaeis guineensis*) is the crop with the highest oil yield per unit area planted (Jalani and Cheah 1997). Therefore earning hard currency from palm oil is a workable possibility for Ghana, since the environmental conditions for the cultivation of the oil palm tree favours Ghana (Hartley, 1984). Palm oil and palm kernel oils have become growth leaders in the whole field of oils and fats since the 1970s. Their growth was associated with unparalleled profitability and by attractive prices. The total world consumption of these oils reached 15.3 percent of all oils and fats used in the 1990s, and it is expected to reach 19.8 percent by the year 2000. The production of palm oil in the world for 1992 was 12.02 million tonnes (Malaysia produced 53.2 percent and Indonesia 11 percent), making them the two largest world producers (Ong *et al.*, 1995). This figure rose to 17.46 million in 1997 (Chow Chee Sing, 1999). Palm oil has had the largest market share of growth registered in the past decade in the oils and fats world. It has been projected that palm oil and palm kernel oil will surpass soyabean oil and will have the greatest share of oils and fats consumption (Shukla, 1994).

It is therefore a credible competitor against other major oils produced in the world as listed in table 2.1. It's competitiveness can be looked at in terms of it's techno-economic advantages. The economic advantages are supply, reliability, productivity, cost of production and price competitiveness (*Ramli, et.a;*1997). Its supply reliability is because it is a perennial crop; comparatively perennial

crops have more stable supply because they are less susceptible to uncertain weather conditions, demand, supply and price of other substitutes. Annuals lack all these thus planting intentions of annual crops can be altered very fast, and long term forecast for annual crops is not very reliable.

In terms of productivity oil palm is the most efficient producer of oil among the oil crops. Oil palm is capable of producing 3,200kg of palm oil and 456.6kg of palm oil products per year from a hectare of land. Compared to soyabean it is ten times more productive, since only 367.9kg per year of soyabean oil can be obtained from a hectare of soyabean crop. The next productive oil apart from palm oil is rapeseed oil which is capable of producing 601.80kg per hectare per year (*Ramli et al.*, 1997)

Comparative cost studies on production costs of oil crops indicate that oil palm has significant cost advantages over alternative oil seeds grown in temperate countries. Cost of production of Malaysian palm oil is $240 per tonne and in Indonesia $185 per tonne. On the other hand Canadian Soyabean oil cost $648 per tonne and EEC rapeseed oil $900 per tonne to produce.

Continuously increasing trade availability coupled with its much lower cost of production have made the prices of high quality palm oil from Malaysia to be very competitive on the world market.

It's technical advantages can be looked at in terms of its flexibility to be used as it is or in fractionated forms to produce a wide range of products either for edible or inedible purposes. Some of it's advantages include a good oxidative stability, low polyunsaturated fatty acid levels, it's low slip meeting point and so it avoids excessive waxiness in most applications. The prediction that it will surpass soyabean oil and have the greatest share of oils and fats consumption

(Shukla, 1994) is a very real possibility in view of the above facts. Taking cognisance of the fact that palm oil can only thrive in tropical areas, it offers a very promising opportunity for Ghana. In actual fact while the export of palm oil from Malaysia started a few decades ago, shipment of palm oil to Europe from Africa was first mentioned in 1588 (Coursey and Macfarlane, 1984). There is fossilized, historical and linguistic evidence for an African origin of the oil palm (Hartley, 1984). Crude palm oil has been consumed as food in Africa for some 5000 years (Mohamed Razar, 1998)

Table 2.1

World consumption of vegetables fats and oils

Oils	Percentage(%)
Fish oil	2
Palm oil	21
Sunflower	12
Coconut oil	4
Soybean oil	29
Peanut oil	6
Palm kernel	3
Rapeseed	15
Cotton seed	6
Olive oil	3

Source: Eittenmiller, 1997

2.2 HEALTH AND NUTRITIONAL ASPECT OF PALM OIL

For centuries it has served as food for man. The major components of palm oil are palmitic, oleic and linoleic acids. They are the commonest fatty acids in the Plant Kingdom. A campaign was, however, initiated in the USA by domestic vegetable oil producers not in the context of any specific scientific evidence but in order to damage the marketability of a competitive product (Berger, 1994). This thus has given palm oil an image of a saturated fat which contains cholesterol. These have all been shown to be false. In a study of serum lipids level of Nigerians who, it was estimated, had 85 percent of their fats and oils supply from palm oil, no significant negative effects were found (Kalyana and Yusof, 1995; Kesteloot, *et. al.,* 1989). It did not result in any difference in the level of LDL cholesterol and VLDL cholesterol when compared to highly unsaturated peanut oil and sunflower oil. The HDL to LDL ratio was highest in the palm oil-fed volunteers compared with the rest of the group. Thus palm oil may have a hypocholesterolemic rather than hypercholesterolemic effect (Baudet *et al.*, 1987) To Chandrasekharan and Kalyana (1995), palm oil should prove to be the healthy alternative in mankind's continuing dependence on dietary oils and fats.

Nevertheless, palm oil is facing a very crucial period of its history as the American Soyabean Association (ASA) in a citizen petition to the Commissioner of the United States Food and Drug Administration (FDA), dated 23 January, 1987, made the request to the effect that it be generally classified as a vegetable oil and that food products containing such oils are required to disclose: "contain palm (or palm kernel or coconut) oil, a saturated fat" (Erickson and Keast,

1987). This fact added to the fact that 90 percent of palm oil is used in food application, makes its nutritional value relevant and significant.

Palm oil has been classified as a saturated fat, though disputed by many, and it is the conception in certain quarters that it is hypercholesterolemic and thus poses a risk to human health. Palm oil is not a fully saturated oil, however; it contains equal amounts of saturated fatty acids and unsaturated fatty acids and should best be described as partially saturated. RBD palm olein, in fact contains more unsaturated fatty acids than the saturated. Even so, the principal saturated fatty acid, the C16 palmitic acid in palm oil which constitutes 44 percent and palm olein which constitutes 40 percent, is recorded as less hypercholesterolemic than saturated fatty acids in the range C6 to C14 of which palm oil has only trace amounts (Horlick and Craig, 1957; Hegsted *et al.*, 1965). It also contains oleic acid, a monosaturated fatty acid that is found in moderate abundance in palm oil, and has been of late, reported to be just as effective as the unsaturated fatty acids in lowering blood cholesterol (Mattsen and Grundy, 1995).

Further to the above, Hornstra (1987), found in five separate studies that human subjects eating their habitual western diets experienced significant reductions ranging from 7 percent to 38 percent in blood cholesterol levels when they were put on a palm oil-rich diet.

Palm oil also contains safe amounts of linoleic acid, which when present above a certain level is considered unsafe. It contains a useful 10-13 percent of linoleic acid, an essential fatty acid (EFA) which is found in lesser amounts in

many other edible oils. Linoleic acid, when fed in large amounts in the diet, appears to promote carcinogenesis, suppress immuno-response, increase risk of gallstones, alter the composition of cell membranes.

Palm oil does not promote atherosclerosis (Nutr. Revs. 1987). Palm oil feeding improves coronary blood flow and has no effect on blood pressure (Hornstra, 1987; Anon, 1987). Palm oil also contains Vitamin E, which acts as nutritional antioxidants and helps to reduce cellular damage due to free radicals arising from the body's hernal oxidative energy metabolism or from the action of toxic chemicals and pollutants in our environment. Free radicals have been implicated in ageing, chronic degenerative diseases and cancer(Ciba Foundation Symposium, 1983).

Tocopherols have been found to impart the following effects: protection against chemically-induced buccal pouch tumours both by systematic administration and topical application (Shklar, 1982), increase in peripheral blood flow (Machlin, 1980), prevention of platelet aggregation (Machlin, 1980).

Tocotrienols have also been found to impart the following beneficial effects: increase in life-span of mice inoculated with transplantable tumour (Kato *et al.*, 1985); reduction of serum cholesterol and LDL cholesterol in broilers (Qureshi *et al.*, 1986), prevention of platelet aggregation (Holub and Thomas, 1994).

Palm oil contains high amounts of Beta-carotene, which has been found to have beneficial properties. Unrefined palm oil is the richest known natural source of the pro-vitamin A pigment, beta-carotene. Though processing removes all the beta-carotene, crude palm oil is eaten in West Africa and some South East Asian countries. Studies have shown that inadequate intakes of carotenoid-

containing vegetables were associated with the risk of lung cancer (Wolf, 1982). Though the required daily average of Vitamin A is one milligram, it was estimated in 1995 that three million children exhibit xerophthalmia, that is, they are clinically Vitamin A-deficient and are at risk of blindness. An additional 250 million children are estimated to be subclinically Vitamin A deficient and are at risk of severe morbities and premature death (Howson *et al.,* 1998). The potential of palm oil, therefore, should be harnessed as a cost-effective way of reducing morbidity and mortality amongst children in developing countries including Ghana (Chandrasekharan and Kalyana, 1997). It is all the more so, since Choo (1995), has expressed the view that of the vegetable oils that are widely consumed, palm oil contains the highest known concentration of agriculturally-derived carotenoids.

Palm oil does not contain trans-fatty acids isomers as in hydrogenated fats. Highly unsaturated oils such as in many seeds and in fish oils, are unsuitable for many food uses because they have very low melting points and also because they are more susceptible to oxidative deterioration. The process of hydrogenation, however, extends the food uses of the polyunsaturated oils whose melting points would otherwise be much too low. Hydrogenation, however, reduces the level of unsaturation and transform the cis-double bonds in unsaturated fatty acids to the trans-form. Consumption of excessive amounts of trans-fatty acids can result in metabolic and nutritional disturbances; one effect is to limit the availability of EFA, affecting possibly, platelet aggregation and cardiovascular functions (Gurr, 1984). Palm oil however, does not have to undergo hydrogenation to increase its suitability for use and stability. It is thus free from all the disadvantages associated with trans-fatty acids.

2.3 COMPOSITION AND CHARACTERISTICS OF PALM OIL

Palm oil is derived from the mesocarp of oil palm fruit and palm kernel oil is obtained from the kernel inside the mesocarp. The general characteristics of all fruit-coat fats are the same; the main components are palmitic, oleic and linoleic acid. Other component acids rarely form more than 2–5 percent of the acid present (Hilditch and Williams, 1964). Palmitic acid and monounsaturated oleic acid each account for about 40 percent of the fatty acids present, either one slightly predominating depending on conditions at the place of origin (de Graaf, 1976). In the case of Malaysia which is the world's leading producer in the palm oil industry, 98 percent of the palm oil presently exported is refined and processed to a large extent (Ong *et al.*, 1995), quality is considered a pivotal factor in the production. Achieving high quality starts from the breeding of *Elaeis oleifera* to obtain a hybrid just as high yielding as the tenera palms. Osagie and Bafor (1990) have catalogued the triglycerols in oil palm originating from Africa in the mesorcarp during maturation. Producing oil of higher unsaturation with an iodine value greater than 72 and palmitic acid less than 26 percent compared with the current value of 53–56 and palmitic acid of about 44 percent is currently engaging the attention of research scientist (see Table 2.2).

These parameters are important in processing, moisture, impurities, peroxide value, ionization value and iron content. Though it was possible to reduce moisture value to less than 0.15 percent, but such a reduction causes rapid oxidation. A maximum of 0.20 percent is therefore recommended (Chong and AB. Gapor 1983). Impurities should be minimized to 0.05 percent maximum based on the standards of Standard and Industrial Research Institute of Malaysia (SIRIM).

Table 2.2

Fatty Acid Composition of Malaysian Palm Oil

Fatty Acid	Percent of Total Acids	
	Range	Mean
C12:0	0.1-1.0	0.2
C14:0	0.9-1.5	1.1
C16:0	41.8-46.8	44.0
C16:1	0.1-0.3	0.1
C18:0	4.2-5.1	4.5
C18:1	37.3-40.8	39.2
C18:3	0.0-0.6	0.4
C20:0	0.2-0.7	0.4

Source: Ong *et al.*, 1995

In the tropics palm oil is a fluid at ambient temperatures with a small fraction present in crystalline form. The melting point of palm oil is graduated from temperatures of 25°C to 50°C, this is because palm oil is in reality, a mixture of lipids and isomers of some oils. If enzymic hydrolysis was stopped at a very early stage, then the monoglycerides content should be approximately, 0.5 percent (Pike, 1980).

Studies by Harrison and Crossfield laboratories have shown that having a FFA of at least less than 3 percent, oil hydrolysis is minimal. Lipase occurs naturally in palm fruits and it is produced by a variety of micro-organisms, which are able to utilize lipid-type substances for nutrition. These are water-soluble

and are inactivated at high temperatures at which proteins are destroyed. Lipases become active as the cell structure is mechanically altered, which could occur through bruising even at as low a temperature as 15°C (Pike, 1980)

Processing of palm oil may lead to oxidation of steroids to form products which were not present in the initial product. This form of oxidation can lead to rancidity and loss of palatability due to obnoxious odours, and this may also affect bleachability. The commonest pro-oxidant found during processing are free oxygen and trace metals e.g. copper and iron. Also, transition metals when present accelerates the oxidation during processing and handling. The palm fruit itself contains very little iron and copper, 6.5ppm and 0.01ppm respectively. It is necessary, due to the role these metals play in oxidative rancidity, to exclude them from the processing line as much as possible. Iron and copper contamination of palm oil can cause considerable problems with quality and processing characteristics. The oxidation of crude palm oil can be clearly seen by the reduction in colour due to the copper picked up by the oil oxidizing the carotene. The effect of the oxidation is also demonstrated in the rise of the secondary oxidation as measured by the ionization value and also in the reduction of tocopherols.

Ionization value increase bears a linear relationship to the copper content of oil, also poorer bleach is obtained as the amount of copper in the palm oil is increased in the bleached and deodorized palm oil. The increase in copper also affects the oxidation levels of the deodorized palm oil and this results in a poor stability of the refined bleached and deodorised oil (RBD) and a rapid reversion in taste within a short period of time. The effect of iron though not as dramatic as copper, is significant.

The use of chelators and antioxidants has enabled the production of RBD palm oils of below 1.5 red Lovibond units. The most effective antioxidant for palm oil was tertbutylhydroquinone (TBHQ) (Sherwin, 1976).

2.3.1 Physical Characteristics of Palm Oil

The physical characterises of palm oil are important in determining its use. Some of the important physical properties in this respect are density, specific heat, heat of fusion, refractive index, viscosity, melting point, solid fat content, polymorphism. The chemical characteristics are fatty acid composition, glyceride content, free fatty acids. Tables 2.3 and 2.4 show the densities and vicosities as they vary with temperature.

2.3.2 Minor Components in Crude Palm Oil

Crude palm oil contains approximately one percent minor components and these are carotenoids, tocopherols, tocotrienols, sterols, phospholipids, aliphatic hydrocarbons and other trace impurities. The carotenes which are precursors of Vitamin A, impart a distinctive orange-red colour to palm oil and together with tocopherols (Vitamin E) contribute to the stability and nutritional value of palm oil. The carotenoids particularly lycopene, $\propto$ and β-carotene are efficient quenchers of singlet oxygen thus explaining their antioxidant properties. Recent research has associated beta-carotene with protective properties against various cancers. The carotenoids in palm oil are $\propto$-carotene, ß-carotene, phytoene, phytofluene, cis-ß-carotene, cis-$\propto$-carotene neurospherene, ß-zeacarotene, $\propto$-zeacarotene and lycopene. The major ones are, however, $\propto$ and ß-carotene which make up more than 90 percent of the total carotenoids in palm oil. The

present refining practice in the palm oil industry is to bleach or remove the carotene by heat and earth bleaching in order to produce a light coloured edible oil, however, a process has been developed to produce a refined red palm oil that contains carotenes. The main constituent of Vitamin E in palm oil are - tocotrinol (44 percent), ∝-tocopherols (22 percent), ∂-tocotrienol (12 percent).

Table 2.3

Average Densities of Palm oil (2 percent FFA and 0.1 percent moisture) against Temperature

Temperature (°C)	Density Kg/m^3
20	925-935
30	910-920
40	897.3
50	890.0
60	883.0
70	876.3
80	869.5
90	862.7
100	857.9

Cocks and van Rede, 1966

Sterols present in palm oil are *campesterol, stigmasterol, sitosterol* and *cholesterol,* which is present in trace quantities, less than 10ppm. Phospholipids and glycolipids are also present with the phospholipids receiving much attention because of their association with deterioration of palm oil. The main phospholipid

in palm oil is phosphatidylcholine and the main glycolipids is monogalactosyldiglyceride. Other components are triterpene alcohols, aliphatic alcohols, aliphatic hydrocarbons which are removed during refining processing (Ong *et al.*, 1995). Table 2.5 shows the minor components of palm oil whilst Tables 2.6 and 2.7 show the chemical constituents of palm oil.

Table 2.4

Viscosity (cP) of Palm oil and Palm olein at various Temperatures

Temperature(°C)	20	25	30	35	40	45	50
Palm Oil	>100	>100	>100	96.3	40.4	33.3	27.0
Palm olein	85.3	69.2	56.3	43.4	3 8.6	32.6	26.5

Source: Ong *et al.*, 1995

2.3.3 Uses of Palm Oil

About ninety percent of palm oil is used in food products (Ong *et al.*, 1995). Its physical properties as a semi-solid vegetable oil makes it suitable for the production of margarine, of which 13 million tonnes are produced annually.

Other applications in foods include the production of confectionery fats since palm oil meets the unique requirements of this category of fats, an example of such a use is in cocoa butter equivalent. (CBE). Because of its inherently stable and relatively healthy fatty acids composition, palm oil is becoming the choice oil with which to reconstitute skimmed milk powder and also in the making of trans-free fatty acids magarine (Mohd Suria and Milksandar, 1999).

Palm oil is now used to produce caroteniods which are among the most widespread and important pigments in living organisms (Choo, 1995).

Other uses of palm oil include non-food applications as in tin plating and in the steel industry. Palm stearin, a fractionated product of palm oil, has also been experimented as a base for ointments and creams. It is also used in their derivative forms, which are obtained from triglycerides from palm oil, for example as in expoxidation of palm oil and palm olein to yield plastiazers and stabilizers for plastics. The oleic acid in the triglycerides can be reacted upon to yield compounds which have been found to be good skin moisturizers.

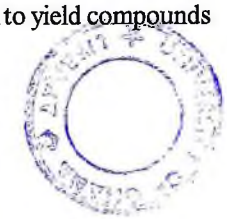

Table 2.5

Minor components in Palm oil

Components	Concentration in ppm
Carotenoids	500-700
Tocopherols and tocotrienols	600-1000
Sterol	326-527
Phospholipids	5-130
Triterpene alcohol	40-80
Methyl Sterols	40-80
Squalene	200-500
Aliphatic alcohols	100-200
Aliphatic hydrocarbons	50

Ong *et al.*, 1995

When converted into alkyl esters its use even multiplies, since alkyl esters are less corrosive and are easier to transport. Metal soaps are formed from fatty acids in palm oil which, it is estimated, has 8 million tonnes of it consumed each year. They can be used as detergents of which 13 million tonnes of surfactants are produced each year. Still yet, other uses include glycerine which in turn find application in cosmetics production, in lubricants (Yeong, 1996) and in polyurethane foams (Partihiban *et. al.*, 1996).

Table 2.6

Component Fatty Acids of Palm Oil

Common Name	Systematic Name	Symbol	%weight
Saturated acids			
Lauric	n-Dodecianoic	C12:0	<1
Myristic	n-Tetradecanoic	C14:0	1-6
Palmitic	n-Hexadecanoic	C16:0	32-47
Stearic	n-Octadecanoic	C18:0	1-6
Arachidic	n-Eicosanoic	C20:0	<1
Monounsaturated acids			
Palmitoleic	n-Hexadec-9-enoic	C16:1	<1
Oleic	n-Octadec-9-enoic	C18:1	40-52
Gadoleic	n-Eicos-9-enoic	C20:1	<1
Polyunsaturated acids			
Linoleic	n-Octadec-,12-dienoic	C18:2	5-7

Hilditch and Williams, 1964

Table 2.7

Typical Analysis of Tryglycerides in Oil

Glyceride Type	Composition(%)
Trisaturated	10.2
Disaturated	48.0
Monosaturated	34.6
Triunsaturated	6.8

Ong *et al.*, 1995

2.4 PALM OIL PROCESSING IN GHANA

Palm oil processing has advanced with time. Its processing has served as a vital source of nutrients and also employment for a considerable number of people. The methods of processing has so advanced that now, we have various degrees of mechanization and scientific inputs being applied. Modifications range from the traditional methods which employ no advance equipment at all to the traditional methods which have been subjected to various degrees of mixing with various types of modern objects of mechanization. Then, there is the power-operated mills which are located in the Central, Eastern and Western regions of Ghana.

The refined, bleached and deodorized (RBD) method which employs various types of equipment which are highly advanced and sophisticated is also applied at present by Lever Brothers Ghana (Ltd), who process a large percentage of the crude oils in Ghana.

2.4.1 Traditional Processing Of Palm Oil in Ghana

Traditional processing of palm fruit and other mesocarps is commonly carried out by women. While details of the actual processing may vary from country to country in Africa, the processing is basically the same. It consists of two methods, the hard oil and the soft oil process (Hartley, 1984).

In the hard oil process, also referred to as the fermentation process, the bunches are usually broken up and placed in disused canoes; especially constructed wooden troughs, or occasionally in pits. Though such methods of fermentation is unknown in Ghana, fermentation is a common practice. The fruit is covered with plantain leaves and water and allowed to ferment for several days through the action of naturally occurring fungi, yeast, as well as enzymes in the fruit. The oil gradually rises to the surface of the water as the fruit decays and is skimmed off at regular intervals. It is usually boiled to remove water and often filtered through a basket to remove any extraneous matter. The process is inefficient in terms of oil yield, it yields about 20–30 percent of the oil present. It derives it's name, hard process, from the fact that the free fatty acid content FFA is very high, which results from the break down of the oil giving it an unpalatable and rancid flavour. Usually, oils with FFA of between 5–7 percent is preferred for cooking. In the case of hard-oil, however, processing results in an FFA of 10–20 percent, the preferred use is therefore, soap making (TDRI, 1984). Hartley (1984), however, has stated that in some areas there is still a taste for high FFA.

The second method is the soft oil process, which involves the boiling of the fruit after separation from the bunches. It is then pounded in wooden mortars with pestles until a mass containing oil fibre, and broken nuts are obtained. After

kneading, the mass is sieved to remove unbroken nuts and fibres. The liquid mixture must be boiled to break the oil and water emulsion. Oil then floats on the surface and is skimmed off with a calabash or ladle. This process yields an oil with a lower FFA content, which is acceptable for food use. Both methods have an efficiency of 50 percent and are labour-intensive and time consuming.

There are various traditional methods which fall under the umbrella of soft or hard used method in Ghana, examples are "Dzomi", "Kyembe" and "Bedo". The last two were studied at Ntafrasu a town near Twifo Praso.

Women in Ghana produce palm oil for both consumption and soap making. In the 1970s because of a shortage of tallow, the demand for palm oil rose sharply. Technology Consultancy Centre, Kumasi (TCC, 1978), therefore, investigated the possibility of producing greater quantities of palm oil if rural extraction methods were improved, so that it could be used extensively for both consumption and soap making. The centre succeeded in designing and constructing a hand-operated screw press for the extraction of palm oil by adapting existing pressers used in Nigeria and Sierra Leone. The press operated by two people is capable of pressing 20kg of pounded boiled fruit at a time. The pressing is done only once as it has been found in Sierra Leone that second pressing yields little additional oil and at a high cost. A smaller version of the press has also been developed to take a maximum of 6.8kg of fruits. TCC has also produced a pounding machine and a clarifying tank. The mill which is capable of producing an average of half a tonne of oil per day, is aimed at farmers with plantations of 150 acres. The introduction of the TCC mini oil mill has made it possible to increase considerably the output of Ghana's small-scale oil palm farmers. Moreover with the TCC mills, the farms aim to process their

own crops. Since the programme started in 1976, 30 oil mills had been created as at 1978 each with an average output of half a tonne of oil per day for 180 days a year, adding up to 2,754 tonnes.

Consequently, there has been a marked improvement in the earning power of the indigenous Ghanaian oil palm farmer. At the 1978 price of 18,000 cedis per drum of 44 gallons and using the TCC estimated daily average output of 2.83 drums (500kg) it would bring in an income of 59,940 cedis at 1978 prices. This increase in earning power was expected to help the small scale farmer a lot, the amount of palm oil imported in 1985 was also considerably less than that imported in 1981 (TDRI, 1984). To a large extent, it is very difficult to come across any large scale processor who does not incorporate a certain level of mechanization.

2.4.2 Power-Operated Palm Oil Mills processing in Ghana

There are 3 large power-operated palm oil mills in Ghana, they are: Ghana Oil Palm Development Company at Kwae, Benso Oil Palm Plantation at Benso, Twifo Oil Palm Plantation at Twifo Praso.

The year 1877 was a landmark year in the industrialization of the oil industry when a machine was introduced to crack palm nuts. Subsequently, the machinery and equipment used in the extraction of palm oil in West Africa and Africa as a whole, underwent several modifications and suppliers came from several countries apart from the UK.

The importance of companies like Unilever in the development of oil extraction equipment in West Africa cannot be over-emphasised (Dyke, 1939). Currently however, most oil mills have the same design and they consist of sections for

sterilization of bunches, stripping of bunches digestion and washing of fruits, extraction of mesocarp oil, clarifying the oil, separation of bare fruits from the nut, drying of nut, nut grading and cracking, kernel separation and discarding of shell and kernel drying and bagging.

2.4.2.1 *Sterilization*

Sterilization constitutes the first significant operation in the milling of palm oil. There are two types of sterilizers; horizontal sterilizers and vertical sterilizers. At Twifo and Kwae, the sterilisers used are the horizontal type. The immediate advantage of horizontal sterilizers is that it does not require hand emptying. It also has other advantages (Stork, 1960; Stork, 1961). At Twifo, electronically programmable sterilizers are used. These make use of the following factors: percentage of hard bunches, percentage of overripe bunches and percentage of ripe bunches. Southworth (1976), sees sterilization as having far-reaching effects on most aspects of the process and it is therefore desirable to optimize sterilization to give the best compromise between the various factors. The independent variables are steam pressure, cycle time, and temperature. The dependent variables were age of fruit, type of fruit. Hartley (1984), has stated that if a harvest consists solely of bunches from 4 to 5 year old palms, then sterilization for half an hour may be quite sufficient to lessen the fruit. Also if the harvest consists of only very ripe bunches with a high proportion of lose fruits, sterilization time may be reduced.

Hartley (1984), recommends that sterilization should be carried out using saturated steam of pressure less than $2kg/cm^3$ and at temperatures below 130°C. Sterilization should be with the following objectives: Softening of the mesocarp

for efficient digestion, loosening of the fruits from the bunch, arresting the production of FFA and microbiological activity, conditioning of the nuts for kernel recovery and the seasoning and recovery of the oil from the fibre (Southworth, 1976). Sterilization at Kwae, normally takes 90 minutes, at Twifo it takes approximately the same time.

2.4.2.2 *Threshing or Stripping of Fruits from the Bunch*

There are two kinds of strippers or threshers, the beater-arm type and the rotary drum type (Stork, 1960). The rotary drum stripper is often preferred because of its high capacity and it is smoother and more efficient to run. Both Twifo and Kwae apply this type of treatment.

The empty bunches are conveyed to the incinerators where they are fired to produce ash which contains 30 percent to 35 percent K_2O and 3 percent to 5 percent MgO. At Twifo it had been found out through experience that direct application of the empty bunches as manure brought better results than the incinerated empty bunches as fertilizers.

2.4.2.3 *Digestion*

The next significant operation is digestion. The purpose of digestion as with pounding is to break up the pulp physically and further, to liberate the oil from the cells in which it is contained, and the nuts from the fibre.

I Digestion requires that the following operating conditions be reached and maintained. The temperature must be about 95°C and the water in the mash must not boil, a condition satisfied at both GOPDC and TOPP.

II The mash must be homogenous and be without undigested fruit.

III The arms must be replaced when they show signs of tear and wear.

IV The perforations must be without impediments to ensure free flow of crude oil at the base.

V The digestors must be kept at least three quarters full at all times (Twichin, 1955; Bek-Nelson, 1969). TOPP had three digestors with a total capacity of 30 tonnes at a time.

2.4.2.4 The Press and Other Methods of Oil Extraction

Machines for extraction of oil have undergone several changes and modifications. The early machines for extraction of oil from digested fruit were centrifuges. The advent of centrifuge in Africa was acclaimed as the answer to all previous difficulties - and it for some time was considered the best method of extraction (Wyer, 1927).

Centrifuge Extraction:

Centrifuge Extraction is virtually sludge-free and clarification losses are relatively small. Steam injection is important, but should not be used towards the end of spinning. A spinning should cease at the end of steam injection and then dry out the matter for subsequent fibre separation (Southworth, 1976).

The Hydraulic Press:

The Hydraulic Press may be hand-operated or automatic. The hand-operated ones have capacities ranging from 1.5 tonness to 3.0 tons bunches per hour. They may also be revolving, comprising two cylinders swivelling on a central column.

There is now an automatic hydraulic press in which the digester forms one unit with the press (Olie, undated). The extraction unit chosen often influences the following: loss of oil, kernel breakage and quality, iron absorption during processing, wear and tear of machinery and digestors. The loss accrued in the fibre was usually found to be lower with screw press than with hydraulic press. The sludge oil losses were lower in the centrifuge type than the hydraulic press. The overall extraction efficiencies are only marginally in favour of screw press (Hartley, 1984).

Screw Press:

There are two types of screw press for the expression of oil from the digested material, they are: the single-shaft screw press, the double-shaft screw press. Both TOPP and GOPDC use the screw press rather than the ones earlier on mentioned. Southworth (1976) has espoused the marginal advantage of the screw press over the other two. This, however, is better when plantations are to deal mainly with the tenera variety which has a low nut/fibre ratio. The advantages of the hydraulic press comes to the fore in the processing of dura variety which has a high nut/fibre ratio. Digestion is also not as critical in the extraction process as in other processes, when using screw press, this is because extra shear forces are at work in this press.

Solvent Extraction:

This is not used in Ghana for processing of palm oil. It has been on the experimental stages throughout the world and is yet to overcome technical and economic obstacles. For example the quantity of solvent required would be

large and losses under tropical conditions considerable (Olie and Tjen, 1974).

Another method under consideration is impulse-rendering, so far oils produced by this method is of good quality and light in colour, though it is difficult to obtain complete separation from protein fraction. However, it could help overcome FFA problems and bleachability in palm oil (Hartley, 1984).

2.4.2.5 Clarification

It is carried out immediately after extraction to purify the oil. Oil issuing forth from the presses is accompanied by water, dirt and cellular matter from the mesocarp. Oil from centrifuge contains 40 percent to 50 percent water and smaller quantities of dirt and other matter. That from the hydraulic press contains about 55 percent water and that from the screw press contains 60 percent water (Hartley, 1984).

Crude oil is largely an oil - water mixture in various phases of oil dispersions in the water. The majority of the oil settles out on top of the water easily but emulsions may be formed if temperatures of over 100°C are attained. Clarification is affected by the properties of the crude oil from the digestion and pressing process, which in turn is influenced by the type of press used and the type of fruit being processed (Hartley, 1984).

Clarification is usually with the following objectives: to minimize moisture, dirt, oil losses, deterioration in oil quality and cost (Southworth, 1976). It is carried out in continuous settling tanks (C.S. tanks) or clarifiers. Important operating conditions that go to optimize the factors mentioned are temperature, residence time, which must be adjusted between a small residence time, which will not ensure good clarification and a long residence time which will increase

the FFA (Hartley, 1984).

After separation of the oil there is then the problem of sludge, which is an objectionable, malodorous waste material. The remaining clarifying equipment depends on the scale of operation and result required; more settling tanks, vacuum driers and centrifuge seperators may be employed. At TOPP and GOPDC, the oil is skimmed off, piped into a clean tank and purified by high speed centrifuges to a dirt content of 0.02 percent maximum (TOPP) or 0.01 percent (GOPDC); the maximum residual moisture after vacuum drying is 0.1 percent at GOPDC and 0.2 percent at TOPP. The waste from the centrifuge is channeled into the sludge pit from which mechanical grade oil is recovered and pumped into barrels for storage. The final effluent is fed into ponds, from where the effluent could be used for irrigational activities after microbiological treatment.

2.4.2.6 Production and Storage Capacities at TOPP and GOPPC

GOPDC has a nominal capacity of handling 15 metric tonnes of fresh fruit bunches (FFB) an hour, this approximates to an hourly production rate of 17 drums of palm oil and cocoa bags of kernel in an hour. The palm oil is then stored in tanks. At TOPP there are 2 of these, each with a capacity of 1,000 tonnes (5,600 barrels or 250,000 gallons). There is also a 15-tonne drum for supply of oil into drums and gallons. Temperature is maintained at recommended levels in both oil mills, by steam coils. TOPP, which was completed in September, 1983, was designed to process 20 tonnes of FFB per hour.

2.4.2.7 Kernel Recovery

Both oil mills, TOPP and GOPDC, do not process their palm kernel into palm

kernel oil. As at the time I visited GOPDC they had ceased further sale of palm kernels, awaiting a future decision on it. Fibre and shell from the nuts are used as fuel to fire the boilers to generate steam which in turn, is used to run the steam turbines to generate electrical power to run the factory for most of the times. The expanded steam is used in the factory for processing.

2.4.2.8 Power and Water Supply

TOPP has two 400KVA caterpillar generating sets to provide electricity when the mill is not in operation. GOPDC had stand-by diesel generators of 250KW, capable of processing 15 metric tonnes of FFB an hour. Water demand at GOPDC was one tonne of water per tonne of FFB. Both TOPP and GOPPC use the fibre and shells retrieved from the process as fuel in boiler furnaces to generate super heated steam at 17bars, (at TOPP, each boiler could produce 15 tonnes of steam per hour) to generate electricity. The live steam from the boilers were also used in a three-stage steam ejector to create vacuum for the drying of the produced oil. Water supply at TOPP was by a borehole and additional supply by the Obuo River, which supplies water in times of need. Both oil mills had a laboratory from where the following test were carried out: Moisture content, dirt content, FFA, and others. The following targets were requested for palm oil:

%	FFA	<	5%
%	Moisture	<	0.2%
%	Dirt	<	0.02%

Palm Kernel Standards

%	Moisture	<	8%
%	Dirt	<	5%

% Broken < 15%

% Oil/Dry Matter > 45%

The oil produced will, therefore, fall in the range of ordinary palm oil for both mills as per Jacobsberg (1971) and Loncin and Jacobsberg (1965).

2.4.3 Refined Bleached and Deoderized Oil Processing in Ghana

Palm oil processed in the mills which are sold as crude palm oil (CPO) are eaten or further processed by Lever Brothers at Tema using the refined bleached and deodorized (RBD) process. Refining starts at the crude oil storage tanks because the right conditions must be met to prevent fractionation and also help in the pumping of the oil. It is then degummed to remove proteins, carbohydrates and phospholipids (Nawar, 1985).

Strong caustic soda (4N) solution is then added, this helps in improving the consistency. Oil is then bleached. This step is necessary to remove soap, trace metals, sulphurous compounds and part of the more stable pigments and pigment break-down products which have resulted from raw materials damage or oxidation. During bleaching, peroxides are broken down to aldehydes and ketones and they are adsorbed on the earth surface reducing the peroxide value to zero and reducing the Totox value = 2 + 2 POV +Anisidine value (Young, 1980).

Bleaching uses earth of 0.2-0.4 percent minimum and 1.5 to 2.0 percent maximum; temperatures are usually around 95°C for vacum bleaching. Excessively high temperatures are to be avoided (Gunstone and Norris, 1983). The contact time is usually 10–15 minutes in continuous process but varies when batch is used. Vacuum is now commonly used and atmospheric bleaching

is a rarity, since this may lead to "fixation" of pigments; a product of better quality and oxidative stability is obtained with vacuum bleaching.

The next step is deodorization, this is necessary because though refining and bleaching removes phosphates and reduces the free fatty acids and colour bodies. It still contains aldehydes and ketones, alcohols, hydrocarbons and other compounds derived from the decomposition of peroxides and pigments. Though the levels are around 200 ppm they are enough to create unpleasant odours and flavours.

It uses high temperatures, steam distillation under high vacum, during which volatile components are removed and free fatty acids are reduced.

Though it is considered a purely physical process for removing volatile flavour present in the oil at the commencement of deodorization chemical processes are also involved in, for example stripping at relatively low temperatures using ultra high vacuum. The process which applies steam hydrolysis and heat pyrolysis apparently breaks down labile compounds that are removed by normal physical processes of deodorization (Gunstone and Norris, 1983). The trend in processing is to minimize the temperatures to less than 250°C and also the residence time, to reduce the tendancy to polymerize and at the same time remove carotenoids and other pigments (Young, 1980).

Another process is hydrogenation. It is an old process, the complete text of the original patent application was submitted by Walhelm Norman in October 1903 (Norman, 1903). It is the conversion of liquid oils to semi-solid fats. It also enhances the oxidative stability and improves the colour of the final product. Hydrogenation uses hydrogen and catalyst example nickel or palladium to convert the double and triple bonds in unsaturated oils to single bonds.

In the process the double bonds undergo both geometrical (cis/trans) and

positional isomerization. All these conversions end up in increasing the melting point of the oil and also the stability (Coenen, 1973).

Figure 2.1, shows processing through the refined, bleached and deodorized (RBD) stage. Table 2.8, shows some characteristics of hardened palm oil. The rate depends on the temperature, nature of oil, the catalyst activity and its concerntration and the rate at which hydrogen and unsaturated oil can be brought into contact.

Table 2.8

Effect of processing conditions on Hydrogenation

	Selectivity	Transacid	Reaction rate
Increased temperature	+	+	+
Increased pressure	–	–	+
Increased agitation	–	–	+
Increased catalyst concerntration	–	+	+

Source: Gunstone and Norris (1983)

Fractionation is an important step because fats contain mixtures of glycerides of differing melting points and solubility and (generally more saturated) glycerides will come out of solution and are seperated. Thus, two or more fats can be obtained from one fat, which enable the oil to widen in applications(see Table 2.9).

The ease with which this is done depends on the method of cooling. It is better to cool gradually since this will yield macrocrystals that are easier to

separate than one rapid cooling which yield microcrystals which are soft and difficult to seperate.

There are several methods of fractionation. One is dry fractionation. This applies filtration to seperate the liquid and solid fractions. This, however, presents a problem and it is to large extent obsolete, used only where there is no credible alternative; an example of when it is used the winterization of cottonseed oils (Gunstone and Norris, 1983).

Another method of fractionation is Lanza fractionation. Crystal magma are formed as in dry fractionation, the solid fractions are then seperated by adding a detergent which preferentially wets the crystal fraction forcing the liquid to separate and float on the surface. The liquid fraction is skimmed off and the solid is melted and seperated from the aqueous solution.

The third method is solvent fractionation; this uses solvents for example hexane, acetone, 2-nitropropane, an example is the production of cocoa butter substitutes from palm oil (Gunstone and Norris, 1983).

Table 2.9

Characteristics of Palm Oil Fractionation Products

Oil	Yield (%)	Iodine Value	Melting Point (°C)
Palm oil	100	55-56	37-38
First olein	60	56-59	29
First stearin	40	49-50	45-46
Second olein	33	60-62	9-12
Second stearin	27	50-54	35-37

Source: Huybrechts, 1964

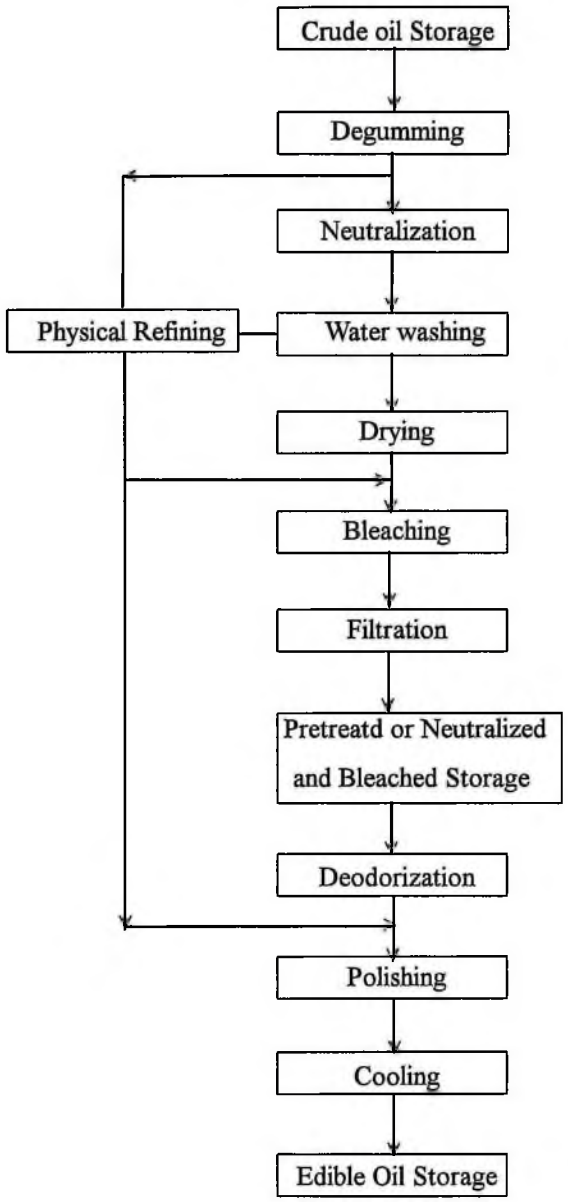

Fig. 2.1: Flow Chart showing various Stages of Refining

Source: Young, 1980

Fig. 2.2 shows the flow diagram of a fractionation process, it consists of two steps. First fractionation to separate stearin from olein and the olein is further fractionated to separate any remaining stearin fractions from the olein. The first fractionation is carried out at ambient temperatures (tropical). During the second fractionation step the melting oil is cooled to between 20°C and 23°C using chilled water as a coolant. The fractions obtained have a lower melting range than the starting material as shown in Fig. 2.2. Soluble non-crystalline components such as carotenes, tocopherols, sterols and oxidized components will be accumulated in the liquid fraction.

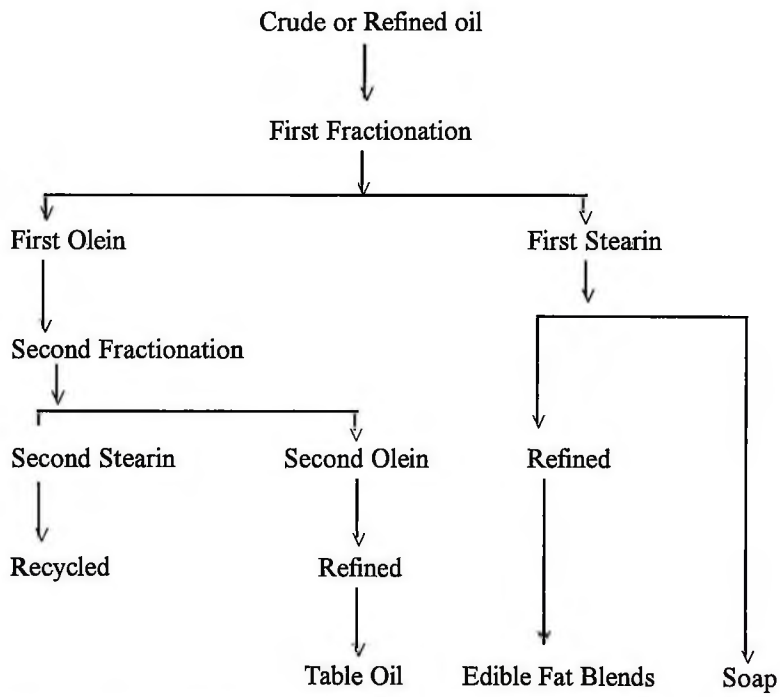

Fig. 2.2: Flow Chart of a Fractionation Process

Source: Huybrechts (1964)

2.5 PROCESSING OF A BY-PRODUCT OF PALM OIL IN GHANA: PALM KERNEL OIL

The processing of palm oil is inextricably linked to the processing of palm kernel, since palm kernel is a valuable by-product its processing can affect the profitability of the industry. In fact at GOPDC, they had decided to cease further sales of this product pending its possible use in the processing of palm kernel oil (PKO).

Palm kernel oil is processed in Ghana using traditional and industrial methods. In 1992, the following oil mills were said to be processing palm kernel oil in Ghana, they were: Tema Food Complex Oil Mills, Mpohor St. Lewis Oil Mills, Tringo Oil Mills (Sefa-Dede and Tano-Debra, unpublished). This was in addition to the one mentioned by Ata (undated) at Atebubu. Gadegbeku (1969), stated that seven industrial mills were capable of processing palm kernels.

The oil mills used high pressure operated expellers. The kernels are cleaned, broken-up into a coarse meal between rollers, heated and then passed through the presses to squeeze out the oil. The oil squeezed out is passed through filters to remove contaminants (Sefa-Dede and Tano-Debra, unpublished).

Hartley (1984) and Southworth (1976), have discussed in detail the various technical intricacies involved in nut screening, cracking kernel, shell separation and kernel drying.

2.5.1 Traditional Methods

The method used for the extraction of palm kernel oil are mainly based on water displacement and low pressure application. There are three methods, in the first, the nuts are cracked manually and grilled over an open fire, using sheet metal pans, iron pots and earthenware pots. Grilling takes between 1-4 hours. The

cracking of the palm kernel is the most difficult part of the processing and losses are very high here, it ranges between 50 percent and 60 percent. The grilled nuts are pounded in a mortar or milled mechanically and then boiled with water. Finally, oil is scooped off the top of the boiling mixture. This process takes between one and two hours. The residue can be used for animal feed (Gordon, undated; UNIFEM, 1987).

In the second method the kernels are soaked in water overnight, after which they are pounded in a mortar and aged with water. The oil separates out as an emulsion on the surface and is skimmed off and heated to dry (Irvine, 1970). The third method involves roasting of the kernel at very high temperatures until the oil oozes out (Addo Consultants, unpublished).

Palm kernels are purchased from plantations where palm oil is processed from householders who use the mesocarp. If the fruits are used as raw materials, they are cooked, digested and the pulp is pressed out and separated from the fibre (Ata unpublished). The nuts are then dried, which may facilitate shrinking of the kernels from the shells, then cracked either manually or mechanically.

2.5.2 The Effect of Processing on Palm Kernel Oil

Jayaleksmy *et al.*, (1991) have attributed the browning in palm kernel oil to heating as a result of Maillard's reaction. Stork (1960) also expressed similar views. Sefa-Dedeh and Tano-Debrah (unpublished) have also confirmed this fact, in stating as follows:

> Laboratory investigations showed that process characteristics significantly influenced the product characteristics, roasting kernels leads to the darkened colour, strong odour

and strong flavour of the oil. However, it facilitates efficient milling and hence higher yields.

In the same work, soaking in the process which does not involve any roasting, was noted to have kept the FFA levels low. The individual unit operations, generally, were found to influence the yield, colour, odour and free fatty acid level.

The modification of the equipment as regards traditional processing has resulted in a significant increase in the extraction percentage to 40 percent (UNIFEM, 1987). To a large extent, milling machines have replaced mortars (Irvine, 1970).

Bailey (1951), has also noted that the mode of storage of the kernels prior to processing can have an effect on the quality of the palm kernel oil. Darkening of the testa and browning of the endosperm in mills with steam pressure sterilizers was to a large degree unavoidable. Severe browning of the kernels renders the oils impervious to bleaching, moderate browning however can be corrected by bleaching (Thieme and Olie, 1969).

If kernels are not well treated, they become susceptible to hydrolysis and lipolysis by fat splitting enzymes in the kernels and from lypolytic moulds. Lypolytic microorganisms have been detected at various stages in the milling process but particularly in the hydrocyclones and clay baths (Turner, 1969). Hartley (1984), has noted that lipolysis may be reduced by sterilization and a reduction in the number of uncracked kernels. The highest quality palm kernels are to be obtained by hand-cracking of nuts which are usually processed in the village.

Stork (1960) has shown that a high moisture content and broken kernels offers the best recipe for the increasing the percentage FFA, whilst whole kernels and low moisture content makes the kernels resistant to the accumulation of

FFA to a large extent.

Tano-Debrah and Sefa-Dedeh (unpublished) have analyzed samples of palm kernel oil, produced at Atebubu Oil Mills and compared them with those produced traditionally as seen in the Table 2.10 below.

2.6 EFFECTS OF PROCESSING ON THE QUALITY OF PALM OIL: AN OVERVIEW

For a long time, most edible oils and fats were extracted by traditional methods: locally and by mechanical operations with or without the application of moisture and external heat and were used in the unrefined form. This practice is still

Table 2.10

Effects of Processing on the Quality Characteristics of Some Industrially Produced and Traditionally Produced Crude Palm Kernel Oil Samples in Ghana

Quality Attribute	Industrial Products at Atebubu Oil Mills	Traditional Products
Colour	Bright Yellow Shand Fairly Attractive	Very Dark Brown and Not Particularly Attractive
Flavour and Smell	Fairly Mild Flavour of Palm Kernel Oil	Very Strong Flavour and Smell of Roasted Palm Kernel
Taste	Very Sticky on Tongue and Soapy Feel	Sweet Taste of Roasted Palm Kernel
FFA	10.0%	0.9%
POV	10.6	2.6

Source: Ata (undated)

widespread in many countries, and apart from minor changes caused by release of FFA or rancidity, all nutrients naturally present remain in the product. The major vegetable oils traditionally processed and consumed in many countries in a clean but unrefined form are groundnut, coconut, rapeseed, mustard seed, palm oil, palm kernel oil, olive oil. For more than 90 years now, vegetable oil has been obtained by more efficient mechanical expression and by solvent extraction. Furthermore, they are subjected to technological processes to make them as bland and colourless as possible. The refining, consists of washing, alkali refining, bleaching and deodorization. The resultant oils and fats may be further processed by hydrogenation, randomization and winterization for different food uses.

Most vegetable oils used for human foods are relatively high in polyunsaturated fatty acids (18:2 n-6) but in some oils small amount of linolenic acid (18:n-3) are also present. These fatty acids are susceptible to oxidation if not properly protected by adequate antioxidants. Vegetable oils naturally contain compounds of the Vitamin E family, tocopherols and tocotrienols, which are effective antioxidants, stabilizing these oils under storage conditions. If oils are overheated or reused excessively for deep fat frying of foods, loss of vitamin E and formation of oxidized and polymerized products occur. Studies on animals have shown that these could be toxic, raising questions of their possible adverse effect on human nutrition (Shukla, 1994; Holub and Thomas, 1994).

2.6.1 Oil recovery

The content of naturally occurring nutrients remain chemically unchanged in mechanically expressed and unrefined palm oil. However, the presence of toxic

materials such as aflatoxin in groundnuts oils and isothiocynates in rapeseed and mustard seed oil, gossypol in cotton seed oil, naturally occurring may cause concern when these oils are consumed in the unrefined form.

The manner in which oil is extracted is believed to have no effect on the glyceride composition, but it does affect the amount and nature of some components. Elsewhere Ma Ah Ngan (1999), has reported that milling of fresh free bunch is essentially a physical and mechanical process. It is unlikely therefore that milling will affect the glyceride components, it may however affect the proportion of tocopherols and tocotrienols (Jacobsberg, 1983). For example cotton seed oil obtained by hydraulic pressing, which involves cooking of the flaked seed under pressure, is relatively low in non oil components, such as pigments and phosphatides, when compared with an oil obtained by screw pressing, which involves higher pressures and a lower moisture content. Spectrophotometric examination of cottonseed oils obtained in one mill-scale test (Boatner *et al.*, 1947), however showed the principal pigment of crude, screw-pressed cottonseed oil to be entirely different from that of crude, hydraulic-pressed oil obtained from scale seed.

Solvent extraction of oil seeds, and screw pressing, tend to remove relatively large proportions of non-oil components including flavour components. Vegetable oil extraction, either directly or from residues of the raw material after mechanical pressing, may contain traces of undesirable solvent residues. The process of heating oil to high temperatures to ensure that substances are broken down may also diminish the value of the oil. The solvent used almost exclusively is hexane. It is volatile so that it can be easily removed (Weiss, 1983).

2.6.2 Degumming and Refining

In the edible oil industry, alkali refining means bringing crude oil into contact with a water solution of sodium hydroxide or other alkali, to render the oil insoluble to most of the objectionable impurities, and then removing these impurities and the water solution by settling or centrifuging (Weiss, 1983).

FFAs are the main acidic substances removed during refining. Their content may vary to up to 40 percent in some instances. Under adverse climatic conditions, cotton seed from some areas may yield oil containing about 5 percent FFA. Some crude oils of American origin, of very good quality average 0.5 percent FFA. Refining reduces the content of FFA to below 0.03 percent. Soaps, which are formed are quite insoluble in the oil, and mechanical separation usually reduces soap content to between a few tenths and a few hundredths of one percent. Subsequent water washing and bleaching reduces the level much further. It also removes phosphatides and other polar hydratable lipids. It has little effect on the triglycerides in the oil and thus on its principal nutritional function. After refining and water washing, the phosphatides content should be below 0.002 percent (Mattikow, 1948).

Crude vegetable oils contain minor components, sometimes specific to a certain type of oil, which react with alkali or are absorbed on the soaps and removed in refining. Among these are gossypol and related pigments, acidic in nature, found to the extent of about 0.05 percent in hydraulic pressed oil and 0.3 percent in solvent extracted oil. Crude oils in general, contain minor components of metals for example copper and iron which are removed during refining (Ong *et al.*, 1995)

In addition, alkali refining of palm oil removes nutritionally valuable

constituents for example carotenoids (often mostly ß-carotenes). Although the removal of water- binding phospholipids may be advantageous, preventing sputtering and browning, if the oil is used for frying operation, it is desirable to minimise the loss of carotenoids and to consider their addition after processing (FAO, 1977). In red palm oil, an important source of carotenes in certain populations, notably Ghanaian, refining may therefore deprive them of a vital source of an indispensable substance.

A number of minor components of vegetable oils, including sterols, Vitamin E, are also affected, only to a limited extent, in refining. Pritchett *et al.,* (1947), found on examining several samples of soybean oil, that the content of chlorophyll was reduced from about 1100 to 880 mg/l on caustic refining in the continuous process. The sterol content of vegetable oils, which for the crude state, ranges from about 0.03 percent for palm oil to 1.7 percent for wheat germ oil (Lange 1950) is reduced to a minor extent on refining.

Vitamin E; which is defined by Eitenmiller (1997) as the collective term for fat-soluble 6-hydroxychroman compounds that exhibit the biological activity of tocopherol and which is generally a mixture of alpha, gamma and delta tocopherols and is present in amounts ranging from about 0.0027 to 0.52 percent depending upon the type of oil (Lange, 1950) is also removed to a minor extent on refining. Rawlings *et al.,* (1948) reported that caustic refining removed 10 to 20 percent of the Vitamin E of soybean oil, which ordinarily has a Vitamin E content of 1.15 to 0.21 percent, similar results have been obtained for palm oil.

Chlorophyll is also partially removed, other colouring matter are reduced, also reduced are proteinaceous materials (FAO, 1977). Chlorophyll affect the oxidative stabilities of oil, together with pheophytin, they have been found to

accelerate the oxidative breakdown of oils but pheophytin does this to a greater extent (Usuki *et al.*, 1985).

2.6.3 Bleaching

Bleaching is the treatment of refined oil with a small proportion of earth, about 0.5 percent of activated earth, often mixed with about 0.05 percent active carbon, the best blend is found by experience and familiarity (Flynn, 1973) at temperatures of around 100°C for 15–30 minutes to remove most of the remaining pigments (carotenoids, chlorophyll, gossypol), (FAO, 1977). Also removed are gums, trace metals, oxidation products, some tocopherols (Ooi *et al.*, 1996). The extent of removal varies considerably depending upon the nature of the colour bodies, the type and amount of adsorbent, the temperature and other operating conditions. Extremely high temperatures during bleaching should be avoided. They lower the keepability and alter the chemical structure of the oil and tocopherols (AB Gapor *et al.* 1983).

Chlorophyll content is rather effectively reduced by bleaching particularly if an acid-active red clay is used. Pritchett *et al.*, (1947) reduced the chlorophyll content of a refined soybean oil from 925 to 78 µg/l on bleaching with 0.75 percent of an activated clay. The level of vitamin E is almost unaffected by bleaching (Lange 1950). However, AB Gapor (1990) has shown that the amount of Vitamin E may be reduced by bleaching, but there is a wide range in the reduction, due to the variation in processing condition. A drastic set of processing conditions e.g. high temperature, longer residence time, result in greater reduction of Vitamin E in the oil, but the tocopherol and tocotrienols have a positive role in enhancing the oxidative stability of oils, (Goh *et al.*, 1990).

Chlorophylls have a negative effect on its stability. Palm oil has about 1558 mg per kg of chlorophyll, part of which is removed during bleaching (Tan *et al.*, 1994).

Metallic compounds and soaps are also effectively removed by bleaching. Soap content is reduced to about 10ppm (Bailey, 1950; Gunstone and Norris, 1983). The FFA content however is increased slightly. Metallic content which has already been reduced at this stage is further reduced to a few ppms. The acidic nature of most bleaching earth may lead to a rise in measurable quantities of conjugated fatty acids derived from the Polyunsaturated fatty acids (PUFA) (Nawar, 1985). Peroxides and fatty acids also break down to yield conjugated compounds. The nutritional significance of conjugated acids has not been clearly defined. Transformation of sterols to materials with unknown biological activity is also suspected to occur during bleaching. During the process of vacuum bleaching when temperatures are as high as 170–190°C and large quantities of acid - activated clay are used, positional and geometrical isomers are produced from the more reactive fatty acids. Active carbon can remove phenathrenes, μ-benzy pyrenes and similar compounds.

Toxic agents, such as polycyclic aromatic hydrocarbons commonly found as an impurity in smoke-dried coconut oil are greatly reduced by activated carbon (FAO 1977; Gunstone and Norris, 1983).

2.6.4 Refining

Chlorophyll is also partially removed, other colouring matter are reduced, also reduced are proteinaceous materials (FAO, 1977). Chlorophyll affect the oxidative stability of oils, but pheophytin does this to a greater degree (Usuki *et al.*, 1985).

Traces of soap should be neutralized by addition of citric acid because they lower the activity of the bleaching earth and increase the rate of hydolysis of the neutralized oil during storage. In physical refining, insufficient elimination of phosphorus from oil itself, or slip through of phosphoric acid produces poor bleachability. Time and temperature have a greater effect during physical refining; holding times and higher temperatures are prime consideration.

Refining of palm oil, if well carried out, improves the quality of an oil of even an inferior quality; it removes products which are not desired and lack compatibility with further application for example phosphatides and levels out inconsistences and irregularities, producing a neutral bland point oil of lower pro-oxidant content and of lower oxidation level than the crude oil (Gunstone and Norris, 1983).

Poor quality crude oil is a great liability as it increases refining costs and sometimes, after more extreme refining conditions of the crude oil the final products lack good keepability. It is very difficult to remove diglycerides or reduce them to acceptable content for fractionation to take place. Refining cannot restore crude oil in which oxidation has proceeded considerably because of a high percentage of copper (Pike, 1980).

2.6.5 Deodorization

Tempering of plastic fats, solidifation and hydrogenation are the only operations that usually follow deodorization (Weiss, 1983). Deodorization is carried out after bleaching and refining since the oil normally has compounds which still impart unpleasant odours to it. Hydrogenation also, creates a distinctive odour in cotton seed oil, peanut oil, and soyabean oils, due to compounds which are

believed to amount to less than 0.1 percent of their weight (Bailey, 1950).

Oils containing significant amounts of FFA have them reduced to levels ranging from 0.015 to o.03 percent. This level actually represents the range where the rate of hydrolysis of the oil by stripping steam equals the rate at which the fatty acids are removed by stripping of the sterols, chlorophyll and Vitamin E are lowered only slightly. Hydrocarbons are removed to some extent, carotenoids, an exception to the removal of unsaponifiables, are largely destroyed resulting in the reduction of the intensity of colour (Gunstone, and Norris, 1983).

Peroxides present in an oil are removed during deodorization, and other pro-oxidants presents are removed, or the anti-oxidants are affected beneficially in some way, because deodorization, markedly, increases the resistance of fats and oils to oxidation. Even the keeping quality of an oil previously damaged by oxidation can be improved. If metal scavengers such as phosphoric acid, citric, tartaric acids, are to be added to an oil to enhance its keeping quality, they are ordinarily added during deodorization. True antioxidants are seldom added to vegetable oils because such additions frequently decrease resistance to oxidation instead of increasing it. Apparently, the Vitamin E and other antioxidants naturally present in these oils are already at an optimum concentration (Bailey *et al.*, 1944). Processing should be such as to preserve the initial content of it. The efficiency of the tocopherols decrease with increasing concentration at the optimum (Jacobsberg *et al.*, 1978).

It is usually the last or the last but one operation in the processing of edible oils and fats. The only operation that normally follows it is the solidification and tempering of plastic fats. Even after refining and bleaching, the vegetable oils have an unpleasant flavor and odour. In addition the operation of

hydrogenation also almost invariably creates a distinctive odours in cotton seeds, peanut, and soybean oils are believed to amount to less than 0.1 percent on a weight basis (Bailey, 1950).

If the oil is to be deodorised contains any significant amount of FFA, these will be reduced to levels of about 0.015 to 0.03 percent. This level actually represents the point where the rate of hydrolysis of the oil by the stripping steam equals the rate at which the fatty acids are removed by stripping contents of sterols, chlorophyll and vitamin E are lowered only slightly. Hydrocarbons are removed to some extent, carotenoids an exception to the removal of unsaponifiables, are largely destroyed resulting in the reduction of the intensity of colour. Thus a refined bleached oil which is essentially free of phosphades low in free fatty adds and has greatly reduced amount of colour bodies, is further improved in quality after deodorisation (Gunstone and Norris, 1983).

Jung *et al.*, (1997) have also shown that processing of soyabean oil leads to a gradual and systematic uninterrupted loss of tocopherol till the deodorization stage after which only 60 percent of the initial tocopherols remains. This means that a loss of 20 percent occurs in this area alone. Since soyabean oil has the highest amount of tocopherols in vegetable oils, this amount which represented the highest amount in all the various steps in processing, makes deodorization a critical step as far as preservation of Vitamin E is concerned.

The Vitamin E content in palm oils is represented largely by tocotrienols; a unique situation in the gamut of vegetable oils. It is lost partially as a result of processing. It has been observed that RBD palm oil, palm olein and palm stearin contain approximately 69, 72 and 76 percent respectively of the original level of Vitamin E in the crude oil (Chandrasekharan and Kalyana, 1995).

The sterols in palm oil are largely sistosterol, campesterol, stigmasterol and cholesterol. As in the case of all edible oils of vegetable origin, the cholesterol content in palm oil is very negligible and this is further reduced during RBD (Chandrasekharan and Kalyana, 1995).

The high temperatures used in the refining of palm oil not only remove oxidation products but also impart a poorer taste, reduce oxidative stability, remove some tocopherols and destroy the carotenes.

High temperatures are an inevitability however, since they are necessary to remove much of the oxidation products whose presence in the oil would impart a poorer taste to the end product and reduce oxidative stability. Under these conditions however, some of the tocopherols and tocotrienols are removed and all the carotenes are destroyed. Hence RBD palm oil contains about 300–500 ppm of tocopherols and tocotrienols and no carotenes (Ooi *et al.*, 1996). In view of this, methods that result in retention of some of the carotenes are welcome. Mohd Suria and Miskandar (1999) outline a method which uses moderate deodorization temperatures to produce high carotene palm olein. This, therefore, is a recommended alternative.

The upper limit of the deodorization temperature is set by the thermal stability of the oils. To minimize the risk of thermal polymerization, cooking and salad oils frequently are deodorized at temperatures lower than those used for the more polymerization-resistant hydrogenated fats. Apparently, deodorized oils, cooking oils and salad oils contain no polymers or no significant amounts of them.

The conditions of deodorization are such that any mono and diglycerides present in the oils tend to be transformed into triglycerides and free glycerol, the

latter being stripped out of solution. So, monoglyceride mixtures added to fats in the preparation of superglycerinted shortenings are added toward the end of the deodorization process. The higher the iodine value of an oil, the more care must be taken in selecting an antioxidant (Bailey and Feuge, 1944).

Jung, *et. al.,* (1997), have expressly stated that the physical properties of Vitamin E makes it susceptible to oxidative losses, which are even accelerated by high temperatures, alkaline pH and various metals primarily iron and copper. The economic importance of this vitamin however makes it a vital compound since, it commands a $300 million market in the U.S.A (Tappel, 1995). In the U.S.A. 20.2 percent of the vitamin is obtained from vegetable oil sources (Murphy *et al.,* 1990). Similarly, Eittenmiller (1997) has stated that, perhaps no other vitamin has received as much attention in the popular press over the past decade as has Vitamin E.

Ubiquinones, newly discovered compounds also with antioxidant properties (Hazura and Choo, 1997) are sensitive to alkaline, acidic and high temperature conditions. The concentration therefore, decreases along the processing line. Hazura and Choo (1997), has postulated that loss of these compounds could be due to phosphoric acid treatment in the deodorisation and deacidification process.

2.6.6 Hydrogenation

The invention and subsequent development of the process of hydrogenation is well documented in the literature (Norman, 1903; Sabatier, 1922). The process however which is widely used in the edible oils industry is still considered as an art and the processing conditions generally used by the refiner to produce a certain hydrogenated product are kept as a well-guarded secret.

Hydrogenation is used to increase the stability of certain fatty acid by selective reduction of the level of ∝-linolenic acid (18:3, n-3). To a great extent, it is used for less selective conversion of quantities of liquid oils into semi-solid fats; which are eaten as such, or after further processing. Partial hydrogenation results in extensive changes in fatty acids of tryglycerols, reducing the carotenoid pigments and lightening these colours, but it does not affect the tocopherols. Extensive shifts of the unsaturated bonds also occur in both polyunsaturated fatty-acids and monounsaturated fatty-acids yielding a wide range of both positional and geometric isomers with the same number of, or fewer unsaturated bonds, as the original fatty-acids. Conjugated materials of a complex nature are known to be produced, and cyclic monomers and intramolecular linear dimers are also generated. A loss of essential fatty acids is axiomatic in hydrogenation. Other monoglyceride components including hydrocarbons are reduced, and some FFA 0.1 to 0.3 percent may be formed.

Hydrogenation reaction tends to be selective, that is, the greater the degree of unsaturation of a fatty acid group in natural oils the greater is its tendency to undergo hydrogenation. Thus, the linoleic acid occurring as the glyceride in an oil tends to be converted to oleic or an iso-oleic acid before any oleic acids are converted to stearic acid. However, the degree of selectivity can be altered, to a large extent, by manipulating the conditions under which the reaction is conducted. Moderate changes in the hydrogenation can change the reactivity ratio of linoleic to oleic acid from about 7.5 to 1 to 50 to 1 (Bailey, 1949). The selectivity of the reaction normally is increased by increasing the temperature, catalyst concentration, decreasing the hydrogen pressure and the rate of mixing the hydrogen with the oil (Gunstone and Norris, 1983; Kheiri, 1984).

There are several different selectivities, examples are: Isomerization versus Hydrogenation, Linoleic acid versus Oleic acid, Linolenic versus Linoleic acid (Gunstone and Norris, 1983).

Trans-fatty acids on the average have higher melting points than cis fatty acids. Double bonds undergo geometrical and positional isomerization (Zeils and Schmidt, 1949). Hydrogenation is usually carried out using a closed vessel in an atmosphere of hydrogen. The catalyst usually used is Nickel, other catalysts are also available commercially, they include copper, copper/chronium combinations, and platinum. Other compounds are capable of poisoning the catalyst used and they include phospholipids, water, sulphur compounds, soaps, partial glycerol esters, carbon dioxide, and mineral acids (Nawar, 1985).

Hydrogenation presents, by far, the most powerful unit operation available to modify the physical properties of oils (Gunstone and Norris, 1983). It requires that the hydrogen gas should be as dry as possible. The oil must be refined, bleached and deodorised oil, free from fatty acids, soaps, water; all of which act as poison to the catalyst.

2.6.7. Fractionation and Winterization

Fats are mixtures of compounds and they are also made up of mixtures of triglycerides. Thus, if cooled carefully the lower melting (i.e. generally less saturated) remain in solution, while the higher melting ones separates out.

Fractionation removes higher melting triglycerides from chilled oil and produces a liquid oil that remain clean at refrigeration temperature (Weiss, 1983). If employed in the processing of oils such as cottonseed oil, of partially hydrogenated materials containing tryglycerides rich in saturated trans fatty acids,

the removal of these compounds increases the proportion of unsaturated fatty acids in the winterised products and can therefore be considered as nutritionally beneficial (Weiss, 1983); (FAO, 1977).

Thus, it is possible to obtain from one type of oil, two or more fats or oils of differing melting characteristics which can be used effectively for a wider range of specialized purposes than can the original fat (Ong *et al.,* 1995).

Gunstone and Norris (1983), list the well known fractionation practise as dry fractionation, detergent fractionation and solvent fractionation. Fractionation is used to process cocoa butter equivalent (CBE). Palm kernel stearin is a high value product obtained from fractionation, and is used for cocoa butter substitute (CBS) (Ong *et al.* 1995). In palm oil fractionation, palm olein is the premium product and palm stearin is the discounted product. By varying the fractionation conditions, the relative yield of the two fractions can be changed (Chandrasekharan and Kalyana, 1998). Other processes which make use of fractionation are de- waxing stearine separation.

2.6.8 Molecular distillation

Weiss (1983), has discussed molecular distillation as a method used in the preparation of monoglyceride of 90 percent, tocopherols and vitamin. It has, however, been recently applied to the processing of red palm oil (RPO) (Ooi *et al.,* 1996; Choo *et. al.,* 1993). This process involves a pre-treatment of the crude palm oil followed by deacidication and deodorization. The RPO produced has less than 0.1 percent of FFA and retains 80 percent of the original carotene and vitamin E. The quality of the red palm oil was comparable with other refined bleached and deodorized palm oil in terms of FFA and peroxide value

(POV). The conditions used are: temperatures of 165°C and pressures of 2.0 to 3.5 x 10^{-3} Torr. With the importance of Vitamin A in developing countries and its importance in prevention of cancers also WHO considers Vitamin A deficiency a public health problem, a major cause of mortality and morbidity and the single most important cause of blindness in children and is entirely preventable (Chandrasekharan, 1997; FAO /WHO, 1994) the processing of palm oil so as to preserve this important vitamin is vital in a developing country like Ghana.

2.6.9 Interesterification

The main source of solid fats in foods are hydrogenated vegetable oils and tropical oils. However, concerns lately about the health implications of using trans-fatty acids example a Canadian expert committee concluded that they have hyper cholesterolemic-effect so they increase the risk of cardiovascular disease (Holub 1991), it also increases the risk of myocardial infarction (Troisi *et al.,* 1992). These concerns therefore has spurred on the use of alternate methods of processing. (Gunstone and Norris, 1983).

There are two types of interesteritication; random interesterification and directed interesterification. In random interesterification, unsaturated fatty acids are generally esterified at the 2-position on the triglyceride chain. This position can be changed, with the aid of a catalyst, following which they will be attached to the 1- ,2- ,3- positions in a random manner, given as a fat with physical properties different from the original fat. (Gunstone and Norris, 1983)

In directed interesterification, there is a rearranging of the fatty acid in the glycerol backbone, directed to favour a fraction with a specific crystallization pattern. This is done by inducing crystallizing of a higher melting fraction thus

stopping its participation in the reaction. The higher melting triglycerides are made to crystallise or agglomerate while the reaction is taking place thus making them unavailable as reactants for the rest of the interesterification (Gunstone and Norris, 1983; Young, 1980). In this case the reaction is conducted at temperatures that approach that of the solid fraction. Interesterification is now being accomplished using the enzyme lipase in a process known as biomodification. This uses this enzyme to modify the palm oil and its fractions, this has been used to develop high-value cocoa butter. This process also exploits the specificity of lipase for the production of margarine and salad oils. Since this type of biomodification does not lead to the formation of trans fatty acids with its accompanying health concerns, it is particularly useful for hardening of oils (Jalani and Cheah, 1997).

This process is now being used in the development of margarine rich in polyunsaturates using palm oil and sunflower oil. Thus, eliminating trans-fatty acids as a problem (Mohd Suria *et al.*, 1995; Yusoff *et al.*, 1997).

Other processing methods are glycerolysis, plasticizing and tempering (Weiss, 1983). Interesterification normally changes the consistency of fats and oils and raises the melting point (FAO, 1977). The list of factors that affect the quality of palm oil is by no means complete, methods of processing are also undergoing changes. The Ghanaian situation has certainly got its peculiar characteristics, since, there are traditional methods which have been developed with time which have, only, recently begun to undergo modification. In the mills, the prime raw material, palm fruits, are produced under different soil and climatic conditions. Minor alterations in the factory setup therefore, may have a significant effect on quality. It is therefore of paramount importance that the effects of

processing on the quality of palm oil in Ghana should be appraised and updated. Table 2.11 shows the effect of processing on the various constituents of oil at the various stages.

Table 2.11

Effect of Processing on Vegetable Oil

Stage	Impurities Reduced or Removed
Crude oil Storage	Oil insolubles
Degumming	Phospholipids, sugars, resins, proteinaceous compounds, trace metals and others
Neutralization	Fatty acids, pigments, phospholipids, sulphur compounds, oil insolubles, water solubles
Washing	Soaps
Drying	Water
Bleaching	Pigments, oxidation products, trace metals, trace soaps
Filtration	Spent bleaching earth
Deodorization	Fatty acids, mono and diglycerides, aldehydes and ketones, hydrocarbons, sulphur compounds, pigment decomposition products
Physical refining	Fatty acids, mono and diglycerides, aldehydes and ketones, hydrocarbons, sulphur compounds, pigment decomposition products
Polishing	Removal of trace oil insolubles (to 30 mm or 19 mm)

Source: Young, 1980

2.7 THE QUALITY OF PALM OIL

The present views of quality in industry is a wholistic or total one, the oils and fats industry is not an exception. In this light, Maycock (1994) outlines several issues that go into making quality; quality control thus forming only a part of the broader issue of quality management. The issues are: General mill conditions and layout, hygienic conditions of the mills, operation efficiency, punctuality in completing log sheets, reports and knowledge of the processes.

Milling Operations: Systematic and relevant logging operation; maintaining proper processing conditions in both the oil line and kernel lines, adequate instruments and proper services.

Quality Control: Laboratory facilities and levels of staff, type of tests carried out, utilization of laboratory information for process and quality control.

Storage Conditions: Storage and handling conditions for crude palm oil and palm kernel.

Waste Treatment: Treatment and utilization of waste, disposal methods for empty bunches, disposal of surplus fibre and shell, as compared with minimum legal requirements.

Maintenance: State of maintenance of the mill, maintenance schedules and facilities and also implementation of ISO 9002. Thus, quality is no more a function of laboratory alone, but the responsibility of every mill employee from the top management to the workers on the mill floor (Maycock. 1994).

Pritchard (1982) and Russel (1982), have also outlined certain quality characteristics of palm oil which includes: even suitable characteristics, regular supply, low processing costs, good keepability, minimal fluctuations of characteristics within specifications of the user, absence of hazards e.g. contamination by pesticide residue, chemical deterioration. Aflatoxins do not occur in palm oil but, they are rarely present in palm kernel oil.

Elsewhere, Mohamed (1998), sees quality mainly as depending on the following sequence, EFA, iron and the bleachability quality begins from harvesting, through extraction, which requires that pressure, which is desirable be maintained to avoid cracking of nuts in order to avoid contamination. As part of the effort to improve quality world-wide PORIM has instituted Refiners Certificate of Competency (RCOC) to determine whether a palm refinery or mill had the skill, equipment and other resources to maintain and produce palm and palm oil products to meet a consistently high-quality standard (Mohamed, 1998). Quality requirements can be divided into five section; general cleanliness and on plant, quality control in the laboratory, instrumentation plant and process conditions and quality assurance, storage and disposal safety and maintenance. A general survey of the mills shows that they to a large extent met these conditions; the same, however cannot be said of traditional processors, who most of the time do not maintain basic hygiene on sites; processing conditions are far from ideal, and workers attitudes betray a lack of knowledge of the contending and predisposing factors that go into maintaining and deteriorating quality in a modern oil extraction and processing unit.

Similarly, Hoffman (1985), has described the concept of quality as pertains in the oils and fats industry as breakable into three broad areas: Extrinsic, intrinsic

and acceptance or rejection by the consumer. Extrinsic properties, as detailed includes, flavour, appearance and consistency.

Most intrinsic qualities can be monitored by physical, chemical and biological techniques in an objective way. Extrinsic qualities are easily and directly assessed by the consumer; the qualities based on these attributes are subjective but have a decisive influence on the ultimate acceptance or rejection of a finished product.

The final quality, according to Hoffman (1985) is dependant on the following factors: choice of crude fats, industrial processes and final product composition as determined by standards norms and users as superimposed on the intrinsic and extrinsic qualities.

These views of quality, are consistent with current concepts on the theory of quality for example in Total Quality Management (TQM), quality is seen in its totality, comprising of several factors. Synder (1994) and Harrington (1987) also view quality control as only an aspect of quality in the concept, TQM, which basically comprises, Quality Improvement (QI), Quality Assurance (QA), and Quality Control (QC).

Hartley (1984) and Flynn (1973) see critical points in the management of quality in palm oil. The critical points are the harvesting of the fruits and seeds harvesting; however, there is a conflict between yield and quality (Hartley, 1984). In Ghanaian oil mills, processing of palm oil is normally done within 24 hours after the harvest of the fruits. This is to stop rapid deterioration of fruits due to lipase activity (Hartley, 1984; Ames, *et. al.* 1960). Chong (1991) also reported the very fast rate of increase in FFA, just sixteen hours, buttressing the view that

in the processing of the fresh free bunches (FFB) time is a very critical factor.

Similarly, Siew (1995) has expressed the view that palm oil users require the oil to have good stability to ensure adequate shelf-life in the products prepared from it. Many factors which are beyond the users control influence the quality of palm oil. Good manufacturing practices must be applied at every step to ensure that high quality is maintained in the oil throughout the processing and transportation.

Thus, Thiagarajan (1998), sees quality in fats and oils industry as also competing on the new dimension of quality. So, modern enterprises are emphasising product and service quality as a competitive issue in doing business. Quality as a corporate strategy, hence, is generating tremendous amount of interest and emerging in the forefront as a corporate initiative that has influenced the export oriented Malaysian Palm Oil industry; thus, graduating from the traditional effort of controlling quality, purely, as an internal factory business, and beginning to manage quality from customers perspective - treating quality as a competitive opportunity. Their example is , therefore, worthy of note.

Chong Chiew (1995) emphasizes on the role of the worker in this modern approach to quality. Workers in both the plantations and mill should be instructed on why maintaining quality at every stage is important. They should manage quality with a sense of purpose, having thus been well instructed. This will avoid their delaying, unnecessarily, the processing of, for example, fresh free bunches (FFB), they will minimise fruit damage at the mills, and they will sterilize fruits as soon as possible. Road tankers should also be cleaned prior to loading in order to preserve oil quality even if the tanker is used to carry a single product. Table 11 shows standards of palm oil by Codex *Alimentarius* (1992).

Quality Control:

Traditional indices of quality still form an essential part of quality management. However, even here it is an evolving one, with new tests being developed every now and then, an example of a new test is deterioration of bleachability index (DOBI) (Siew, 1992). Also being used is ultrasonic wave velocity and its other parameters attenuation velocity etc, which can be used as a basic tool to identify palm oil, (Sidek *et al.*, 1996) to detect adulteration in oils and fats (Rao *et al.*, 1980). Elsewhere, Onwuliri (1998) reported that proton-nuclear magnetic spectroscopy can be used for rapidly assesing the quality of various edible oils in Nigeria. It was recommended that it be adapted by the Nigerian Standards Organization and other bodies to quickly identify fake oils on the market. Laser-Induced Fluorescence (LIF) has likewise proven to be sensitive in determining all the common oxidative and hydrolysis parameters thus making it an attractive and rapid procedure (Tan *et al.*, 1995; Tan *et al.*, 1994). Traditionally, the quality indices are percentage free fatty acid, peroxide value, anisidiene value, melting point, viscosity, retractive index, iodine value, fatty acid profile using gas chromatography. Table 2.12 shows the standareds as prescribed by (Codex *Alimentarius,* 1992).

Table 2.12a

Standards for Palm oil as by Codex *Alimentarius* (1992)

Codex Stan 125–1981

Relative Density/water at 20°C	0.891–0.899
R1 n_D^{50}	1.4449–1.455
Saponification value (mg KOH/g oil)	190–200
Unsaponifiable matter	< 12g/Kg

Table 2.12b

GLC Ranges of fatty acid composition

Carbon Chain Length	Percentage
C12	<0.4
C14	0.5–2.0
C16	<0.6
C18:0	3.5–6.0
C18:1	36–44
C18:2	6.5–12.0
C18:3	<0.5
C20:0	<1.0

Colour: Characteristics of the designated product

Odour and Taste: Characteristic of the designated product, free from fore-ground and rancid odour and taste.

Acid value:

Virgin oil > 10 mg KOH/g oil

Non-virgin oil not more than 0.6 mg KOH/g oil

Peroxide value: 10 meq peroxide oxygen/Kg of oil

Total carotenoids:

(Red Palm oil, RPO) <500 mg/Kg of oil>200 mg/Kg of oil carotene oils, calculated as beta carotene

2.8 BLEACHABILITY OF PALM OIL

The colour of palm oil makes bleaching an overriding consideration, since, although some of the materials for which palm oil is used for are colored, it

must be bleached to definite specifications for the various uses to which it is put (de Graaf, 1976). Since, palm oil is competing with other oils, any difficulty in bleaching palm oil thus giving it an additional expenditure, militates against its use. Hartley (1984) has defined poor quality palm oil as having poor bleachability or high free fatty acid levels or contaminated with water and impurities.

Palm oil from Africa, particularly West Africa, has been noted to be usually resistant to bleaching Nwanze (1964). Ames *et. al.* (1960) has shown that poor bleachability of West African palm oil, was most likely due to: oxidation catalysed by iron during processing and oxidation of lipoxidases in bruised fruits stored for various periods before processing.

Fruit storage for a few days is very common in West Africa, with Ghana being notably included. In some of the processes, fermentation is allowed to take place and this will affect bleaching since oxidation of the unsaturated fatty acids leads to the productions of compounds responsible for colour fixation (Jacobsberg, 1969). Also no significant deterioration in bleachability occurs during milling if the process is well-regulated and prolonged heating in the presence of air is avoided and copper is eliminated in the parts of processing equipments (Hartley, 1984).

Most processors in Ghana used metallic containers at various stages of processing, unaware of the consequences this could have on oxidation and bleachability (Ames *et. al.,* 1960). Storage in metal drums, which are often rolled, increases surface contact increasing the rate of oxidative reactions. Also, they are continually used causing accumulation of rancid oils leading to further infestations of subsequent batches.

Milling also affects bleachability of oils in no small way, too high a pressure

and failure to eliminate air may reduce bleachability (Ames *et. al.,* 1960). For the fact that peroxide value and totox values have not been able to give sufficient measurements of bleachability, deterioration of bleaching index (DOBI) is now encouraged.

$$\text{DOBI} = \frac{\text{Absorbance at 446 nm}}{\text{Absorbance at 269 nm}}$$ (Siew, 1992).

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Palm Fruits: Sampling begun with the fruits. At Ghana Oil Palm Development Corporation (GOPDC), Kwae, and also at Twifo Oil Palm Plantation fruits were randomly collected. The fruits were of the Tenera type. Palm fruits were also purchased from the traditional processors. Sampling of fruits was in line with Hartley (1984) and Ames *et. al.*, (1960).

3.1.2 Palm Oil: Industrial Processes

At both Twifo and Kwae, in both oil mills, seven (7) critical stages were identified from which samples were taken. The seven stages were crude oil tank stage, settling tank, After centrifagution, After purification, After vacuum drying, storage tank, sludge pit. The samples were stored in plastic containers and transported the same day to the laboratory where they were stored in cold room from where they were taken for analysis.

3.1.3 Palm Oil: Traditionl Processes

Two traditional methods: *Kyembe* and *Bedo* were selected. The methods were being used at Hemang and Ntratraso, towns near Twifo Praso.

In the *Kyembe* method the fruits on the bunch were threshed and boiled. The boiled fruits were then aged for 2 days; they were then pounded in mortars after which the nuts were separated from the fibre. The mash was then heated in metal containers, a process known as "Frying". The oil was then scooped.

MATERIAL FLOW CHART

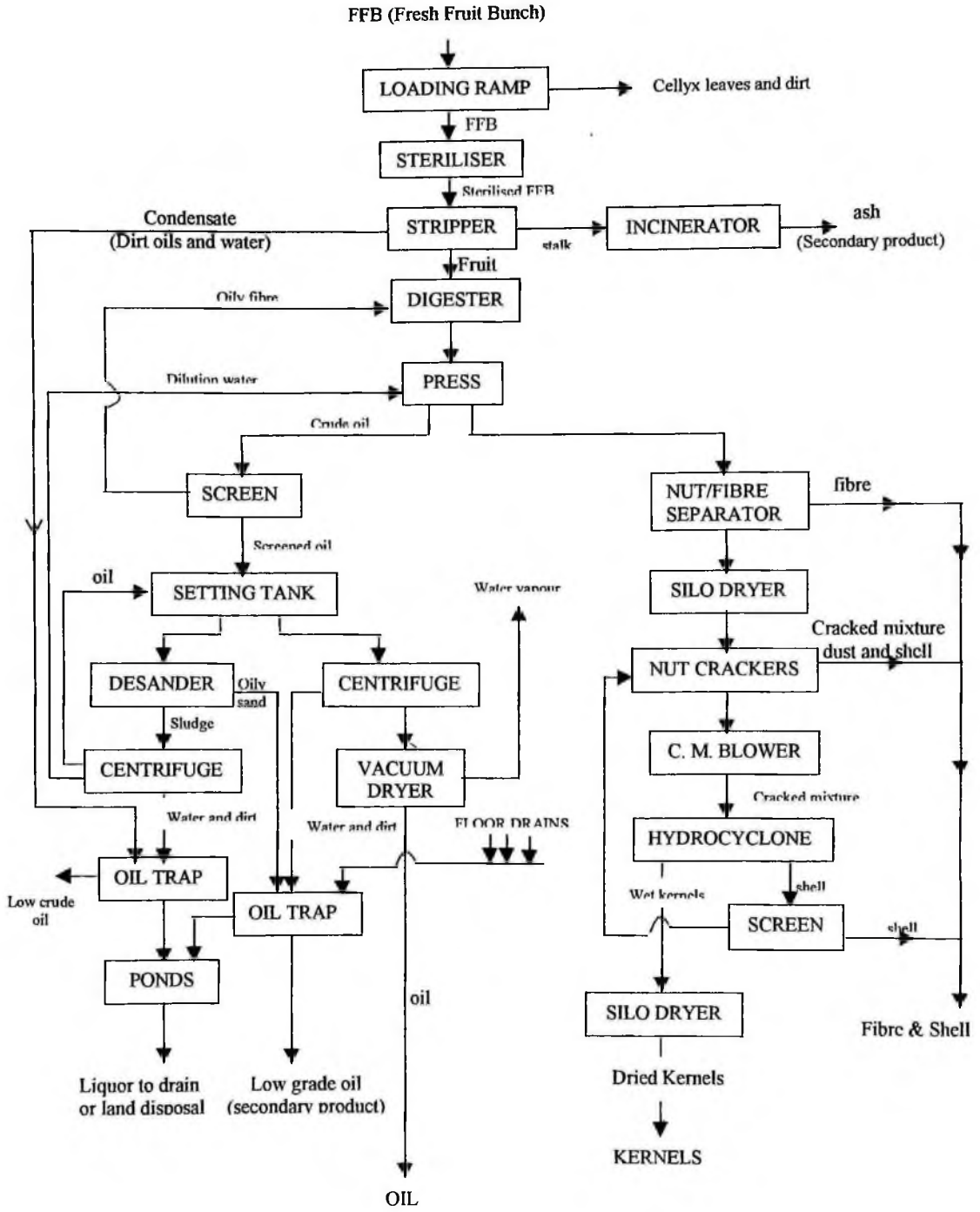

FIG 3.1 FLOW DIAGRAM OF THE VARIOUS STAGES OF PROCESSING AT GOPDC

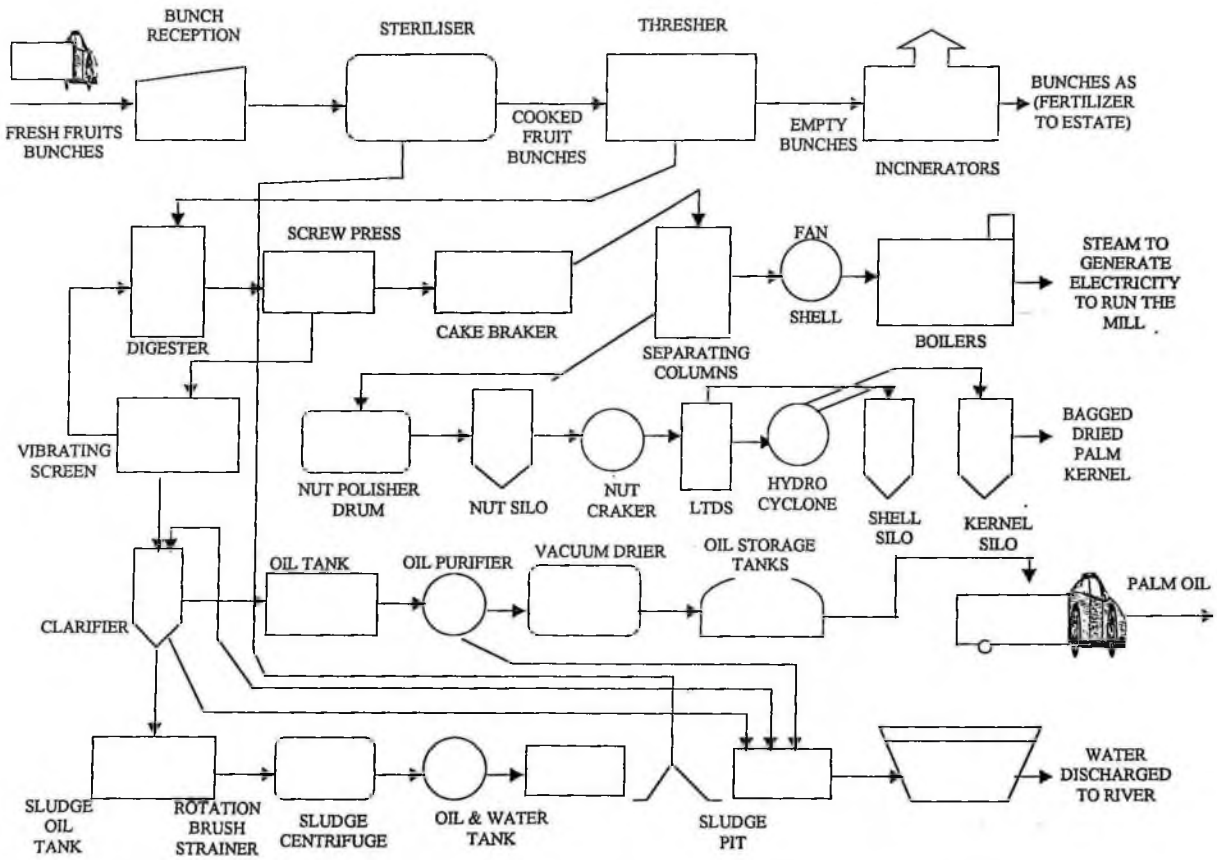

FIG 3.2 FLOW DIAGRAM OF THE VARIOUS STAGES OF PROCESSING OF PALM OIL AT TWIFO PRASO OIL PALM PLANTATION (TOPP)

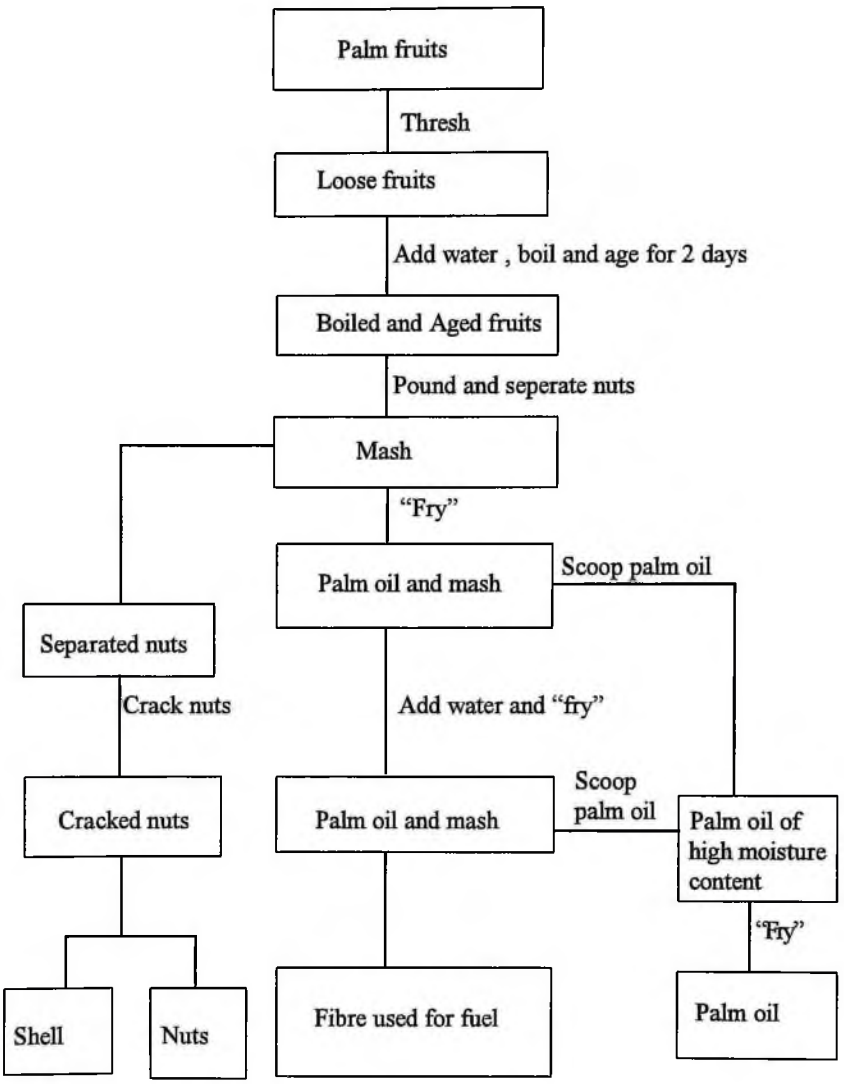

Fig. 3.3: Flow diagram of preparation of *Kyembe*

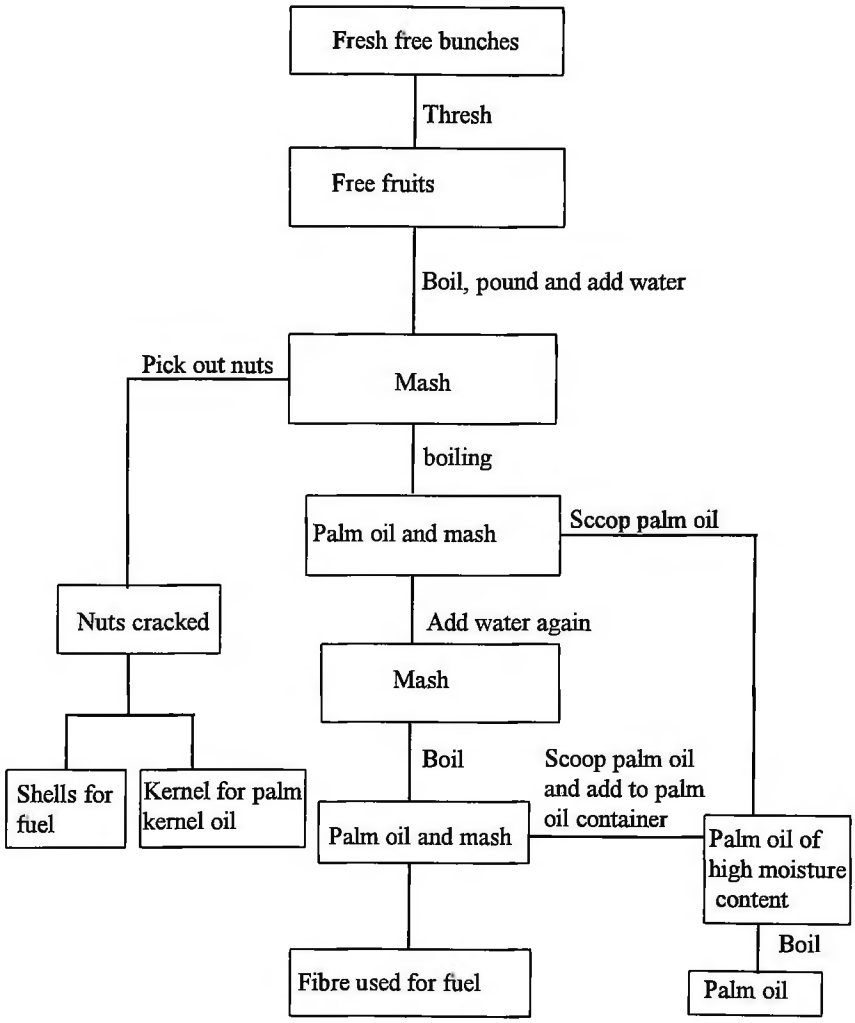

Fig. 3.4: Flow chart of preparation of *Bedo*

Water was added to the mash, it was then heated and any oil appearing on the surface was scooped and added to the first batch. The oil was then concentrated by boiling which evaporated the water. At a stage the evaporation is complete, the oil sticks to the calabash used for testing.

In the second method, known as *Bedo*, the palm fruits were threshed, boiled and pounded, after which they were mixed with water; the nuts were then picked out. The mash was then boiled till oil appeared on the surface, which then was scooped. Water was then added and another extraction made, the accumulated oil was then heated till the moisture content was considerably reduced. This was manifested by the oil sticking to the calabash when dipped into it. Oil obtained from the two traditional methods were stored in metal containers by the processors and covered with polythene sacks. Samples of palm oil were taken from the traditional processes.

The traditional methods of palm oil extraction were also simulated in the laboratory. The total weight of palm fruits was 10.23 kg. After boiling the fruits were pounded and then divided into two parts; 4.30 kg was used for the preparation of *Bedo* and 6.40 kg for *kyembe*. The oil gotten from the *bedo* process was 832 mls and that for the *kyembe* 820 mls they were subsequently used for analysis.

3.2 METHODS OF ANALYSIS

3.2.1 Moisture Content

AOAC (1990) METHODS 926.12

The sample was softened, taking care not to melt it . When it was soft enough it was thoroughly mixed. Weighing off 0.5 ± 0.2 g of the prepared sample was made into aluminium dishes of approximately 5cm diameter and 2cm deep and

they were covered with tight-fit slipover covers. They were dried to constant weight in a vacuum oven at uniform temperatures of 10°C above boiling point of water at working pressure, which was around 100 mmHg. They were then cooled in a desicator for 30 minutes and weighed . Constant weight was attained when successive one hour drying periods showed additional loss of 0.05 percent or less. The percentage loss of weight was reported as moisture and volatile matter. Six trials of each sample was taken and the results were taken and recorded.

3.2.2 Refractive Index Using Abbé Refractometer

AOAC (1990) method 921.08.

This method was based on the observation of position of borderline of total reflection in relation to faces of flint prism. The border line was brought into focus of the telescope by rotating double prism by means of alidade backward or forward until field of vision was divided into light and dark portion. The line dividing this portion is the 'boarder line', and as a rule, will not be obtained as a sharp line but band of colour. Colours were eliminated by rotating screw head of compensator until a sharp, colourless line was adjusted till it fell on point of intersection of cross hairs. The refractive index number 'n' was read. Three readings were taken and averaged. Six trials were performed on each stage. The oil was heated to temperatures of 50°C before the readings were made.

3.2.3 Free Fatty acid

AOCS method Ca 5cc–40.

The sample was well mixed and 5 g of it was well accurately weighed.

Ten(10) ml of neutralized, (95 percent ethanol and diethyl ether mixed in ratio of 1:1v /v) was added. It was then titrated with 1N NaOH with constant shaking until the pink colour persisted for 30 secs.

The percentage free fatty acid, FFA, was calculated as follows :

Percent FFA = Vol. of NaOH (ml) × Normality of NaOH × sample weight

Six trials of each sample were taken and the results were calculated and recorded.

3.2.4 Peroxide Value

AOAC (1990) method No. 965.33.

Five grammes of the oil was dissolved in 30 mls of a glacial acetic acid-chloroform mixture 3:2 v/v. 0.5 mls of saturated potassium iodide was added leading to the liberation of iodine by the reaction with the peroxides in the oil. It was titrated with standardized sodium thiosulphate. The peroxide value was calculated as below :

$$\text{Peroxide values} = \frac{(S - B) \times N \times 1000}{\text{Sample wt(g)}}$$

S = Sample Titration

B = Blank Titration

N = Normality of Sodium thiosulphate Solution.

Six trials of each sample was made and the results were calculated and recorded.

3.2.4.1 *Standardization of Sodium thiosulphate*

0.142 g of potassium iodine was weighed and dissolved in 25 ml of cooled

boiled out water, 2 g of the iodate free potassium iodide was added. (The absence of the iodine was indicated by adding dilute sulphuric acid no immediate yellow coloration indicate the absence of iodine). The liberated iodine was titrated with the thiosulphate with constant stirring. The solution was diluted to 200 ml with distilled water, when the colour of the liquid had become a pale yellow, starch was added as an indicator, and the titration continued till the colour changed from blue to colourless. Two other trials were performed and the average taken.

The normality of sodium thiosulphate solution was calculated.

1ml N - $Na_2S_2O_3$ = 0.03567 moles of KIO_3

3.2.5 Thiobabitaric acid value (Kirk and Sawyer, 1991)

The method used was IUPAC method 2.531.100 mg to 200 mg of sample (m) was weighed into a 25 ml volumetric flask. It was then dissolved in a small volume of 1-butanol, made up to volume with 1-butanol and mixed. Five (5.0) ml of the mixture was pippetted into a dry stoppered test-tube and 5.0ml of TBA reagent (200 mg of 2-thiobarbitaric acid in a 100 ml 1-butanol, filtered, and stored at below 4°C for not more than 7 days) . It was then stoppered, mixed and placed in water bath at 95°C for 120 minutes. It was then cooled and absorbance (AS) measured at 530nm in 10mm cells against distilled water. A reagent blank absorbance (AB) was run not to exceed 0.1.

TBA value was calculated as below:

$$\text{TBA value} = \frac{50 \times (AS - AB)}{m}$$

AS = Absorbance of sample.

AB = Absorbance of blank.

m = mass of sample

Six trials of each sample was taken and the results were calculated and recorded.

3.3 STATISTICAL ANALYSIS

SPSS program, windows 6.1 was used for statiscal analysis. Analysis of variance (ANOVA), and subsquently Tukey's test was used as multiple comparison test. Also used were t test and Levene's test.

CHAPTER 4

4.0 RESULTS

4.1 RESULTS AND ANALYSIS OF SAMPLES FROM GOPDC

4.1.1 Moisture Content

Moisture content of liquor from raw palm fruits before being processed: 26.94 ± 0.106

Table 4.1

Moisture content of palm oil at various stages of processing at GOPDC.

Stages of Processing	Percentage moisture Content
1. Crude oil tank	69.57±0.128
2. Settling tank	55.23±0.350
3. After centrifugation	53.84±1.571
4. After purification	5.25±0.280
5. After vacuum drying	1.43±0.461
6. Storage tank	1.41±0.1341
7. Sludge pit	93.85±1.990

Table 4.1 shows that the crude oil tank stage had the highest percentage moisture, 69.57 percent. Moisture content is expectedly high at the stage because steam is added during digestion. The settling tank stage presents the next highest moisture content, 55.23 percent. The very low moisture content in the after vacuum drying and storage stages, 1.43 and 1.41, respectively was due to the vacuum drying.

4.1.2 Refractive Index

Refractive indices of raw liquor from crushed palm oil: 1.4042±0.0057.

Table 4.2

Refractive indices of palm oil at various stages of processing at GOPDC

Stages of Processing	Refractive indices
1. Crude oil tank	1.3832±0.0044
2. Settling tank	1.3795±0.0032
3. After centrifugation	1.3753±0.0050
4. After purification	1.4408±0.0052
5. After vacuum drying	1.4453±0.0026
6. Storage tank	1.4400 + 0.0043
7. Sludge pit	1.3742±0.0026

From Table 4.2 the Crude oil tank, Settling tank and After centrifugation have lower indices, these have less amounts of oil in them. The higher refractive indices at the After purifier, After vacuum drying and Storage tank stages indicate the rise in the percentage crude palm oil, a reduction in the dirt matter and a reduction in the moisture content. The ANOVA Table shows whether these variations were significant.

From Appendix B, processing at GOPDC thus affected, significantly, the refractive indices in the following stages: stages 3 and 1, 6, 4, 5; 2 and 6, 4, 5; 1 and 6, 4, 5.

Processing at GOPDC employed physical methods, which significantly altered the primary determinants of refractive index in pure palm oil, palm oil and water. As Table 4.2 shows, moisture content of the oil at stages one and seven were very high, 69.57 and 93.85 respectively. These also had very low refractive indices of 1.3832 and 1.3742 respectively. Refractive index of water is 1.333 while that of palm oil at 50 °C should fall within the range of 1.4491 and 1.4552 [Codex *Alimentarius* (1993); Indian Emergency Specification for palm oil (1973)]. This is obtained in the vacuum drying stage; this is the stage where vacuum drying is employed to greatly reduce the moisture content. Purification stage also employs high-speed centrifugation to reduce the dirt and unwanted solid matter to a dirt content of 0.02 percent at the maximum. The waste from the centrifuge is channelled into the sludge pit from which technical grade oil is recovered and pumped into barrels for storage.

4.1.3 Free Fatty Acid (FFA)

Free fatty acid levels in liquid liquor of raw palm fruits: 2.31±0.018.

Table 4.3

Free fatty acid levels in palm oil at various stages of processing at GOPDC

Stages of Processing	Percent Free Fatty Acid
1. Crude oil tank	2.27±0.072
2. Settling tank	2.23±0.084
3. After centrifugation	2.40±0.031
4. After purification	2.29± 0.350
5. After vacuum drying	2.14±0.098
6. Storage tank	2.32±0.080
7. Sludge pit	2.43±0.034

From Table 4.3 the FFA level in the after centrifuge was 2.40. The lowest was in the "after vacuum" drying, 2.14. Ranking them, they follow this order 2.40–After centrifuge; 2.32–Storage tank stage; 2.29–After purifier stage; 2.27–Crude oil tank stage; 2.23–Settling tank stage; and 2.14–After vacuum drying stage. ANOVA was used to test whether these differences in the mean values were significant.

Processing did not produce any significant differences between the stages in the FFA levels at GOPDC.

4.1.4 Peroxide Values

Peroxide values in liquor of raw palm fruits: 2.81±0.051

Table 4.4

Peroxide values of Palm Oil at various stages of processing at GOPDC

Stages of Processing	Peroxide Values in mEq/kg
1. Crude oil tank	2.98±0.412
2. Settling tank	2.74±0.114
3. After centrifugation	2.83±0.116
4. After purification	2.90±0.087
5. After vacuum drying	2.89±0.028
6. Storage tank	2.88±0.060
7. Sludge pit	2.98±0.090

From Table 4.4, there are differences among the means. The highest peroxide value was in the Crude oil tank stage, 2.98; it was followed by the After purifier drying stage, 2.90, After vacuum drying stage 2.89; Storage tank stage 2.88.

After centrifuge stage, 2.83; Settling tank stage, 2.74. The ANOVA test at $P<0.05$ showed whether these differences in means were significant.

From Appendix D, the difference was not significant. Processing employed moisture reduction methods using high-speed centrifuges at stage 4 (using purifiers) and also used vacuum dryers. These will hardly produce any changes in POV, if the temperatures employed were not high enough to evaporate fatty acids and peroxides or cause a reaction between them, the physical methods employed were obviously not drastic enough.

4.1.5 TBA Values

TBA values of liquor of raw palm oil: 0.14±0.008

Table 4.5

TBA values of Palm Oil at various stages of processing at GOPDC

Critical Stages of Processing	TBA Values
1. Crude oil tank	0.15±0.014
2. Settling tank	0.16±0.009
3. After centrifugation	0.14±0.009
4. After purification	0.12±0.008
5. After vacuum drying	0.13±0.011
6. Storage tank	0.14±0.016
7. Sludge pit	0.16±0.012

Table 4.5 shows values which were ranked as follows: Settling tank stage 0.16; Crude oil tank stage, 0.15; After centrifugation stage and Storage tank stage, 0.14; After vacuum drying stage, 0.13; After purifier statge, 0.12. The ANOVA tests shows whether the differences were real.

From Appendix E the differences were significant. Tukey's test showed that the following stages showed significant differences in their means of their TBA values 4 and 3, 6, 1, 2; 5 and 1, 2; 3 and 2 also 6 and 2. The TBA value at stage two was the highest, the processing at stage two was very rudimentary, in the processing line, it had a high moisture content of 55.23 percent, its susceptibility to deterioration which is measurable by a high TBA value was indisputable. It is noteworthy that this analysis took place six months after the analysis had been carried out and had found no significant difference in the FFA levels. However, the TBA value of 0.16 which was the highest, still fell in the acceptable range of TBA value required for crude oil: 0.1–0.2, (Kirk and Sawyer, 1991).

4.2 RESULTS AND ANALYSIS OF SAMPLES FROM TWIFO OIL PALM PLANTATIONS.

4.2.1 Moisture Content

Moisture content of liquor from raw palm fruits: 26.97 + 0.102

Table 4.6

Moisture content of Palm Oil from TOPP at various stages of processing in percentages.

Stages of Processing	Moisture Content (percent)
1. Crude oil tank	69.15±0.928
2. Settling tank	56.06±0.689
3. After centrifugation	53.85±0.829
4. After purification	6.35±0.503
5. After vacuum drying	2.24±0.174
6. Storage tank	3.39±0.433
7. Sludge pit	92.62±1.480

Table 4.6 shows the crude oil tank stage of palm oil had a moisture content of 69.15; Settling tank stage, 56.06; After centrifugation stage, 53.85; After purification stage, 6.35; Storage tank stage, 3.39; After vacuum drying stage, 2.24.

From Appendix F the differences in moisture content was significant. The Tukey's test produced differences in means between stages 5 and 4, 3, 2, 1; 6 and 4, 3, 2, 1; 4 and 3, 2, 1; 3 and 2, 1; 2 and 1. Processing at TOPP, employed physical methods to reduce the moisture content, increase the percentage palm oil, and to reduce the dirt and other unwanted matter to the barest minimum. The crude oil tank had a high percentage of moisture because sterilization included injection of steam in the jacket. The settling tank had a high percentage moisture because the part sampled was the lower layer which had a lower percentage palm oil. The drop in percentage moisture from crude oil tank to this stage was as a result of an increase in solid matter at this stage.

4.2.2 Refractive Index

Refractive index of liquor from raw palm fruits: 1.4050±0.0059

Table 4.7

Refractive indices of Palm Oil at various stages of processing at TOPP

Critical Stages of Processing	Refractive Indices
1. Crude oil tank	1.3793±0.0027
2. Settling tank	1.3762±0.0029
3. After centrifugation	1.3747±0.0021
4. After purification	1.4435±0.0018
5. After vacuum drying	1.4468±0.0012
6. Storage tank	1.4448±0.0019
7. Sludge pit	1.3757±0.0025

Table 4.7 showing the refractive indices according to order of magnitude were: the After centrifugation stage 1.3747, Settling tank stage 1.3762, Crude oil tank stage 1.3793, After purification stage 1.4435, Storage tank stage 1.4448, After vacuum drying stage, 1.4468. The increase in refractive indices reflects to an extent, the increases in oil content, decrease in moisture and dirt content along the processing line. The ANOVA tests whether the differences in means were significant at $p < 0.05$.

From Appendix G, the differences were significant. Processing produced differences in the mean between 3 and 1, 4, 6, 5; 2 and 4, 6, 5; 1 and 4, 6, 5. Processing at TOPP, employed physical methods to reduce the moisture content, increase the percentage of palm oil and to reduce the dirt and other non-oil solid matter to the barest minimum. The crude oil tank had a high percentage of moisture because sterilization included the injection of steam into the jacket.

4.2.3 Free Fatty Acid (FFA)

Free fatty acid levels in liquor from raw palm fruits 2.45±0.017.

Table 4.8

Free Fatty Acid levels in palm oil at the various stages of processing at TOPP

Critical Stages of Processing	Percent FFA
1. Crude oil tank	2.45±0.079
2. Settling tank	2.66±0.173
3. After centrifugation	2.41±0.102
4. After purification	2.41±0.102
5. After vacuum drying	2.39±0.123
6. Storage tank	2.40±0.1087.
7. Sludge pit	2.49±0.160

Table 4.8 shows that FFA could be ranked in the following order: After vacuum drying stage, 2.39; Storage tank stage, 2.40; After purification and After centrifugation stages, 2.41; Crude oil tank stage, 2.45; Sludge pit stage, 2.49; Settling tank stage, 2.66, the ANOVA table showed whether this ranking was real.

From Appendix H, the differences were therefore significant. The stage two had the highest mean 2.66. The Tukey's test showed that differences between 2, and 5,6,3,4,1 were significant. If these differences did not arise as a result of processing, then, repetition of a significantly high FFA value suggesting high rancidity in the settling tank (stage 2) in the samples of both TOPP and GOPPC, as in Table 4.5 where stage two had the highest TBA value of 0.16, affirms the fact that stage two being very rudimentary in the chain of processing was highly susceptible to rancidity. Rancidity and its predisposing factor, FFA, were high because the level of dirt particles, solid matter and other agents of rancidity were very high in the second stage. These differences were reduced in stages 3 and 4 which involved the concentration of the oil from stages one and two using centrifugation at high speed. Vacuum drying also removes the moisture to a large extent and in the absence of oxygen which is a gas absolutely required for oxidation.

4.2.4 Peroxide Values

Peroxide values of liquor from raw palm fruits. 2.97±0.072

Table 4.9

Peroxide values of Palm oil at various stages of Processing at TOPP

Critical Stages of Processing	Peroxide Values in mEq/kg
1. Crude oil tank	3.05±0.082
2. Settling tank	2.97±0.114
3. After centrifugation	2.97±0.114
4. After purification	3.04±0.077
5. After vacuum drying	2.96±0.069
6. Storage tank	3.00±0.074
7. Sludge pit	3.03±0.075

From Table 4.9, peroxide values increased according to the following order: After vacuum drying stage 2.96; Settling tank stage and After centrifugcation stage 2.97; Storage tank stage 3.00; After purification stage, 3.04; Crude oil tank stage 3.05.

From Appendix I, therefore was no significant differences between the POV values of the various stages. Processing at TOPP did not significantly affect the peroxide values. This was because processing employed physical methods, crushing, drying, centrifuge, all of which may not impact significantly on the chemical indications of rancidity, for example peroxides, if they are done in moderation, as occured at TOPP.

4.2.5 TBA Values

TBA values of liquor from palm fruits. 0.14±0.006

Table 4.10

TBA values of Palm oil at various stages of Processing at TOPP

Critical Stages of Processing	TBA Values
1. Crude oil tank	0.13±0.009
2. Settling tank	0.14±0.012
3. After centrifugation	0.15±0.011
4. After purification	0.13±0.008
5. After vacuum drying	0.14±0.011
6. Storage tank	0.15±0.014
7. Sludge pit	0.15±0.015

From Table 4.10, the TBA values increases in this order: Crude oil tank stage and After purifier stage, 0.13, Settling tank stage and After vacuum drying stage, 0.14; After centrifuge stage, and Storage tank stage 0.15. The ANOVA table shows whether these differences were significant at the $p<0.05$.

From appendix J there was no siginificant differences between the TBA values. Processing at TOPP did not significantly alter the TBA values. Processing at TOPP made use of physical methods: separation, as occurs in the crude oil tank; heating, as occurs in the vacuum drying stage; high-speed centrifugation; which occurrs at the centrifugation and purification stages. All these methods may not necessarily affect the chemical constituents if they are done in moderation, as occured at TOPP.

4.3 COMPARISON OF THE RESULTS OF THE TWO INDUSTRIAL PROCESSES, TOPP AND GOPDC

4.3.1 Moisture Content

Moisture content of liquor from raw palm fruits.

TOPP	6.97
GOPDC	6.95
MEAN	6.96

Table 4.11

Means of moisture content of palm oil at the various stages of processing at TOPP and GOPDC (in percentages)

Critical Stages of Processing	GOPDC	TOPP
1. Crude oil tank	69.57	69.15
2. Settling tank	55.23	56.06
3. After centrifugation	53.84	53.85
4. After purification	5.25	6.35
5. After vacuum drying	1.43	2.24
6. Storage tank	1.41	3.39
7. Sludge pit	93.85	92.62

Table 4.11 shows the means of moisture content of the two industries TOPP and GOPDC. The grand means of GOPDC is less than that of TOPP. The two-way Anova test whether the differences between them were significant at $p<0.05$.

Appendix K shows that the moisture content of palm oil of the two processes were significantly different. Since the difference in moisture content was as a result of a lesser moisture content for GOPDC, the process of GOPDC is to be favoured; the difference was, however, not much.

The stages of processing were not significantly different. There were no significant interactions between the two processes.

4.3.2 Refractive Index

Refractive index of liquor from raw palm fruits.

TOPP 1.4050

GOPDC 1.4042

Mean 1.4046

Table 4.12

Means of the refractive indices at the various stages of processing at TOPP and GOPDC at 50°C .

Critical Stages of Processing	GOPDC	TOPP
1. Crude oil tank	1.3832	1.3793
2. Settling tank	1.3795	1.3762
3. After centrifugation	1.3753	1.3747
4. After purification	1.4408	1.4435
5. After vacuum drying	1.4453	1.4468
6. Storage tank	1.4400	1.4448
7. Sludge pit	1.3740	1.3757

Table 4.12 shows the refractive indices of palm oil, the mean for GOPDC was 1.4055 and that for TOPP was 1.4059, the two-way anova seeks to test whether the differences in means were significant, the interactions, and whether there was a main effect for the stages of processing.

From Appendix L, there is no significant difference in the refractive indices of the two industrial processes, GOPDC and TOPP.

There is, however, a main effect in the stages of processing, it is highly significant. In both processes moisture content is significantly reduced. This

significantly increases the oil content, thus increasing the refractive index, this is because palm oil has a higher refractive index than water. There is also significant interactions.

4.3.3 Free Fatty Acid

Free Fatty Acid Levels of Liquor From Raw Palm Fruits.

TOPP 2.41

GOPDC 2.31

Mean 2.36

Table 4.13

Means of Free Fatty Acid levels of Palm Oil at the various stages of Processing at TOPP and GOPDC (in percentages)

Critical Stages of Processing	GOPDC	TOPP
1. Crude oil tank	2.27	2.45
2. Settling tank	2.23	2.66
3. After centrifugation	2.40	2.41
4. After purification	2.29	2.41
5. After vacuum drying	2.14	2.38
6. Storage tank	2.32	2.40
7. Sludge pit	2.43	2.48

Table 4.13 shows the FFA as headlined. There were differences among the means in the various stages, the mean for GOPDC was 2.30 and that for TOPP was 2.46. The two way ANOVA test if these differences were significant and also if any interaction occurred at $P<0.05$

From Appendix M, there was a significant difference in the FFA in the two processes TOPP and GOPDC. The main FFA for GOPPC was 2.30, TOPP had 2.46. Thus on the whole TOPP had a higher FFA than GOPDC and this was

in the favour of GOPDC. There was also significant interactions.

4.3.4 Peroxide Values

Peroxide Values of liquor from raw palm fruits

TOPP	2.81
GOPDC	2.97
Mean	2.89

Table 4.14

Means of the Peroxide values of Palm Oil at the various stages of Processing at GOPDC and TOPP (in mEq/kg)

Critical Stages of Processing	GOPDC	TOPP
1. Crude oil tank	2.98	3.05
2. Settling tank	2.74	2.97
3. After centrifugation	2.83	2.97
4. After purification	2.90	3.04
5. After vacuum drying	2.89	2.96
6. Storage tank	2.88	3.00
7. Sludge pit	2.98	3.03

Table 4.14 gives the peroxide values of palm oil as indicated, the means at various stages were not equal, for example at crude oil tank stage (GOPDC), 2.98 mEq/kg and TOPP, 3.05 mEq/kg. Two-way ANOVA tests whether these differences in means were significant, real and not necessarily due to chance and also if there were some interaction.

From Appendix N, there was significant difference in the POV of the two industrial processes. The difference in POV of the two was therefore significant. A lower POV is preferred, the POV was therefore in the favour of GOPDC. The Codex *Alimentarius* (1992) prescribes a POV of not more than 10mEq/kg.

Thus, though there was a significant difference in the POV of the two, the values, 3.05 mEq/kg and 2.98 mEq/kg for GOPDC and TOPP respectively, were well below the maximum acceptable limit. The causes of these differences were not immediately obvious. There was also no significant difference in the stages, processing using the two methods, did not significantly alter the POV values.

4.3.5 TBA Values

TBA values of liquor from raw palm fruits.

TOPP 0.14

GOPDC 0.14

Mean 0.14

Table 4.15

Means of TBA values of Palm Oil at the various stages of Processing at TOPP and GOPDC

Critical Stages of Processing	GOPDC	TOPP
1. Crude oil tank	0.15	0.13
2. Settling tank	0.16	0.14
3. After centrifugation	0.14	0.15
4. After purification	0.12	0.13
5. After vacuum drying	0.13	0.14
6. Storage tank	0.14	0.15
7. Sludge pit	0.16	0.15

Table 4.15 shows the TBA values at GOPDC and TOPP as headlined. The means were not equal at the various stages of processing. Two way Anova at $p<0.05$ test whether they were the same and also if there were any interactions.

From Appendix O, there was no siginificant differences between the values of the two processes TOPP and GOPDC. There were, however, significant differences between the values TBA of the various stages of processing.

There was significant interactions, the two industries employed the same techniques and had the same standard as regards quality. It is difficult to see the causes of these differences. One argument will be the time difference in analysis of this particular test (6 months after samples had been collected from TOPP) this, and the interruptions in power supply could have accounted for the anomaly.

4.4 RESULTS AND ANALYSIS OF SAMPLES PREPARED USING TRADITIONAL PROCESSES

4.4.1 Results of samples at stages of processing using *Kyembe* method of processing

Results obtained of the *Kyembe* Process.

Moisture content of raw samples used for processing of *Kyembe* and at stages of processing.

Moisture content of raw samples before processing using *Kyembe* method, 26.86±0.055.

Table 4.16a

Moisture content of palm oil at stages of processing using *Kyembe* method

Critical stages of processing	Moisture content
1. Mashed	56.69±0.209
2. After "frying"	5.64±0.199

Refractive indices of raw samples used for the processing of *Kyembe,* and at the stages of processing.

Refractive index of liquor obtained from raw palm fruits before processing using the *Kyembe* method 1.3059±0.0067

Table 4.16b

Refractive indices of palm oil at the stages of processing using *Kyembe* method.

Critical stages of Processing	Refractive Index at 50°C
Mashed	1.3960±0.0093
After "frying"	1.4175±0.0033

Free fatty acid levels of raw samples used for the processing at the various stages of processing.

Free fatty acid levels of liquor of raw palm fruits before processing using *Kyembe* 2.14±0.011.

Table 4.16c

Free fatty acid levels in palm oil at the stages of processing using *Kyembe* method.

Critical stages of Processing	Percent Free Fatty Acid level
Mashed	2.12±0.114
After "frying"	2.14±0.107

Peroxide values of raw samples used for the processing of *Kyembe* and at the stages of processing.

Peroxide values of liquor of raw palm fruits before processing using *Kyembe* method in mEq/kg. 3.06±0.020.

Table 4.16d

Peroxide values of palm oil at the stages of processing using *Kyembe*.

Critical stages of processing	Peroxide values mEq/kg
Mashed	3.10±0.050
After "frying"	3.04±0.080

TBA values of samples prepared using *Kyembe* method of processing and at the various stages of processing.

TBA values of liquor of raw palm fruits before processing using *Kyembe*. 0.15±0.009.

Table 4.16e

TBA values of palm oil at the various stages of processing using *Kyembe*

Critical stages of processing	TBA values
Mashed	0.16±0.016
After "frying"	0.16±0.016

Table 4.16a shows the moisture content of palm oil at the stages of processing. There was a very big difference between the mashed stages, 56.69 percent and the after "frying" stages 5.64 percent. Processing thus greatly reduces the moisture content to manageable levels. Too much moisture is undesirable.

Table 4.16b shows the refractive indices as headlined for *Kyembe*, that for the mashed stage was 1.3960 and that for the after frying stage was 1.4405. The results therefore suggest differences in the refractive indices as a result of processing. The t-test was therefore used to draw conclusive decisions as to whether these differences were real and not due to chance.

An analysis of refractive indices of palm oil at the stages of processing using the *Kyembe* method by t-test showed that it was significant. Processing using *Kyembe*, significantly alters the refractive index of palm oil. It increases it. This is so because the physical methods employed alters the percentage moisture in the oil, thus altering the proportion of water to oil; the two components that contribute to the refractive index most significantly.

Table 4.16c shows the FFA levels at the stages of processing were 2.12 percent, mashed stage and after "frying" stage 2.14 percent. High FFA levels are undesirable, t-test was used to test if the differences were real and not due to chance.

Analysis of the FFA levels in palm oil at the stages of processing using *Kyembe* method by t-test showed that the data does not give any evidence of a difference in means. Processing using *Kyembe* does not significantly alter the FFA levels. The methods involved mainly physical processes for example pounding, crushing etc these were not drastic enough to alter the FFA levels significantly.

Table 4.16d shows the means of peroxide values as headlined of the Kyembe process the means were not equal, 3.10 mEq/kg for the mashed stage and 3.04 mEq/kg, for the after "frying" stage. t-test was used to draw conclusive decisions as to whether these differences were real and not due to chance.

Analysis of peroxide values of palm oil at the various stages of processing using *Kyembe* by t-test showed that there was no significant differences in FFA values between the two stages.

There is, therefore, no strong evidence to suggest that processing using the *Kyembe* method significantly altered the peroxide value. This was because the methods employed were physical and they were not drastic enough to alter the peroxide value.

Table 4.16e shows the TBA values as headlined. The two stages had values 0.16 each, t-test was used to conclusively decide whether it was real and not due to chance.

Analysis of TBA values of palm oil at the stages of processing using *Kyembe* method by t-test showed that there was no significant differences in TBA values

of palm oil between the two stages.

The data therefore does not give evidence of alteration in the TBA values in the stages of processing using *Kyembe* method. The methods employed were not drastic enough to chemically alter the indicators of TBA value. The TBA values of 0.16 falls within the required ranges of TBA values for good crude oils (0.1 to 0.2) as per Kirk and Sawyer (1991).

4.4.2 Results of samples at the stages of Processing using *Bedo* method of processing.

Results of the *Bedo* Process

Moisture content of raw samples used for the processing of *bedo* and at various stages of processing.

Moisture content of liquor of raw palm fruits before processing using the *bedo* method 25.75±0.045.

Table 4.17a

Moisture content of palm oil at the stages of processing using *Bedo*.

Critical stages of processing	Moisture content in percentages
Mashed	56.69±0.454
After boiling	5.54±0.143

Refractive index of raw samples used for the processing of *bedo* and at the various stages of processing.

Refractive index of liquor of raw palm fruits before processing using bedo method 1.3059 ± 0.0067.

Table 4.17b

Refractive indices at the stages of processing using *Bedo* method

Critical stages of processing	Refractive indices at 50°C
Mashed	1.4003±0.0064
After boiling	1.4175±0.0

Free fatty acid levels of raw samples used for the processing of *Bedo* and at various stages of processing.

Free fatty acid levels of liquor of raw palm fruits before processing 2.14±0.011.

Table 4.17c

Free fatty acid levels of palm oil at the various stages of processing of palm oil (*Bedo* process).

Critical stages of processing	Free fatty acid levels in percentages
1. Mashed	2.05±0.134
2. After boiling	2.12±0.095

Peroxide values of samples at stages of processing using *Bedo* method of processing (mEq/kg).

Peroxide values of liquor from raw palm fruits before processing 3.06±0.020.

Table 4.17d

Peroxide values of palm oil at the stages of processing (*Bedo* Process)

Critical stages of processing	Peroxide values mEq/kg
1. Mashed	3.03±0.100
2. After boiling	3.07±0.080

TBA values of samples at stages of processing using *Bedo* method of processing. TBA values of liquor from raw palm fruits before processing 0.15±0.009.

Table 4.17e

TBA values of palm oil at the various stages of processing (*Bedo* Process)

Critical stages of processing	TBA value
1. Mashed	0.16±0.012
2. After boiling	0.16±0.012

Table 4.17a shows the moisture content as headlined using the bedo method. High moisture content is undesirable since it provides a conducive environment for the proliferation of microbiological agents it thus increases the FFA and peroxide values. The reduction in the moisture content as a result of processing is desirable.

Table 4.17b shows the refractive indices as headlined, 1.4003 for the mashed stage and 1.4175 for the after boiling stage. The t-test was used to draw conclusive decisions.

Analysis of the refractive indices of palm oil at the stages of processing using *Bedo* method of processing by t-test showed that processing using the *Bedo* method significantly altered the refractive indices of palm oil. The *Bedo* method of processing employs physical methods, for example boiling, which reduces the moisture content thus altering the moisture to oil ratio, a significant determinant of refractive index.

Table 4.17c shows the FFA levels at the various stages of processing were 2.05 for the mashed stage and after boiling 2.12, t-test was used to conclude whether the differences were real and not due to chance.

Analysis of FFA levels in palm oil at the stages of processing using *Bedo* by t-test showed that there was no significant differences in the FFA values in the two stages of processing. There is, therefore no real alteration in the FFA levels using the *Bedo* method. Processing employs no chemicals, and the physical methods may not be drastic enough as to significantly alter the levels of FFA.

Table 4.17d show peroxide values as headlined of the stages of processing using *bedo* method. They were not the same 3.03 mEq/kg and 3.07 mEq/kg. The t-test was used to find out whether these differences were real and not due to chance.

Analysis of the peroxide values of palm oil at the stages of processing using *Bedo* by t-test showed that processing using *bedo* method does not significantly alter the peroxide values. The physical methods used may not be drastic enough so as to alter, significantly, the peroxide value. This also supports the conclusion made with respect to the FFA levels using this same method of processing.

Table 4.17e gives the TBA values using bedo method for processing. They were equal and this was tested using t-test to draw conclusive decisions.

Analysis of the TBA values in palm oil at the stages of processing using *Bedo* by t-test showed that there was absolutely no significant difference between the means, as shown in Table 4.17e. Traditional methods employed only physical methods which did not alter significantly of the indicators of TBA value, malonadehyde, as postulated by Sinnhuber *et al.*, (1958).

4.4.3 Comparison of the results of traditional processes.

Table 4.18a

Moisture content of traditional processes in palm oil at stages of processing in percentages.

Critical stages of processing	*Bedo*	*Kyembe*
1. Mashed	56.74	56.69
2. After "frying"/boiling	5.10	5.54

Table 4.18b

Refractive indices of palm oil of traditional methods at stages of processing.

Critical stages of processing	*Bedo*	*Kyembe*
1. Mashed	1.4003	1.3960
2. After "frying"/boiling	1.4175	1.4405

Table 4.18c

Free fatty acid levels in palm oil at the stages of processing using traditional method in percentages

Critical stages of processing	*Bedo*	*Kyembe*
1. Mashed	2.05	2.12
2. After "frying"/boiling	2.12	2.15

Table 4.18d

Means of peroxide values of palm oil at the stages of processing using traditional methods in mEq/kg.

Critical stages of processing	***Bedo***	***Kyembe***
1. Mashed	3.03	3.10
2. After "frying"/boiling	3.07	3.04

Table 4.18e

TBA values of palm oil at the stages of processing using traditional methods

Critical stages of processing	***Bedo***	***Kyembe***
1. Mashed	0.16	0.16
2. After "frying"/boiling	0.16	0.16

Table 4.18a shows the moisture contents of two traditional processes in their two critical stages of processing. The mean moisture in *Bedo* was 30.92 percent, and the mean for *Kyembe* 26.97 percent. The two way ANOVA tests whether these differences were real and not due to chance.

Analysis shows that there was no significant difference in the moisture content arising as a result of using the two traditional methods of processing. The stages present a significant value. Processing using *Bedo* had a more drastic fall in moisture content 51.64 percent as compared to *Kyembe* 51.15 percent. This produced the main effect due to stages.

Table 4.18b showed refractive index for mashed *bedo* to be 1.4003 and

that of *Kyembe* had a refractive index of 1.3905, while after boiling *Bedo* had a refractive index of 1.4175 and that for *Kyembe* 1.4405. There were differences in the refractive indices of these stages. The two-way anova test whether they were significantly different.

Appendix P showed that there was a significant difference between the refractive indices of the two processing methods. The process known as "frying' involved heating of mashed fruits without the addition of any water. *Kyembe* had a higher refractive index, 1.4182 as compared to 1.4089. As far as refractive indices is concerned, *Kyembe* is to be favoured.

Table 4.18d shows the peroxide values to be 3.03 mEq/kg for mashed *Bedo* and 3.10 mEq/kg for mashed *Kyembe.* A peroxide value of 3.07 mEq/kg for boiled *Bedo* and 3.04 for "fryed" *Kyembe,* these were different. Two-way ANOVA tests whether these differences were significant. Appendix P showed that the peroxide values as headlined were not significantly different. There was no significant differences between the stages. They also produced no interactions.

The TBA values as shown in Table 4.18e were the same for all the stages, 0.16. Two-way anova test whether there were differences. Appendix P shows that there was no significant difference between the two traditional processes. *Kyembe* and *Bedo* as regards TBA values. There was no significant differences also in the stages, as far as TBA values were concerned, neither did the result indicate any interactions in the TBA values. Traditional methods employed physical methods, which did not alter significantly the indicators of TBA value malonaldehyde, as postulated by Sinnhuber *et al.*, (1958).

4.5 COMPARISON OF THE RESULTS OF THE FINAL STAGES OF PROCESSING OF THE INDUSTRIAL AND TRADITIONAL METHODS

Results of the final stages of processing of the industrial and traditional methods

Table 4.19a

Moisture Content of Palm Oil of the Industrial and Traditional Methods of Processing at their final stages.

Method of Processing	Percent Moisture
1. Industrial	2.40±1.076
2. Traditional	5.32±0.280

Table 4.19b

Refractive Indices of Palm Oil of the Industrial and Traditional Methods at their final stages of Processing

Method of Processing	Refractive index
1. Industrial	1.4424±0.0047
2. Traditional	1.4290±0.0125

Table 4.19c

FFA levels of Palm Oil of the Industrial and Traditional processes at their stages of Processing

Method of Processing	Percent FFA levels
1. Industrial	2.36±0.100
2. Traditional	2.13±0.009

Table 4.19d

Peroxide values of Palm Oil of the Industrial and Traditional Methods at their final stages of processing

Method of Processing	Peroxide value mEq/kg
1. Industrial	2.94±0.089
2. Traditional	3.05±0.077

Table 4.19e

TBA values of Palm Oil of the Industrial and Traditional processes at their final stages of processing

Method of Processing	TBA Value
1. Industrial	0.14±0.014
2. Traditional	0.16±0.014

From Table 4.19a the industrial methods had a moisture content at the sixth stage of 2.40 percent and the traditional method had 5.32 percent.

From appendix Q, Levene's test for equality of variances showed that the variences were not equal. If equal variances cannot be assumed then from appendix R there was a significant difference in the moisture content of the two processes since the traditional method had a moisture content of 5.32 percent and industrial 2.40 percent, the industrial method was significantly better.

Table 4.19b showed the industrial method had a refractive index 1.4424, the traditional was 1.4290, From appendix Q, Levene's test of equality of variance

showed the variances were not equal. Therefore, there was a significant difference between the refractive indices of the final stages of the two processes. Since the industrial one had a refractive index of 1.4424 as compared to the traditional one (1.4294) it was significantly higher. It is therefore better as far as refractive index was concerned.

Table 4.19c showed that the industrial methods had an FFA of 2.35 percent, as against 2.13 percent for traditional method, the industrial method was therefore higher. From appendix Q, the Levene's test for equality of variances showed that equality of variances can be assumed. From appendix R, therefore, there was significant differences between the two processes. The industrial were, therefore, with significantly higher FFA levels, FFA is an undesirable quality it appears that the traditional methods were better as far as percentage FFA was concerned since they produced a lower FFA.

In all the groups, except in the GOPDC group where processing produced a weakly significant difference in percent FFA, processing did not produce any significant difference in the FFA levels. It is very noteworthy that the levels of FFA in the raw palm fruits were initially higher in the industrial methods (2.31 percent for GOPDC, 2.41 for TOPP as compared to 2.14 percent for the traditional processes). The significantly higher levels of FFA was, therefore, due to the fact that they were so initially and not really due to the methods of processing.

Table 4.19d showed that the industrial method had a lower peroxide value 2.94 mEq/kg than the traditional method, 3.05, mEq/kg. From appendix Q equality of variances could be assumed according to Levene's test. From appendix R, the differences in peroxide values were significant. The industrial ones, being

lower produced a better oil as far as peroxide values were concerned.

Table 4.19e showed that the industrial methods had a TBA value of 0.14 as compared to 0.16 for the traditional methods. From appendix Q, equality of variances could be assumed. From appendix R, the differences in TBA values were therefore significant, since the industrial method was lower, although they all fell in the acceptable range (0.1 to 0.2), the industrial method was to be prefered.

CHAPTER 5

5.0 DISCUSSIONS

GENERAL DISCUSSION ON PALM OIL PROCESSING

The processing of palm oil, though having different methods, makes use of certain principles which are common to all processes. It is a widely accepted opinion in the mills that the earlier the fresh fruit bunches (FFB) are processed, the better. In the traditional processing however, the FFB may be left for the fruits to loosen their attachment to the bunches before threshing. This practice increases the FFA content of the oil produced. Fats, it has been postulated (Hartley, 1984) are protected from lipase by membranes of the cell vacuole which may be raptured when disturbed by harvesting, processing should therefore proceed without delay to arrest the activities of these enzymes. In the mills, however, sterilization is done as quickly as possible, within 24 hours of harvesting; this therefore ceases further production of FFA as early as possible and helps in the process of detachment of the fruits from the bunches.

In the next stage, pounding and pressing out of the oil, the traditional processing makes use of rudimentary equipment like mortars and pestles. However the same principles underly both traditional and industrial methods. In the industrial method, the fruits which have been sterilized are pounded by rotating shafts with stirring arms, including sufficient amount of heat (temperatures 90 °C to 95 °C). The oil, therefore, melts at this stage; the use of heat at this stage is conspicuously missing in the traditional method and it remains a major deficiency of the traditional method (Hartley, 1984). Digesters should usually be sufficiently large to provide fruits for an hour's processing. The size is,

therefore, adjusted to suit the rate of work of the press or centrifuge to be used. In the traditional process which makes use of fermentation, the fruits are covered with leaves (fermentation takes place by microbial and enzymatic action) after which they are vigorously trodden on, the oil skimmed off after which water is added to the mash. A second treading is done, the remaining oil is also skimmed off. The oil obtained by this method easily solidifies, the proportion of low melting point constituent is reduced considerably by oxidation and hydrolysis (Hartley, 1984). Extraction rate is very low, 6 percent oil to mesocarp in the case of fruit and an FFA of 30–50 percent. It is used because it makes low demands on labour and it is claimed that there is still a taste for high FFA oil in cooking in some areas (Hartley, 1984).

The mills employ screw presses or hydraulic presses to extract oil. In Ghana screw presses are used. The screws rotate in opposite directions and thereby force the mash introduced into it against the walls of the case to enable the liquor to escape through the perforations to the streams of liquor coming from the feed screw drain plate. The crude liquor is finally filtered by a vibrating screen to remove retained non-oils solid (n.o.s). The liquor is collected into a crude oil tank.

The next stage is the clarification of the oil; the liquor from the crude oil tank is pumped into a continuous settling tank (C.S), the oil that floats on top of the column and the water-cum-dirt mixture (sludge) sinks to the bottom. The skimmed off oil is then pumped into a clean oil tank; it is purified using high speed centrifuges. The sludge oil also undergoes centrifugation to remove a greater percentage of the impurities as possible. The oil in the clean tank is dried using vacuum drying, this is to prevent oxidation from taking place. In the drying

process of the traditional methods, these conditions cannot be met.

Storage in the mills takes place under hygienic conditions, and temperature and atmospheric conditions are controlled to a degree. This cannot be said of the traditional processors. Their handicaps is in their belief that every thing goes; hygienic practices on sites are very poor, they also fail to use well cleaned containers. They use metal containers which do not exclude heavy metals from the processing line, they lack knowledge of rudimentary factors like metals, non-oil solids (n.o.s), FFA, peroxides, enzymes and microorganisms which affect the stability and the quality of oil. The results of this study will, therefore, be of benefit to traditional oil processors.

5.1 DISCUSSION OF RESULTS

5.1.1 Moisture Content

Processing in the industrial methods reduced moisture content to 2.4 percent. The processing techniques were very effective in the industrial methods in reducing moisture, 69.57 percent to 1.41 percent, at GOPDC; 69.15 to 3.39 percent, at TOPP. From the figures, the purifying and vacuum drying stages were the two most important stages in moisture reduction. In the traditional processing the boiling and "frying" stages present the most critical stages in the reduction of moisture.

Moisture is an undesirable quality in oil, since, it increases the rate of hydrolysis, which may be explained by the fact that moisture together with impurities contain or provide nutrients for micro-organisms. When sterile conditions do not obtain, therefore, the rate of FFA formation will become dependent on dirt and water present in the oil. The blending of oil containing

lipolytic organisms is likely to increase, further, the FFA production in storage. It must be clear that in order to provide an oil which will maintain a low free fatty acid content – the final milling operations must be directed, primarily, to attaining a very low moisture content. Secondly, the dirt content must be reduced to a minimum and clean and sterile conditions must be maintained in order to avoid the invasion of the oil by lipolytic micro-organisms (Hartley, 1984).

It is incumbent on management, therefore, to find the optimum amount of water needed for the operation. Thus, even though sterilisation and digestion all require inputs of water, just the amount needed must be used in order to avoid the over burdening of moisture reduction units: purifier and vacuum driers.

The characteristics of special bleach oil (SPB) includes a moisture content of <0.1 percent Jacobsberg (1971). The moisture content thus obtained was not favourable; it was higher than the target required of 0.10 percent. Figure 5.1 illustrates the amount of water in palm oil in two critical stages of processing in the industrial and traditional methods

5.1.2 Refractive Index

Refractive index is an intrinsic property of the material (Bauman 1987). In this case, it is produced as a result of a medley of materials; moisture, which has a refractive index of 1.33; palm oil, 1.449-1.455 at 50°C (Codex, *Alimentarius* 1992); and other non-oil solids. Centrifuging and vacuum drying are critical steps in obtaining the required refractive index; centrifuges, remove dirt and some moisture; vacuum drying reduces moisture to a very small percentage. The oil then approaches a high percentage of purity, after these processes, which is reflected in the refractive indices, 1.4400 for GOPDC and 1.448 for TOPP in

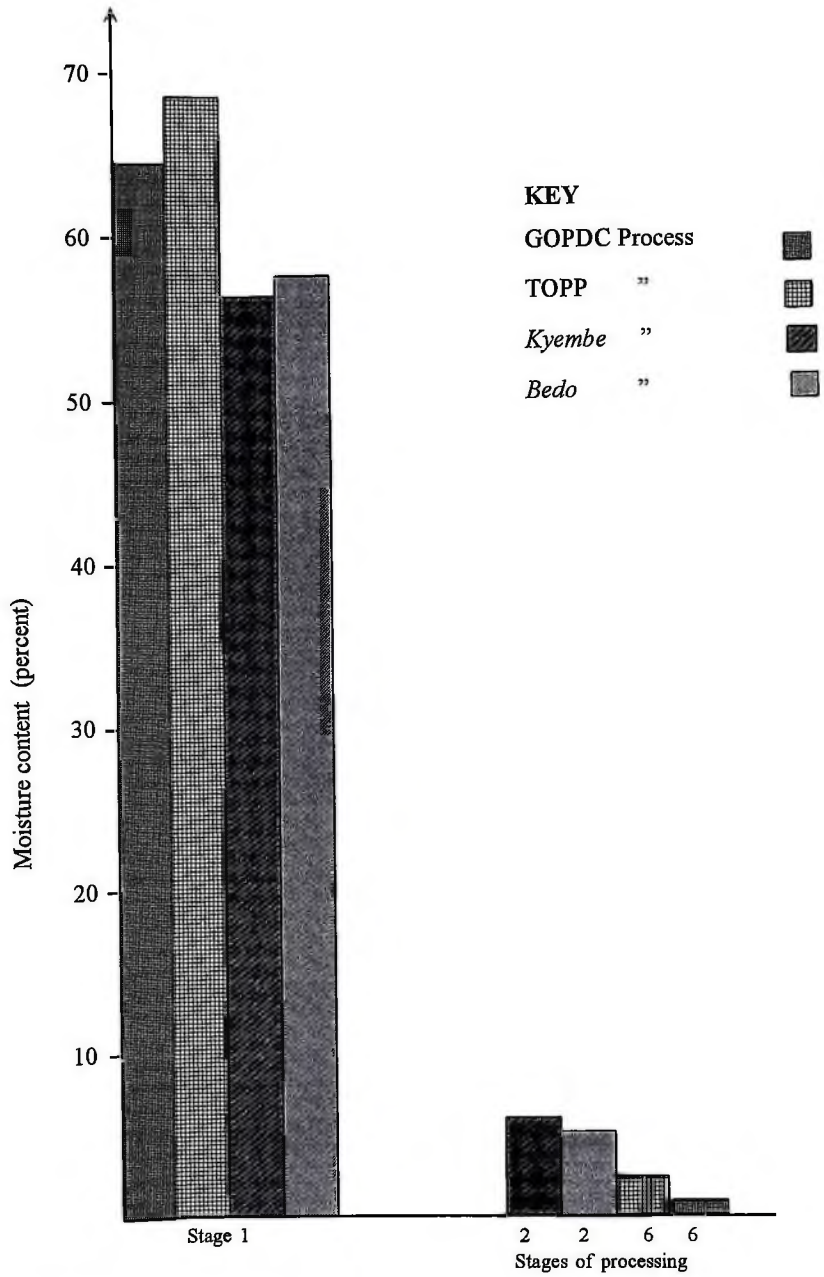

Figure 5.1: A Histogram of Moisture content of Palm Oil of the Industrial and Traditional methods of processing in their initial and final stages of processing

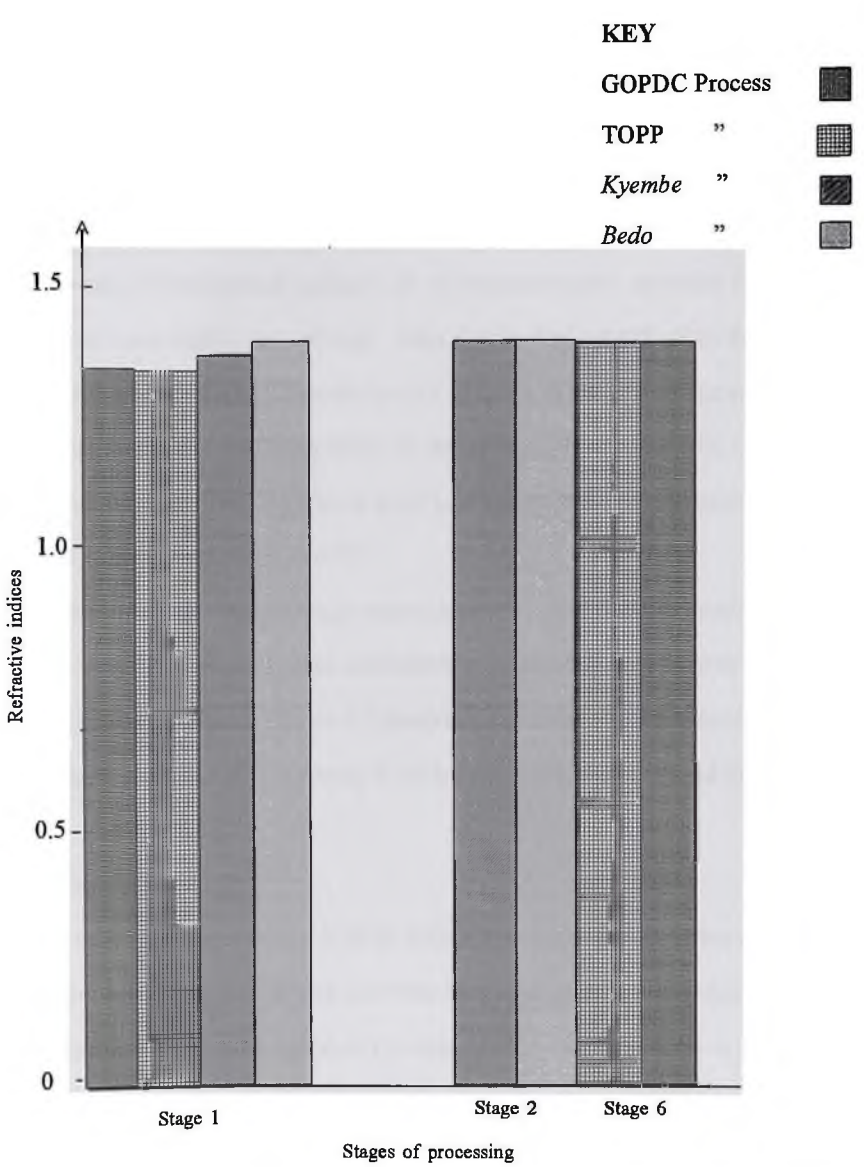

Fig. 5.2: Histogram of Refractive Indices of Palm Oil in their initial and final stages of processing for both Traditional and Industrial methods.

the storage tank. After vacuum drying both TOPP and GOPDC obtained the codex standards of 1.449-1.455.

The range obtained in the refractive indices is as a result of the fact that palm oil is a mixture of pure compounds. Their proportions however vary according to climatic season, breed, and soil conditions in which the palm tree grows and thrives (Ong *et al.*, 1995; Hilditch and Williams, 1964).

In case of traditional methods of oil processing the moisture reduction techniques were boiling and "frying". Also they lacked centrifuge to drastically reduce dirt and other non-oil solids (n.o.s.). (The Centrifugation stage will purify the oil even further and bring them in the acceptable range). The refractive indices of 1.4084 and 1.4182 were quite low compared to the required 1.449-1.455 (Codex, *Alimentarius* 1992).

In the absence of centrifuge and vacuum dryers the fruits should be well washed to reduce dirt and other solids before processing, to improve purity in the traditional processes. Figure 5.2 illustrates the refractive indices of palm oil in two critical stages of processing in both traditional and industrial methods.

5.1.3 Free Fatty Acid

Free fatty acid occurs as a result of fat splitting reactions in which the glyceride molecule combines with water to yield free fatty acid, in succession, diglycerides, monoglycerides and free glycerol (Loncin, 1952). This reaction is aided by microbial lipase. The progression of this reaction leads to the decrease of triglycerols which are the most important constituents of fats and oils, and a corresponding increase in diglycerides and monoglycerides.

Sterilisation, usually, results in the denaturing and destruction of these

lipolytic enzymes, the only channel open to production of free fatty acids is autocatalysis (Hartley, 1984). In this reaction, the fatty acid already present in small quantities act as catalysts in the reaction between the triglycerides. The Kinetics of the reaction is represented by the equation put foward by Loncin (1952): $Kt = 2.3 \log A/A_0$; where

K = the velocity coefficient

t = the acidification time

A_0 = initial FFA content

A = FFA content

t = is given in 10-day units

K = 0.12 at 60°C and it is doubled approximately for every 10°C increase in temperature

The above equation shows that though the FFA in all the process ranged from 2.05 to 2.66, the danger lies in the initial content increasing with time (t) from an initial content (A_0). The equation shows that if oil is to be stored for a relatively long period of time (t) it is of crucial importance that a low FFA level be an important goal of management.

Water is a limiting factor, only, when it does not saturate the oil. The reaction velocity is independent of water when it is saturated. The equation is modified at higher temperatures, since other works have shown that water has an effect on hydrolysis, increasing the rate of formation of FFA (Hartley, 1984). There is also considerable evidence to warrant the assertion of the fact that lipolytic micro-organisms are active in stored oil when the conditions are rife. Micro-organisms implicated in analysis of samples from Nigeria include, *Geotrichium candidum* (Loncin and Jacobsberg, 1965). Still yet, in Nigeria,

fungi of the species *Paecilomyces*, *Aspergillus*, *Rhizopus* and *Torula* have also been implicated (Coursey, 1963).

The sources of infection are palm fruits, bunch refuse, oily films on drums and other receptacles. Rises in FFA due to lipolytic fungi are likely to occur wherever oil is produced under generally dirty conditions and where the means of sterilisation are inadequate (Hartley, 1984). Conditions which were, to a large extent, met at the industrial establishment but which were absent in the traditional processing units.

Several works have reported on the crucial and critical importance of the time of harvesting and processing after harvesting in fluencing the percent FFA. At both GOPDC and TOPP care was taken to process as quickly as possible, this was because the workers were informed about these factors.

Processing at GOPDC and TOPP did produce significant alteration in the FFA. The lowest FFA recorded at GOPDC was 2.14 precent and the highest was 2.43 percent. It is however noteworthy that there were no significant difference between stage 5 and any of the samples from stages 1-6. The samples from TOPP, however, produced significant difference in FFA between some of the stages of processing. The FFA in stage 2 for TOPP was 2.66, that was high, suggesting that it could be due to some extent, to micro-organisms listed above.

Processing using traditional methods did not alter, significantly, the FFA content; in both *Kyembe* and *Bedo*. There seems to be no strong evidence that processing alters, significantly, the FFA levels. It therefore, cannot be overemphasised that the time of harvesting is critical. Also, since Loncin's (1965) equation on autocatalysis is temperature dependant at lower moisture content

till a moisture content of 0.1 percent, it is incumbent on processors to avoid exposure, to excessively high temperatures.

Since storage also constitutes a time for the infestation and proliferation of lipolytic organisms, the oil should be stored in a way as to exclude the conditions necessary for lipolysis to take place; it should be well covered to exclude the absorption of moisture from the atmosphere, the deposition of dust particles and other non-oil solids (n.o.s) eg. proteinaceous material whose inclusion will provide nutrients for the proliferation of micro-organisms should also be excluded (Hartley, 1984). Clean and sterile conditions must always be maintained. In comparison with traditional processors, the industrial methods produced higher FFA levels, on the average, 2.35 percent; as compared to 2.13 percent for the traditional processing methods. It, therefore, still reinforces the usefulness of processing just after harvesting; also, time of harvesting, which presents contending factors of percent FFA and yield is crucial. Ng and Southworth (1973) have shown that whilst there is a curvilinear increase in oil in mesacarp with increasing detachment, there is also a corresponding increase in FFA of both the fallen fruit and also the fruits on the bunch (Salunkhel and Desai 1986). The time of harvesting is therefore critical so that quantity is not increased at the expense of quality; since oil quantity increase with time at ripening to a large extent (Desasis, 1982).

Chong Chiew (1995), has emphasised the role of the worker in the management of quality; this is critical since, without this there is no way quality could be well managed. Since, there are many critical steps which go to determine whether there will be an increase in FFA; an increase, however, is very difficult to reduce.

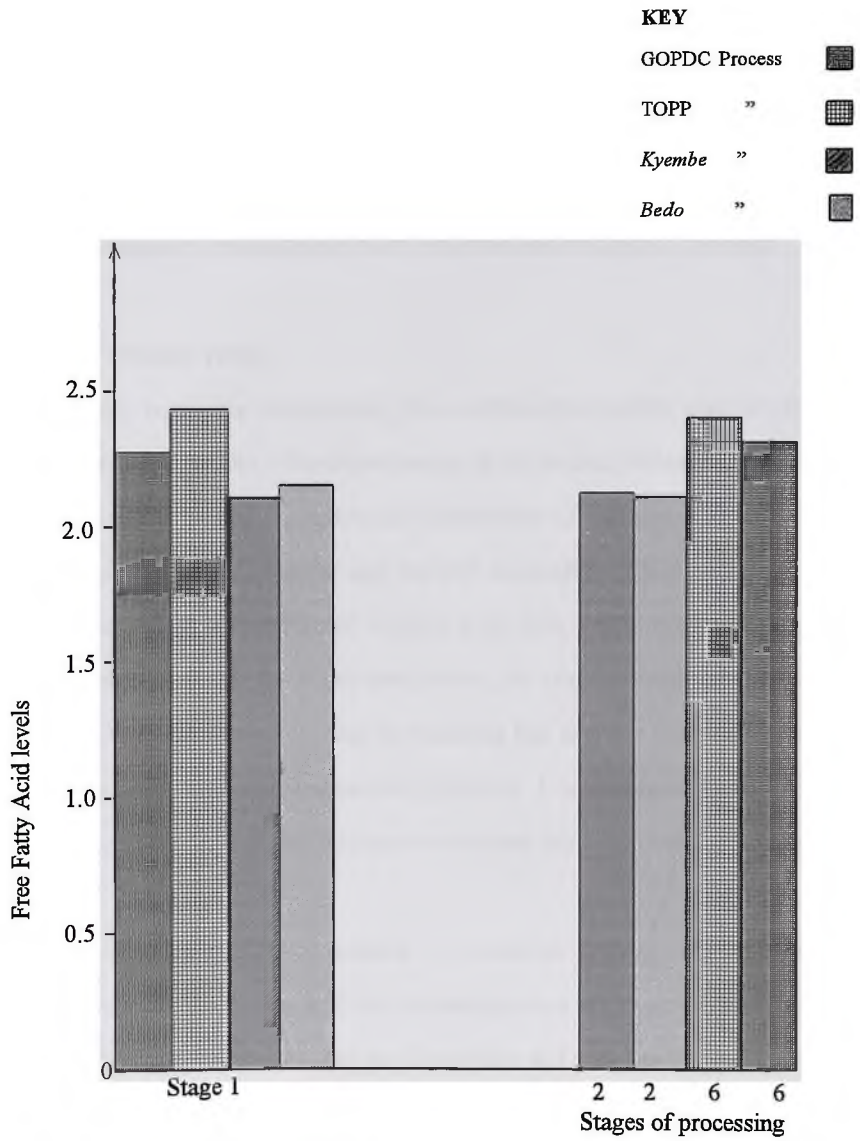

Figure 5.3: Histogram of FFA levels of Palm Oil using the Traditional and Industrial methods of Processing in two critical stages of processing

On health and nutritional importance of FFA levels, since they are natural products they do not present any immediate health hazards. Their importance, as far as this issue is concerned, is that they make the oils susceptible to deterioration.

The control of FFA levels is important since they are more susceptible to oxidation than fatty acids esterified to glycerol (Nawar 1985; de Man, 1992; Frankel, 1984). Figure 5.3 shows the freefatty acids levels in palm oil in two critical stages of processing in both industrial and traditional methods.

5.1.4 Peroxide Value

"Oil easily combines with oxygen. This combination is either slow or rapid. In the first case rancidity is the consequence, in the second, inflammation" (Berger and Hamilton, 1995). Spontaneous combustion of fish meal cargoes on high seas has been noted to occur and are well documented. This is the case when considering highly unsaturated oils and even their seeds. In combination with metals as low as 70 ppm in the case of iron, the reaction could be very fast.

Processing is with the aim of rendering fats and oils oxidative stable and free from impurities – among several objectives. Contrary to achieving oxidative stability, however, fats and oils may be oxidised during processing, storage and usage.

One of the aims of processing is to remove, destroy or reduce oxidised substances, however, some of the processing steps such as caustic refining and bleaching may achieve the reverse. Stored fats and oils may eventually develop rancid odours and flavours due to the presence of breakdown of oxidative products (Chow and Gupta, 1994).

Other undesirable reactions include dimerisation, trimerisation, polymerisation, hydrolysis and cleavage of fatty acids when fats and oils are exposed to high temperatures. Oxidative products can exert negative effects on health and nutrition (Alexandar, 1986). They could be atherosclerotic (Glavind *et al.*, 1952). Components of oxidised fats and oils may also accelerate the turnover of Vitamin E and increase the susceptibility of the red blood cells to hemolytic stress, including hemolysis in certain cases (Chow and Gupta, 1994). This could present a dangerous scenario for sickle cell anaemic patient, very common disease in sub-Saharan Africa.

The degree of susceptibility of fats and oils to oxidation is directly related to the degree of unsaturation. Oxidation is also important to the food because it leads to the development in edible oils and fat containing foods, of undesirable products which reduces their susceptibility and shelf-life. Nawar (1985), has listed certain factors that could affect the rate of oxidation. They include the following: the fatty acid composition; the number, position, and geometry of double bonds; on free fatty acid content, they oxidise faster than the esterified ones; oxygen concentration, unlimited supply of oxygen produces rates which are not dependent on it and vice versa; temperature, in general increases the rate of oxidation; surface area, the rate of oxidation increases in proportion to surface area. Also affecting oxidation are moisture content and pro-oxidant activity.

Hydroperoxides, normally referred to as peroxides, are the primary intermediate products of oxidation which proceeds via four main ways autoxidation, photoxidation, thermal oxidation and enzymic oxidation.

Autoxidation, constitutes the most important route to oxidation of oils and fats. The reaction has been postulated to proceed according to the equation:

$$\text{Rate} = \frac{d[0_2]}{dt} = \frac{Ka[RH][ROOH]}{1 + [RH]/P}$$

RH = is the substrate fatty acid

ROOH = is the peroxide formed

P = is the pressure of oxygen

= a and K are empirical constants. A three step simplified, free radical scheme has been postulated to explain the experimental results.

1. Initiator $\xrightarrow{K_1}$ free radical (initiation)
2. $R + 0_2 \longrightarrow ROOH$
3. $ROO + RH \longrightarrow ROOH + R$ (propagation)
4. $R + R \quad K_4$
5. $R + ROO \quad K_5$ — non-radical producers
6. $ROO + ROO \quad K_6$

Chain termination steps

At high oxygen pressure ([RH]/P) much smaller than 1) reactions 4 and 5 can be neglected to give Rate = $K_3(K_1/K_6)^{1/2}$ [ROOH][RH].

Thus, the rate of oxygen absorption is independent of oxygen pressure. At low oxygen pressure ([RH]/P) greater than 1) steps 5 and 6 can be neglected to give

$$\text{Rate} = K_2 \left[\frac{K_1}{K_4}\right]^{1/2} [ROOH][0_2]$$

(Nawar, 1985).

This equation is therefore of crucial importance during the vacuum drying stages where oxygen pressure is low. At GOPDC, vacuum drying stage had a peroxide value of 2.89 m Eq/Kg, the highest value was 2.98 mEq/Kg and the lowest was 2.74 mKq/Kg. The 2.89 m Eq/Kg is a mid-point between these two values. The peroxide value of GOPDC in the after vacuum drying was 2.96 mEq/Kg the variation in the peroxide values between the various stages was however not significant, as already noted.

The direct degradation of fatty acid by oxidation is almost not thermodynamically feasible, the activation energy is very high, 35 Kcal/mole. Catalysis, which lowers this, is thus the pathway of choice, to a large degree.

Transition metals are one of the possible causes of oxidation. They can do this because they posses more than one oxidation state.

$$M^{(n+1)} + RH \longrightarrow M^{n+} + R' + H^{+}$$

where $M^{(n+1)}$, represents the metal in a higher oxidation state; RH, the fatty acid; M^{n+}, the metal in a lower oxidation state; R'; the free radical in oxidation of metals, which is rife.

The conversion of the metal to a lower oxidation state M^{n+} initiates the next step of reaction with oxygen forming complexes which may provide singlet oxygen

$$M^{n+} + 0_2 \longrightarrow [M^{n+1} \text{——} 0_2]$$

These complexes are more important in non-polar systems such as bulk oils and fats. The chain propagation steps, 2 and 3, lead to the formation of hydroperoxides, while the chain terminating steps, 4-6, results in dimmers of both fatty acids and triglycerides. In some instances, the triglycerides are linked by means of a carbon – carbon bonds and in others by oxygen - oxygen bond.

These termination reactions also include the interactions of the radicals with molecules which act as free radicals quenchers. These may be natural products, examples are chlorophyll, pheophytin. Enzymatic oxidation: the next pathway which leads to the production of hydroperoxides with its concomitant products is enzymatic oxidation. This is normally absent in refined oil which make use of temperatures which denatures the enzymes, which are thermolabile.

The enzymes involved are lipoxygenase which are dioxygenases, thus incorporating a molecule of oxygen at a certain position of unsaturated fatty acid. Other enzymes involved are cytochrome P450 systems (Frankel, 1982; Hsieh and Kinsella, 1989). The process GOPDC, TOPP, *Bedo* and *Kyembe* did not alter, significantly, the peroxide values which ranged from GOPDC 2.74 to 2.98; TOPP, 2.96 to 3.05; *Bedo* 3.03 to 3.07. The low range, and insignificant difference in the figures are indications of the fact that enzymatic oxidation is arrested by the heating processes.

Photoxidation: it is that autoxidation stimulated by sunlight. It can lead to off-flovours e.g. formation of Oct-1-en-3-ene. In this reaction energy from sunlight is transferred to a photosensitiser (methylene blue, flavin, porphyrin, anthracene, rubrene, chlorophyll, pheophytin) (Frankel, 1984).

The excited photosensitiser then may react directly with a molecular oxygen in the triplet ground state or with an acceptor which in turn reacts with ground state oxygen to form a singlet state oxygen. Singlet oxygen is more reactive than triplet oxygen. It can overcome the spin restriction and energy barrier to react directly with C = C double bonds of unsaturated fatty acids to form hydroperoxides (Berger and Hamilton 1995; Chow and Gupta, 1994). The singlet state oxygen is more electrophilic than the triplet state, and thus can react 1500

times faster than the triplet state (Nawar, 1985). The resulting hydroperoxides can then cleave to initiate conventional free radical chain reaction.

The peroxide values of the traditional processes were on the whole higher than the industrial processes 3.03 to 3.07 m Eq/Kg for *Bedo*; *Kyembe,* 3.04 to 3.10 m Eq/Kg; GOPDC, 2.74 to 2.98 m Eq/Kg; TOPP, 2.96 to 3.05 m Eq/Kg. All these are pointers to the fact that industrial processes were more efficient in producing lower peroxide values. This is confirmed by table 19 and t = -3.478 which tested the significance differences in the final stages of processing. The mode of processing in the traditional methods makes it highly probable that photosensitizers eg chlorophyls and pheophytin would be included. They are also exposed to light thus creating a conducive milieu for photoxidative reactions.

Contrary to the action of free radicals, there are singlet oxygen ($^1O_2$) quenchers, the most effective is β-carotene, others are tocopherols. These are present in palm oil in very high amounts as noted in the literature review.

Thermal oxidation: This is the oxidation of high temperatures. During cooking, baking and deep frying of fats and oils oxidative reactions are greatly accelerated. Prolonged exposure of fats and oils to elevated temperatures leads to the formation of various oxidation products which includes polymeric compounds. Also the rate of hydroperoxides formation and decomposition is increased substantially, during thermal oxidation. This leads to the formation of several radicals for example alkyl, hydroxyl, vinyl (Frankel, 1984), the allyl radical, hydroxyl radicals or molecular oxygen to form aldehydes and olefins. Thus, hydroperoxides can be broken down into volatile products – such as saturated and unsaturated aldehydes, ketones, hydrocarbons, alcohols, acids and esters, numerous other oxidation products have been identified (Gunstone 1984; Chang

et al, 1978). Organoleptic changes associated with the deterioration of fats and oils are not by the primary oxidising product, but rather the secondary oxidising products for example, aldehydic compounds. These are strong flavour compounds and have very low flavour thresholds. Some of the oils at the traditional processing sites had strong odours giving indications of the presence of such strong flavour compounds.

Oxidation of fats and oils therefore is made of complex reactions. Once it has started it is not easy to predict the outcome because of the numerous reactions involved, but one thing is certain – the deterioration in the quality of oil. To avoid oxidation, therefore, Berger and Hamilton (1995) have made the following recommendations.

1. Maximum retention of natural antioxidants should be aimed at during processing.
2. Processing should be done at the lowest temperature possible and where high temperatures are unavoidable, the time of exposure should be reduced to a minimum.
3. Access to air must be curtailed.
4. Maintaining good practice of stock rotation and cleanliness and never refilling a partly empty container is a recommended procedure.

It is noteworthy that processing in both industrial set-ups (GOPDC) and TOPP, did not alter, significantly, the P.O.V. The peroxide may have been introduced before processing. The lower peroxide value of the industrial method 2.94 as compared to the traditional method 3.05 was significant though the difference is small (0.11). The hydroperoxides produced are by no means static,

they are very reactive (Kirk and Sawyer, 1991).

Traditional processing delays the time of sterilisation for the fruits to naturally loosen from the bunch, and this may cause a rise in peroxide value. The practise of exposing the raw materials and products to light is also undesirable since they make them subject to photoxidative deterioration.

Traditional processors also make use of metal containers of unverified origin contents and constituents. Just the introduction of a small quantity of copper metal could greatly reduce stability. The effect of copper on stability is about a 1000 times more pronounced than aluminium, amplifying the fact that the type of metal used in making receptacles for processing is crucial in oxidative stability (Berger and Hamilton, 1995).

The workers involved in traditional processing have little information of the issues that go into making quality, Chong Chiew, (1995) however, advices that they should be well informed, and manage quality with a sense of purpose.

It is also important to keep the surroundings hygienic to avoid the numerous micro-organism which could begin enzymatic oxidation this is however not the case with the traditional processors (Loncin and Jacobsberg, 1965; Coursey *et al.*, 1963).

Turner (1969) has shown that lipolytic fungi could be present in all parts of the mill in both the atmosphere and on the floors, walls and apparatus. Even sterilised fruits were open to reinfestation by *Neurospora*. Constant cleaning of equipment is therefore necessary, and also Hartley, (1984) recommends that once processing has started, it should be such that, the fruits or oil does not cool down. At the oil mills processing was carried out without interruptions which is commendable.

Pistles, mortars and containers used in processing by traditional processors should therefore be well cleaned with hot water to reduce the chances of microbical infestation, a practice which was lacking among traditional processors.

The practice of covering fruits with plant material, which is practised by traditional processors to ferment the fruits is also not to be recommended, as far as the introduction of hydroperoxides is concerned. Plant materials contain chlorophyll which are photosensitisers (Nawar, 1985) they could therefore increase photoxidation with its concomitant underisable effects (Chow and Gupta, 1994).

In view of the part heat plays in peroxidation, (Nawar, 1985), processing should be with the minimum inclusion of heat since it could increase thermo-oxidation, and increase the rate of reaction of autoxidation, photoxidation and enzymatic reactions. In the industrial processing, during moisture reduction, vacuum drying is used, this excludes oxygen and thus reduces peroxidation. Traditional processors do not have access to this technology. Thus *Kyembe* is a preferred option in this wise since it include minimum amount of water thus the time spent for heating is reduced, it is not a conclusive decision, however, it could be drawn after having all the facts including, percentage yield of the two methods which is beyond the scope of this study.

All the peroxide values fell well below the Codex *Alimentarius* (1992) standards. The highest recorded 3.10, was well below the maximum recommended value of 10meq peroxide oxygen per a kilogramme of fat or oil.

Products of oxidised fats and oils have been implicated in several negative health aspects. For example, in atherosclerosis (Duthie, 1989). They could also be carcinogenic or co-carcinogenic (Hageman *et al.*, 1991).

Fatty acid hydroperoxides have been found to be very toxic to experimental animals when taken orally (Chow and Gupta, 1994). Also, vitamin E deficiency symptoms such as creataunuria, erythrocyte hemolysis, have been observed in animals infused with methyl linoleate hydroperoxides Kokatnur *et al.,* (1966).

The secondary products of lipids oxidation are many and various. Since they are normally not natural products their implications could be dangerous. Kanzawa *et al.*, (1985) have done comprehensive works on these and found them to include 35 percent polymers 35 percent endoparasite-rich components and 40 percent low molecular weight compounds. A small percentage of administered products were located in the liver, the organ involved in detoxification, hypertrophy, elevation of transaminase activities – suggesting that the secondary products of lipid oxidation cause oxidative damage (Chow and Gupta, 1994).

Polymeric and cyclic monomers are not easily absorbed (Kanzawa *et al.*, 1985) but may cause diarrhoea. They have been found to be toxic to experimental animals and to heart cells in culture (Chow and Gupta 1994) also they cause fatty livers (Perkins and Taublold, 1978).

4 - Hydroxynonenal, a product of secondary oxidation, has been widely investigated because of its relatively higher quantities formed during lipid peroxidation (Oarada *et al;* 1986; Esterbauer *et al.*, 1991). They have been found to be toxic to rats. They can react with functional sulfhydryl groups of enzymes, inactivate glucose-6-phosphate and inhibit hepatic DNA - polymerase and 0^6 - methylynanie -DNA methyltraunsferuses, they can also cause severe disturbances of cell functions at the biochemical and genetic levels. Alkenals, hydroxyl alkenals and hydroxyperoxy alkenals, have also been shown to be more

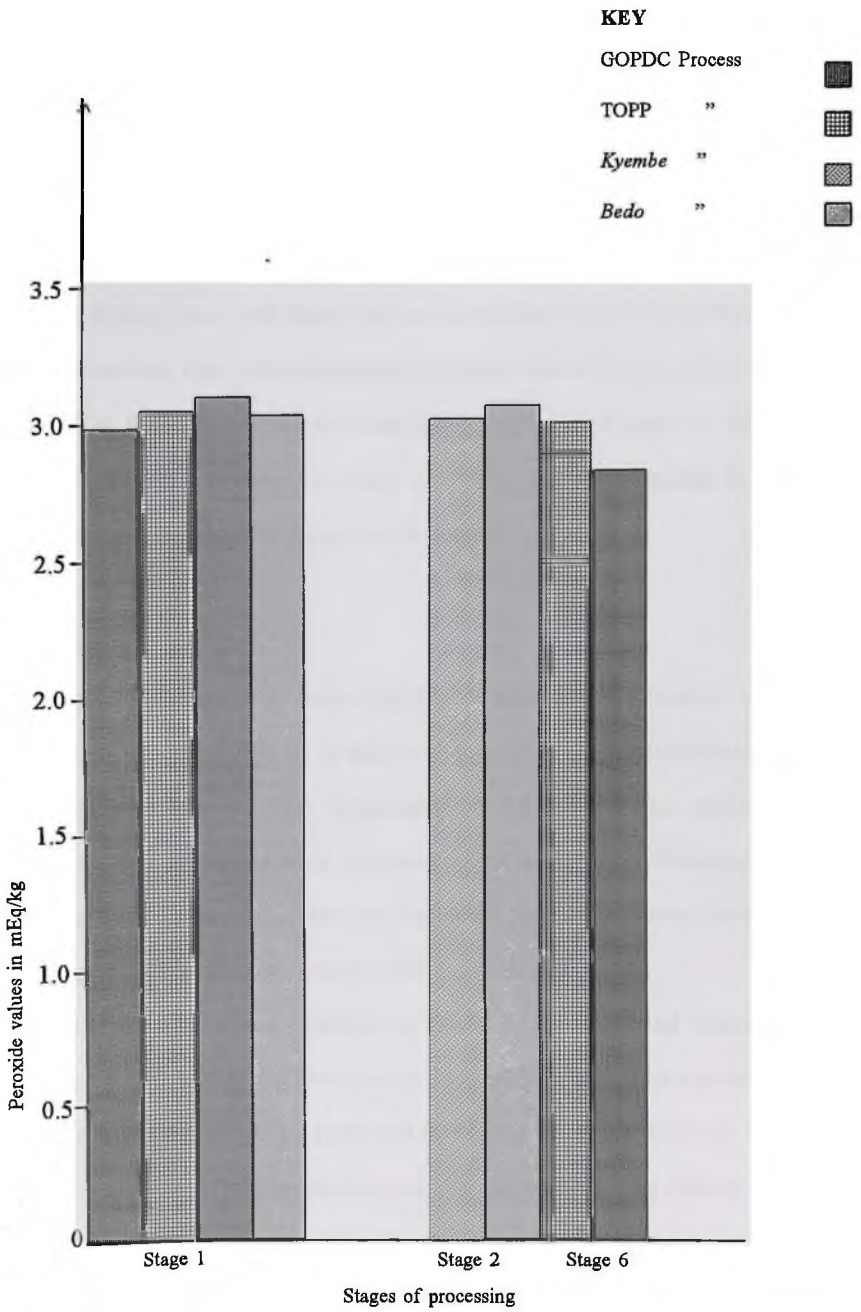

Figure 5.4: Peroxide values of Palm Oil of Traditional and Industrial methods of Processing in their initial and final stages of processing

potent than methyl linoleate hydroxy perioxide in inducing hemolysis (Chow and Gupta, 1994).

The health implications of peroxides are many and various, it is incumbent on management and traditional processors to work so as to produce the barest minimum of peroxides. The peroxide values recorded which ranged from 2.96 to 3.10 mEq/Kg were well below the recommended value of 10 mEq/Kg, the fear however was their propensities to increase to exceed these accepted values through the channels of oxidation mentioned earlier on. Figure 5.4 illlustrates the peroxide values in palm oil at two critical stages of processing in the two methods of processing traditional and industrial.

5.1.5 TBA Value

TBA value test is one of the most widely used tests for evaluating the extent of lipid oxidation (Nawar, 1985). It has been postulated that the chromagen results from condensation of two molecules of TBA with one molecule of malonaldehyde. Malonaldehyde, however, is not an all pervasive compound in every oxidised system. There are two suggested wavelengths used for this text, 450nm and 530nm, they are equally desirable (Nawar, 1985).

TBA reactive (TBAR) material is produced in substantial amounts only from fatty acids containing three or more double bonds. The mechanism by Dahle *et al.* (1962) has been explained by Nawar (1985) as follows: Radicals from double bond β– to the carbon bearing the proxy groups (which can only arise from acids containing more than two double bonds) cyclize to form peroxides with five membered rings, which decompose to give malonaldehyde. Other explanations have been suggested eg. protstaglandlike, endoperoxides

produced during the autoxidation of polyunsaturated fatty acids.

The drawbacks are that other compounds interfere with this test by producing the characteristics red pigment upon reaction with the reagent, examples of such are sucrose and some compounds in wood smoke, this lead to higher than expected values; on the other hand lower values results with reaction with protein in an oxidising system. It does not also correlate well with flavour scores. In many cases, however, the test is applicable for comparison of samples of a single material at different stages of oxidation.

The TBA values were not altered significantly during processing in almost all the processes (TOPP, *Kyembe* and *Bedo*) it was only at GOPDC which recorded significant differences between some of the stages. Polyunsaturated fatty acids which could form the substrate for the formation of this product constitute only 5 percent by weight of palm oil. The chances of it being formed are less than in certain oils with a higher profile of unsaturated fatty acids. In all cases the TBA values fell within the range of acceptance, 0.1 to 0.2. But since there was no grounds for acceptance of the fact that processing alters the TBA values, it is very necessary that good manufacturing practices are observed to avoid an increase in the content before processing (Berger and Hamilton 1995). A comparison of the final stages of processing using t-test showed that on the average the traditional produced higher TBA values. There is still therefore room for improvement as far as this method is concerned.

Nutritional and health implications: Malonaldehyde has been found to be toxic to experimental animals (Crawford *et al.*, 1965). some of their effects as enumerated by Chow and Gupta (1994) in literature include: they can react with mitochondrial membranes, disrupt red blood cells membrane and decrease erythrocytic survival.

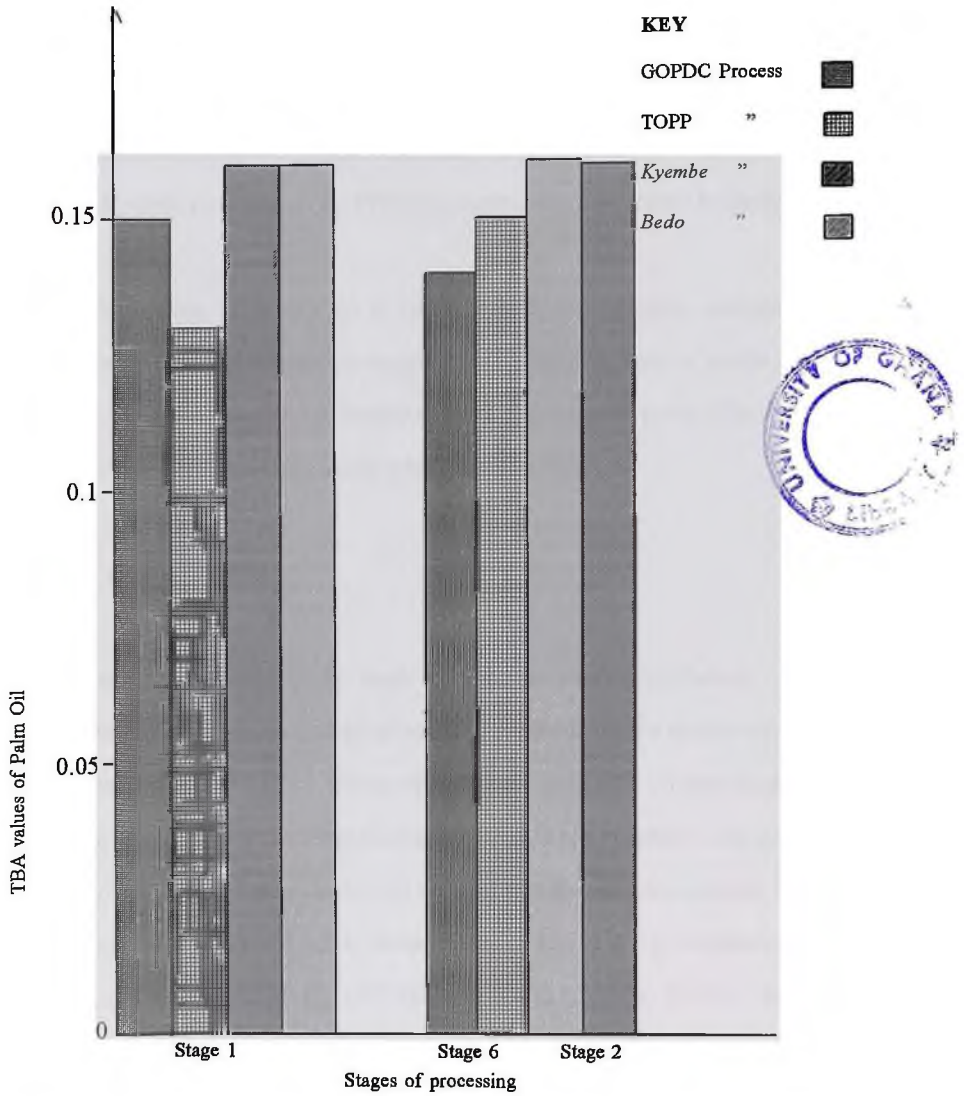

Figure 5.5: Histogram of TBA values in Palm Oil using Traditional and Industrial methods of processing in two critical stages of processing

It has also been postulated that it can be carcinogenic or co-carcinogenic; since it has been found to produce tumours, it is mutagenic and cytotoxic, it has also been found to play a role in regulating tumour metastasis; host immune mechanisms and multiplication and differentiation of tumour cells has also been implicated to it (Begin, 1987), it also causes chromosomal aberration in cultured fibroblasts. The preferential reaction sites on the DNA molecule for MDA are the bases guanine and cytosine. They have also been found to be chemotactic for neutrophils (Curzio *et al.*, 1990) Cytotoxic to many cells (Benedetti *et al.*, 1986).

Processing, therefore, so as to exclude this compound, malonaldehyde, which is involved in numerous negative health implications is worth pursuing with all the effort. Figure 5.5 illustrates the TBA values of palm oil in two stages of processing for both traditional and industrial methods.

5.2 CONCLUSION

Based on the objectives of the study the following were concluded:

On the effects of industrial processing methods on the quality of palm oil, a comparison of the quality indices of palm oil in the crude oil tank stage and the storage tank stage showed that the industrial methods resulted in the production of a significantly of better quality oil with respect to moisture content, GOPDC, crude oil tank stage, 64.57%, storage tank stage, 1.47%; moisture content, TOPP, crude oil tank stage, 69.15%, storage tank stage, 3,39%. Refractive index, GOPDC, crude oil tank stage, 1.3822, storage tank stage, 1.4400,TOPP, Crude oil tank, 1.3793, storage tank, 1.4448. Processing of crude palm oil at GOPDC was significantly better than at TOPP with respect to FFA, GOPDC

2.30%; TOPP, 2.46%; POV, TOPP, 3.05 mEq/kg; GOPDC, 2.98m Eq/kg; moisture content, GOPDC, 39.36, TOPP, 43.66%

On the effects of traditional processing on the quality of palm oil, they resulted in the production of significantly better quality palm oil with respect to moisture content, *kyembe,* mashed stage, 56.69%, After "frying" stage, 5.64%; moisture content, *Bedo,* mashed stage, 56.74%, After boiling, 5.10%; refractive index, *Bedo,* mashed, 1.4003, After boiling, 1.4175; *kyembe,* mashed, 1.3960; After frying, 1.4405. Processing using the two traditional methods *kyembe* and *Bedo* did not result in any significant difference between them with respect to FFA, POV, TBA and moisture content. Processing using kyembe was however significantly better as far as refractive index was concerned, *kyembe,* 1.4182; *Bedo,* 1.4089.

On the relative efficacy of the processes in the production of good quality crude palm oil, industrial methods resulted in the production of a significantly better quality palm oil with respect to moisture content, industrial methods, 2.40%; traditional methods, 5.32%; POV, industrial methods, 2.94 mEq/kg; traditional methods 3.05 mEq/kg; refractive index, industrial methods, 1.4424; traditional methods, 1.4290; TBA, industrial methods, 0.14; TBA traditional methods, 0.16. In light of the above facts, it can therefore be concluded that to a large measure, industrial methods result in the production of a significantly better quality palm oil.

5.3 RECOMMENDATIONS

Based on the above 1 recommend the following:

i. Workers involved in traditionally processed palm oil should be advised

that after harvesting of the palm fruits processing should proceed with a minimum of delay.

ii. Workers involved in traditionally processed palm oil should be advised that washing of palm fruits should be thorough in order to exclude the maximum amount of impurities.

iii. A study should be conducted in the southern part of Ghana to identify and catalogue the other traditional methods of processing palm oil and the steps involved, for the benefit of posterity.

iv. A study should be conducted to come out with the optimum amount of water that will achieve the best extraction per a unit weight of palm fruits.

v. A practical study of the refined bleached and deodorized stage of processing should be included in a future study to bring the whole study to its logical conclusion.

REFERENCES

AB Gapor, M.T. (1990): Content of Vitamin E in palm oil and its antioxidants, Palm Oil PORIM

AB Gapor, M.T.; Berger, K.G.; Hashimoto, T.; Kato, A.; Tanabe, K.: (1983): Effects of processing on the content and composition of tocopherol and tocotrienol and Palm Oil, Palm Oil in the eighties, PORIM.

Addo Consultant (1989): A Study of the Oil Palm industry in Ghana, J.S. Addo Consultants, Opeibea House, Accra.

Alexander, J.C. (1986); Heated and oxidized fats in progress in Clinical Biological Research Vol.222 Dietary Fat and Cancer eds. J.P.C., Birt, D.F., Rogers, A.B. and Curtis, M., Alan R. Liss, pp.185-209, New York.

Ames, G.R.; Raymond, W.D. and Ward, F.B. (1960): The bleach-ability of Nigerian Palm Oil. J. Sc, Food and Agric 2, 194.

Association of Official American Chemist (1990): Association of Official American Chemist, 15th Edn. pp. 951-974, Arlington, Virginia.

Ata, J.K.B.A. (undated): Quality Characteristics of Some Industrial and Traditional Palm Kernel Oils in Ghana. Food Research Institute Document.

Bailey, A.E. and Feuge, R.O. (1944): Oils and Soap, 21, 286.

Bailey, A.E. (1949): J. Am Oil Chem Soc 24, 644

Bailey, A.E. (1950): Industrial Oil and Fat Products Interscience, New York.

Barnes, A.C. (1924): Chemical Investigations into the Products of the Oil Palm, Nigerian Special Bulletin of Agriculture, Government Printer, Lagos, 10p.

Baudet, M.F., Dachet, G.; Lasserre, M.; Esteva, O. and Jackotot, B. (1984): Modification in the composition of Human Low Density Lipoprotein by Different fats, J. Lip, Research 25, 456-468.

Bauman, Robert P. (1987): A first course in physical Science, pp.149-160, John Wiley and Sons, New York.

Bek-Nielsen, B. (1969): Quality Aspects of Oil Palm kernel production, in the quality and marketing of Oil Palm products, Soc. of Plantser Kuala Lumpaur, 144p.

Begin, M.E. (1987): Effects of polyunsaturated fatty acids on cell survival. Chem Phys. Lipids 45, 269-314.

Benedetti, A.; Pampella, A.; Fulceri, Romani, A; and Camparti, M. (1986): Detection of 4-hydroxynonenal other lipid peroxidation products in the liver of bromobenzen poisoned mice. Biochem. Biophys. Acta 876, 658-666.

Berger, K.G. (1994): Oils from underutilised palm forest products in Technological Advances in Improved and Alternative Sources of Lipids pp.209-231 eds. Kamel B.S. and Kakuda, Y. Balckie Academic Professionals, London.

Berger, K.G. and Hamilton, R.J. (1995): Lipids and oxygen rancidity, avoidable in practice? In Developments in Fats and Oils pp.192-203 eds R. J. Humilton Blackie Academic Professionals.

Boatner, C.H.; O'Connor, C.M.; Costillion, L.E. and Curet, M.C. (1947) J. Amer Oil Chem. Soc 24, 97.

Carroll, K.K. and Khor, H.T. (1971): Effects of level and type of mammary tumors induced in female Sprague-Dawley rats by 7, 12 dimethylbenz[a]anthracane Lipids 6, 415-420.

Chandrasekharan, N. and Kalyana, S. (1998): Health and Nutritional aspects of palm stearin perceptions and facts, Palm Oil Developments 28, 30–43.

Chandrasekharan, N. and Kalyana, S. (1995): Minor Components in Edible Oils and Fats; Their Nutritional Implications. Palm Oil Developments, 22-26.

Chandrasekharan, N. (1997): Red Palm Oil for the prevention of Vitamin A Deficiency, Palm Developments 27, 20-24.

Chang, S.S.; Peterson, R.J. and Ho, C.T. (1978): Chemical reactions involved in the deep frying of foods. J. Am. Oil Chem. Soc. 55, 718-727.

Chong, Chiew L. (1995): Handling storage and transport of fresh free bunch and palm oil products. Palm oil Technical Bulletin 8, 2-4.

Chong, C.L. and Gapor A. B. (1983): Proceedings of Workshop on Quality in the Palm Oil Industry, 5th Workshop organised by PORIM pp.46-66.

Chong, C.L. (1991): An Overview of the effects of milling practices on the quality of crude palm oil, seminar on Developments in Palm Oil Milling Technology and the Environment, PORIM, Kuala Lumpur.

Choo Y.M.; Ma, A.N.; Yap, S.C. (1993): Production and application of deacidified and deodorised Palm Oil, Palm Oil Developments 22, 1-6.

Choo, Y.M. (1995) Carotenoids from palm oil, Palm Oil Developments 22, 1-6.

Chow, C.K. and Gupta, M.K. (1994): Treatment, oxidation and health aspects of fats and oils in Technological Advances and Alternative sources of lipids, pp.239-353 eds Kamol, B.S. and Kakuda, Y. Blackie Academic Professionals, London.

Chow Chee Sing, (1999): Revised Long-term forecast on World Palm Oil Production and Consumption, Palm Oil Developments 30, 45-48.

Ciba Foundation Symposium on Vitamin E. (1983): Biology of Vitamin E, Pitman, London.

Cocks, L.V. and Van Rede, C. (1966): Laboratory Handbook for Oils and Fats Analysis, p.419 Academic Press, London, pg.419.

Codex Alimentarius (1992): Vol.8, Palm Oils Codex STAN 125 - 1981.

Coenen, J.W. E. (1973): Modification of oils and fats. Int. Union of Pure and Applied Chemistry (IUPAC) 16th International Congress, 2-8 Sept. Hambury.

Cohen, L.A. (1987): Dietary effects of high - fat diets rich in polyunsaturated, monounsaturated or medium chain saturated fatty acids on rat mammary tumor promotion, in proceedings of the AOCS short course on Polyunsaturated Fatty acids Eico Janoids ed W.E.M. Lands AOCS - Chambaign II.

Crawford, D.L.; Sinnuhuber, R.O.; Stout, F.M.; Oldfeld, J.E. and Kaufmes, J. (1965): Acute toxity and malonaldehyde. Toxico. Appl Pharmacol. 7, 826-832.

Crossley, A. and Hilditch, T.P. (1951): The Fatty acid Glyceride of Okro Seed Oil. J. Sci. Food. Agric. 2.

Coursey, D.G., and Macfarlane, N. (1984): Comparison of Traditional and Industrial Palm Oil. Palm Oil News, 28.

Coursey, D.G. (1963): The deterioration of Palm Oil during storage. Jour. Afr. Sci. Ass. 7, 101.

Coursey, D.E.; Simmons, E.A. and Sheridom, A. (1963); Studies on the quality of Nigerian Palm Kernels. J.w. Afri. Sci. Ass., 8, 18.

Curzio, M.; Esterbauer, H.; Di. Mauro, C. and Dianzani, M.U. (1990): Influence of the lipid peroxidation product 4-hydroxynonenal on human neutrophils migration. Int. J. Immunother 6, 13-18.

Dahle, L.K.; Hill, E.G. and Holman, R.T. (1962): The thiobarbitaric acid reaction and the autoxidation of polyunsaturated acid methyl esters. Arch. Biochem. Biophys. 98, 253-261.

de Graaf, J. (1976): Composition, quality and end uses of palm oil in Developments in Crop Science (1) Oil Palm Research, pp.493-503 Eds R.H.V. Corley et al. Elsevier Scientific pubs.

de Man, J.M. (1992): Chemical and physical properties of fatty acids in foods and their health implications pp.17-45 ed. chow, C.K., Marcel Dekker, New York.

Dessasis, A. (1982): Sur les modalities de formation des matiers grosses dans le fruit d'Elaeis guinensis Jaq. Inst. Rech. Huiles. Oleagineux Ser. Sci 13.

Duthie, G.G. (1989): Oxidants, antioxidants and cardio-vascular diseases Nutri Res Rev. 2, 51-62.

Dyke, M.F. – M (1939): Le palmier à l'hule en Afrique son exploitation au Congo-Belgique et en extreme orien. Men. Instr. Sect. Sci. Nat. Med. 7(3) 1-105.

Eittenmiller, R.R. (1997): Vitamin E. Content of fats and oils, Nutritional Implications. Food Technology 51(5), 78-81.

Erickson, D.E. and Keast, J.D. (1987): Petition for initiation of rule-making to require that certain tropical vegetable oils contain saturated fats. Docket 87, 26.

Esterbauer, H.; Schaur, R.J. and Zollner, H. (1991); Chemistry and Biochemistry of 4-4 hydroxynon and Malonaldehydes. Free radical Biol. Med. 11, 81-128.

Flynn, G. (1973): An economic study of Lauric oil seed processing, Foreign and Commonwealth Office Overseas Development Administration.

Food and Agricultural Organisation and World Health Organisation (FAO/WHO) (1994): Fats and oil in human nutrition. Report of a joint expert consultation, Rome, 19-26 Oct., 1993, FAO Food and Nutrition Report.

Food and Agricultural Organisation and World Health Organisation (FAO/WHO) (1977): Report of an expert consultation jointly organised by the Food and Agricultural Organisation, 21-30 Sept., Rome.

Frankel, E.N. (1982): Lipid oxidation mechanisms products and biological significance. Am. Oil Chem. Soc. 1908-1917.

Frankel, E.N. (1984): Lipid Oxidation, Mechanisms Products and Biological Significance. Am Oil Chem. Soc. 61, 1908-1917.

Gadegbeku, R.K. (1969): Seminar on Vegetable oil mills processing 1st Seminar on Food Science and Technology in Ghana. pp.105-108 Food Research Institute Report, 105-108.

Glavind, J.; Hartman, S.; Clemmensen J.; Jessen, K.E. and Bam, H. (1952): Role of lipoperoxides in human pathology lipids in the atherosclerosis aorta Acta. Pathol. Microbiol. Scand. 30, 1-6.

Goh, S.H.; Hiew, N.F.; Ong, A.S.H.; Choo, Y.M. and Bramby, S. (1990): Palm oil: Tocotrienols from Palm Oil Election Spin resonance spectra. J. Am. Oil Chem. Soc. 67, 251-254.

Gordon, J. (unpublished). Biomass, energy devices for income generation at the household or common level. UNIFEM, London.

Gunstone, F.D and Norris, F.A. (1983): Lipids in Food Chemistry, Biochemistry and Technology, pp.62-69 Pergamon Press, New York.

Gunstone, F.D. (1984): Reaction of oxygen with unsaturated fatty acid esters. J. Am. Oil Chem. Soc. 69, 127-129.

Gurr, M.I. (1984): Role of fats in nutrition, pp.95-146. Elsevier Applied Science, London.

Hageman, G.; Verhagen, H.; Schutte, B. and Kleinjans J. (1991): Biological effects of short-term feeding on rats of repeatedly used deep frying fats in relation to fat mutagen content. Food Chem. Toxicol. 29, 689-698.

Hartley, C.W.S. (1984): The Oil Palm, Longman, pp.697-780, London.

Harrington, H.T. (1987): "The improvement process: How America's leading companies improve quality" Mc.Graw Hill Book Co., New York.

Hazura, A.H. and Choo, Y.M. (1997): Natural antioxidants from Palm Oil. Palm Oil Technical Bulletin, 3, (4) 5-7.

Hegsted, D.M.; McGandy, R.B.; Myers, M.L. and Stare, F.J. (1965): Quantitative effects of dietary fats on serum cholesterol in man Am. J. Clin. Nutr. 17, 281-295.

Hilditch, T.P. and Williams, P.N. (1964): The chemical constitution of natural fats. 745pp Chapman and Hall, London.

Hoffman, G. (1985): Some quality aspects of modern refining in fat science (1983) Proceedings of the 16th ISF Congress. Budapest, Hungary, 4-7 Oct., 1983. pp. 405-417 Eds Hllo, J. Akademai Kiddo Budapart, Elsevier, Tokyo.

Holub, B. and Thomas L.M. (1994): Nutritional aspects of fats and oils in technological advances in improved and alternative sources of lipids. pp.16-29 Ed. Kamel, B.S. and Kakuda, Blackie Academic Professionals, London.

Holub, B.J. (1991): Cholesterol free foods: where is the trans? Can. Med. Assoc. J. 144, 330.

Horlick, L. and Craig, B.M. (1957): Effect of Long Chain polyunsaturated and saturated fatly acids on serum lipids in man, Lancet 2, 566-570.

Hornstra, G. (1987): Dietary Lipid and Cardiovascular Disease: Effects of Palm Oil. International Oil Palm/Palm Oil conference. 29th June - 1 July, Kuala Lumpur.

Howson, C.P.; Eileen T. Kennedy, and Abraham Horrwitz (1998): Prevention of micronutrient deficiency, tools for policy makers and public health workers, committee on micronutrient deficiencies Board on International Health, Food and Nutritio, p.14. National Academy Press.

Hsieh, R.J. and Kinsella, J.F. (1989); Oxidation of polyunsaturated fatty acids: mechanisms, products and inhibition with emphasis on fish. Adv. Food Nutr. Res. 33, 233-241.

Huybrechts, H. (unpublished): Palm oil fractionation by cooking and decanting, Unilever, report, 1964.

Indian Emergency Standard Specification for Palm Oil (1977): pp.25 Indian Standards Institution, New Delhi.

Irvine, F.R. (1970): West African Agriculture, pp.4-35. Oxford University, London.

Jacobsberg, B. (1971): La production d'une huile de palme de haute qualité, Oléageneaux 26 781.

Jacobsberg, B. (1969): The influence of milling and storage conditions on bleachability of palm oil in the quality of marketing of oil palm products. Inc. Soc. of Planters Kuala, Lumpur. 106-130.

Jacobsberg, B. (1983): Quality of Palm Oil PORIM: Occasional Paper 10, 1-12.

Jacobsberg, B.; Deldino, P.; Abdul, Gapor (1978): Tocopherols and tocotrienols in Palm oil. Oleagineux 33(5) 239-247.

Jalani, B.S. and Cheah, S.C. (1997): The role of biotechnology in making oil palm the major supplier of edible and renewable industrial feedstock, Palm Oil Technical Bulletin 3, (4) 2-4.

Jayaleksmag, A. and Mathew, A.G. (1991): Effects of roasting on the lipids of oil Palm Kernel Oleaginex 46(4).

Jung, M.Y.; Yoon, S.H. and Min, D.B. (1997): Effects of roasting on the content of minor compounds and oxidation of soyabean oil J.A.O.C.5, 66, 118-120.

Kamel, B.S. and Kakuda, Y. (1994): Tropical fruits: a source of lipids in Technological Advance in improved and alternative sources of lipids, pp.116-144 Eds. Kamel, B.S. and Kakada, Y. Blackie Academic Professionals, London.

Kalyana, S. and Yusof, Basiron (1995): Market place acceptance of palm oil: The nutritional angle. Palm Oil Technical Bulletin 9, 4-5.

Kalyana, S. (1993): Transfatty acids: Their dietary and Health implications. Palm Oil Development 19, 22-25.

Kanzawa, K.; Kanzawa, E. and Natake, M. (1985); Uptake of secondary

autoxidation products of linoleic acid by the rat. Lipids 20, 412-419.

Kato, A.; Yamaoka, M.; Tanah, A.; Komiyama, K. (1985): Physiological effects of tocotrienol Yukagaku Jap Oil Chem Soc. 34, 375-376.

Kesteloot, H.; Oviasu, V.D.; Obasoham, A.O.; Olamu, A., Cobbaert, C. and Lissens, W. (1989): Serum lipid and apolipoprotein levels in a Nigerian sample Atherosclerosis 78.

Kheiri, M.S.A. (1984): Hydrogenation Technology Palm Oil Technology, 10, 1-28.

Kirk, R.S. and Sawyer, R. (1991): Pearson's composition and analysis of foods, pp.609-656. Longman Scientific and Technological, London.

Kokatnur, M.G.; Begin, J.G. and Praper, H.H. (1966): Observations on decompositon of hemin by fatty acid hydroperoxides. Proc. Soc. Exp. Biol. Med. 123, 254-258.

Kordylas, J.M. (1990): Processing and production of tropical and subtropical foods. pp.149-159. Macmillan, London.

Lange, M. (1950): Cholesterol, phytosterol content of food products and animal tissues. J. Amer Oil Chem. Soc. 27, 414.

Loncin, M. and Jacobsberg, B. (1965): Research in Belgium and Congo at Conference on Palm Oil, Tropical products Institute.

Loncin, M. (1952): L'hydrolyse spontanée autocatalique des triglycerides. Oleagineux, 7, 695.

Ma Ah Ngan (1999): Environmental management for Palm Oil industry in palm oil developments. 30, 1-10.

Machlin, L.T. (1980): Vitamin E, a comprehensive treatise, Marcel Dekker Inc. New York.

Mattikow M., (1948) J. Amer. Oil Chem Soc. 25, 200

Mattsen F.H., and Grundy, S.M. (1995): Comparison of effects of dietary saturated, monounsaturated and polyunsaturated fatty acids on plasma lipid and lipo protein in man J. Lip. Res. 26, 194-202.

Maycock, J.H. (1994): Quality management in Malaysian Palm Oil Mills. Palm Oil Developments 20, 9-12.

Ministry of Food and Agriculture Statistics Division, (MOFA). PPME, Statistics Division.

Mohamed Razar, M. (1998): Quality improvement in production of Malaysian palm oil Palm Oil developments 29, 15-21.

Mohd Suria, Affandi Y, and Noor Lida, H.M.D. and Kamli, A. (1995): Trans-free food products based on Palm Oil, Palm Oil Technical Bulletin 1 (9) 2-4.

Mohd Suria A., and Miskandar, M.S. (1999): Highlights of research on food uses of palm oil and its products. Palm Oil Developments, 30, 2-4.

Murphy S.P.; Sabar, A.F. and Block, G. (1990): Vitamin E intake and sources in the U.S. Am. Journal of Clinical Nutrition, 52, 361-367.

Nawar, W.F. (1985): Lipids in Food Chemistry ed. O.R. Fenema, Marcel Dekker, New York, 139-244pp.

Ng, K.T. and Southworth, A. (1973): Optimum time of harvesting Oil Palm in Advances in Oil Palm Cultivation, Eds Wastie, R.L. and Earp, D.A. Incorp. So. of Planters, Kuala Lumpur.

Norman, N. (1903): British Patent No. 1515.

Nutr. Rev. (1987): 45, 205-207

Nwanze, S.C. (1964): West African Inst. for Oil Palm Research Twelth Annual Reports. p.97. Ministry of Overseas Development, U.K.

Oarada, M.; Miyazawa, T. and Kaneda, T. (1986): Distribution of 14C after oral administration of (U 14C) labelled methyl linoleate hydroperoxides and their secondary products in rats. Lipids 21, 150-154.

Olie, J.J. (undated): The automatic hydraulic press and its field of application, stork Amsterdan, Mimeograph.

Olie, J.J. and Tjeng, T.D. (1974): The extraction of palm oil, paper presented at society of oils and fats group, Oil Palm Symposium, London.

Ong, A.S.H.; Choo, Y.M. and Ooi, C.K. (1995): Developments in Palm Oil in Developments in fats and Oils eds. Hamilton, R.J., Blackie Academic Press, 153-187.

Ooi, C.K., Choo, Y.M., Yap, S.C. and Ma, An (1996): Refining of Red Palm Oil. Elaeis 8(1) 20-28.

Onwuliri, V.A. (1998): Proton-nuclear magnetic resonance spectroscopy of palm oil and groundnut. African Journal of Natural Science 1(1) 73-75.

Osagie, A.U. and Bafor, M.E. (1990): Triacylglycerols of oil palm (Elaeis guineensis of variety Dura) mesocarp during maturation biochem. Cell Biol. 68, 313-317.

Parthiban, S.; Salmiah, A. and Ooi, T.L. (1996); Polyurethane foams in developing of palm based polyurethane foams an overview. Palm Oil Developments 24, 1-5.

Perkins, E.G. and Taubold, R. (1978): Nutritonal and metabolic studies on non-cyclic dimeric fatty acid methyl esters in the rats. J. Am. Oil chem. Soc. 55, 632-634.

Pike, M. (1980): Growth in importance of palm oil, in fats and oils: chemistry and technology, pp.215-247. Eds. R.J. Hamilton and A. Bhati, Applied Science, London.

Pritchard, J.L.R. (1982): Quality requirements for processing, Amer. Oil Chem. Soc. (AOCS) World Conference on Oil Seed and Edible Oil Processing, The Hague Oct., 1982.

Pritchett, W.C.; Taylor, W.G.; Carrooll, D.M. (1947): J. Am Oil Chem Soc. 24, 225.

Qureshi, A.A.; Burger, W.W.; Peterson, D.M. and Elson, C.E. (1986): The structure of an inhibitor of cholesterol biosynthesis isolated from Barley J. Bio Chem. 261, 10544-10550.

Ramli, Abdullah, Mohd Nasir H., Amiruddin and Hamirin Kafli (1997): Price, Trends and Techno-Economic advantages of Palm Oil, Palm Oil Technical Bulletin 3(2) 2-5.

Rao, C.R.; Reddy, L.S. and Prabbu, C.A.R. (1980); Study of adulteration in oils and fats ultrasonic method, Current Sci 49, 185.

Rao, P.S.; Rao, P.U. and Sesikran, B. (1991): Serum cholesterol tryglycerides and total lipid fatty acids of response to okla oils in J. Am Oil Chem. Soc. 68, 433-435.

Ratledge, C. (1994): Yeast, moulds, algae and bacteria as sources of lipids in Technological Advances in Improved and Alternative Sources and Lipids, pp.235-283. Eds Kamel, B.S. and Kakuda, Y., Blackie Academic Professionals, London.

Rawlings, H.W., Kurht, N.H. and Baxter, J.G. (1948); J. Amer. Oil Chem. Soc. 25, 24.

Rossell, J.B. (1982): Integrity and purity of oils AOCS World Conference on oil seed and edible oil processing, Hague. Oct. 1982.

Sabatier, P. (1922): Catalysis in organic chemistry translated by Reid, E.E. Van Nostrand, New York.

Salunkhe, D.C. and Desai, B.S. (1986): Post Harvest Biotechnology of Oils. pp. 147-158. eds. CRC Press, Boca Raton, Florida.

Santhiapillai, J. R. (1995): Transfatty acids in USA products, Palm Oil Technical bulletin 1 (9), 6

Sefa-Dede and Tano-Debrah (unpublished): Traditional Palm Kernel Oil Processing in Ghana, M.Phil. thesis, Department of Nutrition and Food Science, University of Ghana.

Sidek, H.A.A.; Chow, S.P.; Shaari, A.H. and Senin, H.B. (1996): Ultrasonic studies of palm oil and other vegetable oils Elaeis 8 (1) 37-44.

Siew, W.L. (1992): Oxidative Index for Crude Palm Oil PORIM Bulletin 24, 42-52.

Siew, W. L. (1995). Current Research on Palm oil, Palm oil Developments, 23, 18–2.

Sinahuber, R.O., Yu, T.C. and Yu, T.C. (1958): Food Research 23, 626.

Sherwin, E.R. (1976): Antioxidants for vegetable oils J. Am. oil Chem. Soc. 53(6) 430-436.

Shklar, G. (1982): Inhibition of oral mucosal carcinogenesis by Vitamin E J. Natl Chem Institute 68, 791-297.

Shukla, V.K.S. (1992): New and speciality oils unconventional and exotic in oils and fats in the nineties eds. Shukla, V.K.S.

Shukla, V.K.S. (1994): Present and future outlook of the world fats and oil supplier in technological advances in improved and alternative sources of lipids.pp.1-4 Eds. Kamel, K.S. and Kakuda, Y., Blackie Academic Professionals, London.

Stork (1960): Stork Palm Oil Review 1, 3.

Stork (1961): Palm Oil Review 2, 1.

Southworth, A.A. (1976): Processing, storage and transport of palm oil and kernels in developments in Crop Science (1) Oil Palm Research pp.479-492 eds. Corley, R.H.V., Wahle, K.W.J. and James W.P.T., Elsevier Scientific, London, 479-492.

Synder, P.O. (1994): Achieving Successful Total Quality Management Through behavioural Management. Food Technology, 48, 144-151.

Tan, Y.A., Low, K.S. and Chong, C.L. (1994): Rapid determination of Chlorophyls in vegetable oils by Laser based fluorometry. J. Sci. Food Agric. 66, 479-484.

Tan, Y.A., Chong, C.L. and Kow, K.S. (1995): Relationship between laser-induced fluorecence intensity and Crude Palm Oil Quality. J. Sc. Food Agric 62, 375-379.

Tappel, A.L. (1995): Antioxidants protection against peroxidation inform 6, 780-783.

Technology Consultancy Centre, TCC (1978) Extraction of palm oil using appropriate Technology Hand Screw Press.

Telek, L. and Martin, F. (1981): Okra seed, and protein in the humid low land in tropics in new sources of fats and oils AOCS Campaign II. Eds. Pyrde E.H., Prince, and L.H. Makharjee, K.B.

Thiagarajan, J. (1998): Beyond product quality competing on the new dimensions of quality Palm Oil Technical Bulletin 4 (2), 7,8.

Thieme, W.L. and Olie, J.J. (1969): Discoloration of oil palm kernels in relation to processing temperatures and time. In the quality and marketing of oil palm products, p.144 in Soc. of Planters, Kuala, Limpur.

Troisi, R.; Willet, W.C. and Weiss, Siti (1992): Trans-Trans-fatty acid intake in relation to serum to lipid concentration in adult men. Am. J. Clin. Nutr. 56, 1019-1024.

Tropical Development and Research Institute (TDRI) (1984): Oil Palm News No.28.

Turner, P.D. (1969): The importance of lipolytic micro-organisms in the degradation of oil palm products in Malaysia. In the quality and marketing of oil palm products, Inc. of Soc. Planters, Kuala Lumpur, p.53.

Twichin, J.F. (1955): Palm oil machinery, reprinted, The Planters, Incorp, Soc of Planters, Kuala Lumpur.

United Nations Developments Fund for Women (UNIFEM) (1987): Oil Extraction Food Cycle Source Book, pp.8-26, New York.

Usuki, Y.E.; Endo, T. and Suzuki, J.K. (1985): Proxidant activities of Chlorophyls and related compounds of edible oils in Developments in Food Science (II) Fat Science: Part A, pp.627-637 Ed. Hollo, J. Elsevier, New York.

Weiss, T.J. (1983): Food oils and their uses, pp.65-101. Ellis Harwood Ltd. Chichester.

Wolf, G. (1982): Is dietary Beta-carotene an anti-cancer agent? Nutr. Revs 40, 257-261.

Woodrof, J.G. (1994): Nuts as a source of edible oils in Technological Advances and Alternative Sources of lipids. pp.150-176. Eds B.S. Kamel and Y. Kakudu, Blackie Academic Professionals, London.

Wyer, G. van de (1927): Procédés d'extraction de huile de palme. Bull. Ass. pour le perfionnement de palme, material colonial.

Yeong, S.K. (1996): Vegetable oils and its derivatives for lubricants. Palm Oil Developments 24, 6-10.

Young, V. (1980): Processing of oils and fats in fats and oils: chemistry and technology, pp.135-165 Eds. Hamilton, R.J. and Bhati, A., Applied Science, London.

Yussoff, M.S.A.; Kifli, S.A.; Noor, L.H.M.D. and Rozie M.D. (1997): The formulation of trans-fatty acid free-margarines palm oil technical bulletin 3 (5) 6-7.

Zeils, N.W. and Schmidt, W. (1949): Hydrogenating Fat U-S Pat.2, 468, 799.

APPENDICES

GOPDC

APPENDIX A

MOISTURE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	50289.655	6	8381.609	8527.308	0.000
Within Groups	34.402	35	0.983		
Total	50324.057	41			

Mean	Stages Groups	Groups 6 5 4 3 2 1 7
1.4117	6	
1.4317	5	
5.2533	4	* *
53.8417	3	* * *
55.2300	2	* * *
69.5700	1	* * * * *
93.8500	7	* * * * * *

* Indicates significant differences which are shown in lower triangle after Tukey test.

APPENDIX B

REFRACTIVE INDEX

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.255E-02	6	7.092E-03	433.444	0.000
Within Groups	5.727F-04	35	1.636E-05		
Total	4.312E-02	41			

		Groups						
		7	3	2	1	6	4	5
Mean	Stages Groups							
1.3742	7							
1.3753	3							
1.3795	2							
1.3832	1	*	*					
1.4400	6	*	*	*	*			
1.4488	4	*	*	*	*			
1.4433	5	*	*	*	*			

APPENDIX C

F F A

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.353	6	5.880E-02	2.092	0.030
Within Groups	0.764	35	2.184E-02		
Total	1.117	41			

		Groups						
		5	2	1	4	6	3	7
Mean	Stages Groups							
2.1383	5							
2.2300	2							
2.2650	1							
2.2900	4							
2.3183	6							
2.3967	3							
2.4300	7	*						

APPENDIX D

P O V

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.255	6	4.247E-02	1.377	0.251
Within Groups	1.080	35	3.085E-02		
Total	1.335	41			

Groups
7 3 2 1 6 4 5

No two groups are significant different at the 0.050 level.

APPENDIX E

T B A

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8.695E-03	6	1.449E-03	11.356	0.000
Within Groups	4.467E-03	35	1.276E-04		
Total	1.316E-02	41			

Groups
4 5 3 6 1 7 2

Mean	Stages	
0.1183	4	
0.1250	5	
0.5400	3	*
0.1400	6	*
0.1450	1	* *
0.1583	7	* *
0.1650	2	* * * *

* Indicates significant differences which are shown in lower triangle

TOPP

APPENDIX F

MOISTURE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4780.769	6	7967.962	11899.635	0.000
Within Groups	23.436	35	0.670		
Total	47831.208	41			

Mean	Stages Groups	Groups 5 6 4 3 2 1 7
2.2083	5	
3.3917	6	
6.3583	4	* *
53.8517	3	* * *
56.0583	2	* * * *
69.1517	1	* * * * *
92.6300	7	* * * * * *

APPENDIX G

RI

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.851E-02	6	8.085E-03	1645.107	0.000
Within Groups	1.720E-04	35	4.914E-0		
Total	4.868E-8	41			

Mean	Stages Groups	Groups 3 7 2 1 4 6 5
1.3747	3	
1.3757	7	
1.3762	2	
1.3793	1	* *
1.4435	4	* * * *
1.4448	6	* * * *
1.4468	5	* * * *

APPENDIX H

F F A

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.335	6	5.580E-02	3.584	0.007
Within Groups	0.545	35	1.557E-02		
Total	0.880	41			

Mean	Stages Groups	Groups 5 6 3 4 1 7 2
2.39	5	
2.40	6	
2.41	3	
2.41	4	
2.45	1	
2.49	7	
2.66	2	* * * * *

APPENDIX I

P O V

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.780E-02	6	7.966E-03	1.024	0.426
Within Groups	0.272	35	7.780E-03		
Total	0.320	41			

No two groups are significantly different at the 0.050 level.

APPENDIX J

T B A

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.714E-03	6	2.857E-04	2.182	0.068
Within Groups	4.583E-03	35	1.310E-04		
Total	6.298E-03	41			

No two groups are significantly different at the 0.050 level.

APPENDIX K

Two-way ANOVA
Dependent Variable: MOISTURE

Source	Type III Sum of Square	df	Mean Square	F	Sig
Corrected Model	98101.433	13	7546.264	9133.088	.000
Intercept	136440.487	1	136440.487	165131.113	.000
PALM	4.009	1	4.009	4.852	.031
STAGES	98077.190	6	16346.198	19783.467	.000
PALM* STAGES	20.235	6	3.372	4.082	.001
Error	57.838	70	.826		
Total	235599.757	84			
Corrected Total	98159.271	83			

a R Squared = .999 (Adjusted R. Squared = .999)

APPENDIX L

Dependent Variable: R1

Source	Type III Sum of Square	df	Mean Square	F	Sig
Corrected Model	9.106E-02	13	7.005E-03	658.461	.000
Intercept	165.975	1	165.975	15601993.930	.000
PALM	3.048E-06	1	3.048E-06	.286	.594
STAGES	9.088E-02	6	1.515E-02	1423.788	.000
PALM* STAGES	1.806E-04	6	3.010E-05	2.830	.016
Error	7.447E-04	70	1.064E-05		
Total	166.067	84			
Corrected Total	9.181E-02	83			

a R Squared = .992 (Adjusted R. Squared = .990)

APPENDIX M

wo-way ANOVA
ependent Variable: FFA

Source	Type III Sum of Square	df	Mean Square	F	Sig
Corrected Model	1.240	13	9.536E-02	5.098	.000
Intercept	474.430	1	474.430	25363.172	.000
PALM	.552	1	.552	29.515	.000
STAGES	.320	6	5.333E-02	2.851	.015
PALM* STAGES	.368	6	6.127E-02	3.275	.007
Error	1.309	70	1.871E-02		
Total	476.979	84			
Corrected Total	2.549	83			

R Squared = .486 (Adjusted R. Squared = .391)

APPENDIX N

wo-Way ANOVA

pendent Variable: POV

ource	Type III Sum of Square	df	Mean Square	F	Sig
orrected Model	.583	13	4.500E-02	2.330	.012
ntercept	727.415	1	727.415	37659.720	.000
ALM	.282	1	.282	14.618	.000
TAGES	.232	6	3.863E-02	2.000	.077
ALM* TAGES	7.088E-02	6	1.181E-02	.612	.720
rror	1.352	70	1.932E-02		
otal	729.353	84			
orrected otal	1.937	83			

R Squared = .302 (Adjusted R. Squared = .172)

Two - way ANOVA
Dependant Variable: TBA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.042E-02	13	8.016E-04	6.200	.000
Intercept	1.660	1	1.660	12843.103	.000
PALM	1.071E-05	1	1.071E-05	.083	.774
STAGES	6.912E-03	6	1.152E-03	8.910	.000
PALM* STAGES	3.498E-03	6	5.829E-04	4.509	.001
Error	9.050E-03	70	1.293E-04		
Total	1.680	84			
Corrected	1.947E-02	83			

a R Squared = .535 (Adjusted R Squared = .449)

APPENDIX P

Two-way ANOVA for
Traditional Processes
Dependent Variable: MOISTURE

Source	Type III Sum of Square	df	Mean Square	F	Sig
Corrected Model	15849.760	3	5283.253	68281.875	.000
Intercept	23090.668	1	23090.668	298428.645	.000
PALM	.226	1	.226	2.924	.103
STAGES	15849.190	1	15849.190	204838.266	.000
PALM* STAGES	.343	1	.343	4.436	.048
Error	1.547	20	7.737E-02		
Total	38941.975	24			
Corrected Total	15851.307	23			

a R Squared = 1.000 (Adjusted R. Squared = 1.000)

APPENDIX P

Two-Way ANOVA for
Traditional Processing

Dependent Variable: R1

Source	Type III Sum of Square	df	Mean Square	F	Sig
Corrected Model	7.348E-03	3	2.449E-03	62.934	.000
Intercept	47.957	1	47.957	1232305.649	.000
PALM	5.227E-04	1	5.227E-04	13.430	.002
STAGES	5.704E-03	1	5.704E-03	146.574	.000
PALM* STAGES	1.121E-03	1	1.121E-00	28.797	.000
Error	7.783E-04	20	3.892E-05		
Total	47.963	24			
Corrected Total	8.126E-03	23			

a R Squared = .904 (Adjusted R. Squared = .890)

APPENDIX P

Two-way ANOVA for
Traditional Processes
Dependent Variable: FFA

Source	Type III Sum of Square	df	Mean Square	F	Sig
Corrected Model	3.282E-02	3	1.094E-02	.849	.483
Intercept	106.429	1	106.429	8264.176	.000
PALM	1.500E-02	1	1.500E-02	1.165	.293
STAGES	1.500E-02	1	1.500E-02	1.165	.293
PALM* STAGES	2.817E-03	1	2.817E-03	.219	.645
Error	.258	20	1.288E-02		
Total	106.719	24			
Corrected Total	.290	23			

a R Squared = .113 (Adjusted R. Squared = -.020)

APPENDIX P

Two-Way ANOVA for
Traditional Processing

Dependent Variable: POV

Source	Type III Sum of Square	df	Mean Square	F	Sig
Corrected Model	1.708E-02	3	5.693E-03	.895	.461
Intercept	224.543	1	224.543	35310.104	.000
PALM	3.037E-03	1	3.037E-03	.478	.497
STAGES	5.042E-04	1	5.042E-04	.079	.781
PALM* STAGES	1.354E-02	1	1.354E-02	2.129	.160
Error	.127	20	6.359E-03		
Total	224.687	24			
Corrected Total	.144	23			

a R Squared = .118 (Adjusted R. Squared = -.014)

APPENDIX P

Two-Way ANOVA for
Traditional Processing

Dependent Variable: TBA

Source	Type III Sum of Square	df	Mean Square	F	Sig
Corrected Model	1.500E-04	3	5.000E-05	.248	.862
Intercept	.621	1	.621	3078.430	.000
PALM	1.500E-04	1	1.500E-04	.744	.399
STAGES	.000	1	.000	.000	1.000
PALM* STAGES	.000	1	.000	.000	1.000
Error	4.033E-03	20	2.017E-04		
Total	.625	24			
Corrected Total	4.183E-03	23			

a R Squared = .118 (Adjusted R. Squared = -.014)

APPENDIX Q

INDEPENDENT SAMPLES TEST

		Levene's Test for Equality of Variances	
		F	Sig
MOISTURE	Equal variances Assumed	59.018	.991
	Equal variances Not Assumed		
RI	Equal variances Assumed	43.225	.000
	Equal variances Not Assumed		
FFA	Equal variances Assumed	.000	.991
	Equal variances Not Assumed		
POV	Equal variances Assumed	.091	.766
	Equal variances Not Assumed		
TBA	Equal variances Assumed	.050	.826
	Equal variances Not Assumed		

APPENDIX R

INDEPENDENT SAMPLES TEST

		t-TEST FOR EQUALITY OF MEANS			
		t	df	Sig. 2-tailed	Mean Difference
MOISTURE	Equal variances Assumed	-9.091	22	.000	-2.9200
	Equal variances Not assumed	-9.091	12.482	.000	-2.9200
RI	Equal variances Assumed	3.524	22	.002	1.3242 E-02
	Equal variances Not assumed	3.524	13.300	.004	1.3242 E-02
FFA	Equal variances Assumed	5.537	22	.000	.2283
	Equal variances Not assumed	5.637	21.987	.000	.2283
POV	Equal variances Assumed	-3478	22	.002	-.1183
	Equal variances Not assumed	-3.478	21.577	.002	.1183
TBA	Equal variances Assumed	-3.046	22	.006	-1.7500 E-02
	Equal variances Not assumed	-3.046	21.965	.006	-1.7500 E-02

APPENDIX S

GROUP STATISTICS

Methods of Processing		M	Mean	Std Deviation	Std Error Mean
MOISTURE	Industrial	12	2.40	1.076	.3108
	Traditional	12	5.32	2.801	8.087 E-03
RI	Industrial	12	1.4424	4.078 E-03	.177 E-03
	Traditional	12	1.4290	1.254 E-02	3.620 E-02
FFA	Industrial	12	2.36	.1004	2.89 E-02
	Traditional	12	2.13	9.802 E-02	2.83 E-02
POV	Industrial	12	2.94	8.89 E-02	2.57 E-02
	Traditional	12	3.05	7.73 E-02	2.03 E.02
TBA	Industrial	12	.1433	1.435 E-02	4.144 E-03
	Traditional	12	.1608	1.379 E-02	3.981 E-03