QUALITY CHARACTERISTICS OF PALM OILS PRODUCED FROM IMPROVED TRADITIONAL, ARTISANAL, MEDIUM AND LARGE SCALE PROCESSES

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DECLARATION

This is to certify that this thesis is the result of research undertaken by Jonas Sebigbon towards the award of Master of Philosophy in Food Science in the Department of Nutrition and Food Science, University of Ghana.

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ABSTRACT

The quality of palm oil depends on the method of extraction. Mechanized methods of extracting palm oil result in better oil quality. In Ghana over 80% of palm oil is produced by small scale processors whose lack of mechanization results in poor oil quality. A study conducted in 2011 resulted in the development of an improved traditional process (ITP) to augment the quality of palm oil from the small scale. This study sought to compare palm oils from different processing scales to ITP oil to identify gaps in quality for further improvements. The objective therefore was to assess the quality characteristics of palm oils produced from the improved traditional process, small (artisanal), medium and large scale processes.

Palm oils from 8 different processing methods were purposively sampled. Physico-chemical analysis which included; moisture, impurities, colour, Free fatty acids (FFA), peroxide value, iodine value and saponification value were conducted on both fresh and stored palm oil samples. A descriptive sensory analysis was also done by a trained panel to identity, describe and quantify perceivable palm oil sensory attributes. Analysis of Variance (ANOVA) was carried out to establish the effects of the extraction method on physico-chemical parameters. Principal Component Analysis (PCA) was used to identify major sensory attributes of the different palm oil samples.

FFA which is the key quality index in determining oil quality varied among processing methods. Palm oil sample from the large scale processing facility where fruits are harvested and processed almost immediately (L1) had the lowest FFA of 2.51%. It was the only sample that met the standard of 5% maximum FFA. ITP samples recorded 5.93% while oil samples from the small scale had the poorest quality with over 31% FFA. Moisture values for all samples except L1 (0.1%) ranged from 0.5 - 1.15% and may alter the physical state of the oils. Palm oil samples from the spindle press (SSP) and hydraulic press (SHP) were not clarified and had very high amounts of impurities (0.45%). The range of values obtained for both iodine value and saponification value (50 – 55 and 190 – 210 respectively) identifies the oils as palm oil. Stored palm oils deteriorated with storage especially after the first four weeks. Deterioration in L1 was minimal.

Orange - red colour, turbidity, rancidity, smoky, burnt, bitter taste, sweet taste, mouth coating and roughness were the descriptors used to identify the perceivable palm oil sensory attributes. Oils from the small scale were predominantly rancid, oils from the medium scale and the improved traditional process were smoky while oils from the large scale were fresh.

Palm oils from the large scale had better physico-chemical and sensory quality and longer shelf stability due to mechanized processing which is more efficient. Boiling of fresh fruit bunches (FFB) should be done to facilitate fruit stripping so that fruit storage which is the major cause of FFA accumulation can be avoided. Careful clarification and the introduction of a drying process would be necessary to extend shelf stability of palm oil produced at the small and medium scale levels.

DEDICATION

To my late father, Michael Naa Billa Tii Sebigbon

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LIST OF ABBREVIATIONS

CPO:	Crude palm oil
CSIR:	Council for Scientific and Industrial Research
ECOWAS:	Economic Community of West African States
DAGs:	Diacylglycerides
FFA:	Free fatty acids
FFB:	Fresh fruit bunches
MAGs:	Monoaclyglycerides
MoFA:	Ministry of Food and Agriculture
NOS:	Non-oily solids
OPRI:	Oil Palm Research Institute
PSI:	Presidential Special Initiatives
RBDO:	Refined, bleached and deodorized oil
TAGs:	Triacylglycerides

1.0 INTRODUCTION

1.1 Background

The oil palm (*Elaeis guineensis Jacq.*) is an important cash crop in Ghana and many West African countries**.** There are three major oil palm varieties: Dura, Pisifera and Tenera. Tenera which is a monofactorial hybrid between Dura and Pisifera, is the variety cultivated commercially (Musonge and Baryeh, 1991). Oil palm produces two distinct kinds of oil: palm oil which is obtained from the mesocarp of the fruit and palm kernel oil which is obtained from the kernel, both of which are important in world trade. In West Africa and especially those in the coastal and forest zones, palm oil constitutes the single most important source of edible oil (Baryeh, 2001). Apart from the use of palm oil as cooking oil, it is also used industrially for margarine and soap production as well as fuel blend for internal combustion engines.

There is a huge potential for palm oil as a major source of income through the local market and as a major export crop for the country. In 2012, an estimated total of 305,758 ha of oil palm was cultivated in Ghana (MoFA, 2013). Out of this, over 80% was cultivated by private small-scale farmers. MoFA (2013) further estimated that a total of 243, 852 tons of palm oil were produced with an unmet demand of 35,000 tons for Ghana and 850,000tons for the ECOWAS sub-region. These unmet demands could be attributed to poor farming practices and constraints, and more importantly inefficient processing practices. To augment the shortfall in palm oil production in Ghana, several Government interventions with the support of international agencies according to Angelluci (2013) were undertaken to revamp the palm oil sector and boost both production and productivity. These interventions according to Angelluci (2013) include;

i. 3,000ha outgrower project currently ongoing in the Upper and Lower Denkyira Districts.

ii. Expansion of the seed nuts production capacity of OPRI from 2 million to 5 million seed nuts per year.

iii. Cultivation of over 10,000 ha small-scale farms under the President's Special Initiative (PSI) on oil palm.

The short fall in production of palm oil is further worsened by the production of poor quality oil from the small scale processors who according to Angelluci (2013) produce about 80% of the country's palm oil. Crude palm oils from these small scale processors do not meet the quality standard for industrial utilization and export due to very high amounts of free fatty acids (FFA), water and dirt. Many industrial operatives adopt the basic quality standard specification of 5% maximum for FFA, and 0.25% maximum for moisture content and impurities of crude palm oil (CPO) and sanctions are imposed on CPO that does not meet these specifications (Berger, 2010). Small scale producers therefore turn to the local market and the traditional soap making industries which are less lucrative markets, where the oils are used as cooking oil and for making soap respectively.

The processing practices in the production of CPO are important factors that influence the quality of the CPO. Palm oil processing is a capital intensive venture that requires huge machinery. The extent to which mechanization is involved in palm oil processing is therefore the basis for categorizing palm oil production into small (artisanal), medium and large scale (Taiwo *et al.*, 2000; Owolarafe *et al.*, 2002; Orji and Mbata, 2008). The large scale is completely mechanized, the medium scale is semi-mechanized while the small scale is barely mechanized. These differences in mechanization result in differences in processing techniques and these results in differences in the quality of oils produced. Storage of fruits for extended periods of time in the small and medium scale to facilitate manual fruit stripping due to the absence of mechanical strippers is particularly the major cause of higher FFA content of oils in these scales of production (Orji and Mbata, 2008; Frank *et al.*, 2011).

1.2 Rationale

The palm oil industry in Ghana is dominated by small scale palm oil production. However the quality of the oil produced is poor due to improper handling and processing techniques. Previous work by Agbotse (2011) studied the influences of various traditional processing methods, fruit variety, fruit condition and fruit age on the quality of palm oil. His work resulted in an optimised processing condition known as “improved traditional process” (ITP) and how it could be employed to obtain good quality palm oil that meets international standards.

Furthermore, issues of marketing constraints and profitability in small scale palm oil production have led to adulterations such the addition of red dye to maximize profit. It is envisaged that palm oil produced from improved traditional processes has a great potential to solving the problem of poor oil quality and it subsequent low market value. It is therefore prudent to compare oil from ITP to those of the different scales of production to identify the gaps in quality both physico-chemical and sensory, improve on it so as to create a solid foundation that would inform key actors in the palm oil industry on best practices to adopt to sustain the improved quality and maximize profit.

1.3 Objective

To assess the quality characteristics of palm oils produced from the improved traditional process, small (artisanal), medium and large scale processes.

1.3.1 Specific Objectives

The specific objectives of this work were:

i. To determine the physico-chemical characteristics of palm oil from improved traditional, small, medium and large scale processes.

ii. To investigate changes in the physico-chemical characteristics of palm oils from improved traditional, small, medium and large scale processes during storage.

iii. To establish the sensory characteristics of palm oils from improved traditional, small, medium and large scale processes.

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter reviews available literature on palm oil relevant to achieving the objectives of this work. Particularly, this chapter focuses on providing information on the processing practices of palm oils in different scales of production, the chemistry and quality parameters of palm oils. It outlines the facts, findings, controversies and gaps of previous works pertaining to oil quality.

2.2 General overview of oil palm

Oil palm (*Elaeis guineensis Jacq.*) is a monocotyledonous perennial tree crop of West African origin. It is the highest oil producing plant, producing palm oil and palm kernel oil (Sambanthamurthi *et al.*, 2000, Teoh, 2002). Oil palm grows well in tropical climate especially in coastal and forest zones (Teoh, 2002) that receive adequate rainfall of over 2000 mm per year spread evenly through the year, adequate sunshine of over 2000 h per annum, and moderately high temperature of 25–33^{o}C (Basiron, 2005).

2.3 Composition of Oil Palm Fruits

The oil palm fruit is an oval-shaped drupe that is pointed at the apex, varies between 20 to 50 mm in length and could be as large as 5 to 25 mm in diameter and 3 to 25 g in weight (Owolarafe *et al.*, 2002; Orji and Mbata, 2008; Hadi *et al.*, 2009). Fruits are formed in a tight bunch. The pericarp comprises three layers - exocarp (skin), mesocarp and endocarp. The mesocarp is the pulp that contains palm oil while the endocarp is a hard layer that encloses the kernel (the endosperm) which contains oil and carbohydrate reserves for the embryo.

The composition of the pericarp depends on the fruit variety. Dura variety has a thin mesocarp content (35% - 55% of fruit weight) which responsible for the low oil content of this variety, 2 – 8 mm thick endocarp with generally large kernel that makes it suitable for kernel oil production (Owolarafe *et al*., 2007). Pisifera type is characterized by thick mesocarp about 95% (with very little oil content), no endocarp (shell-less) with small kernels (Baryeh, 2001; Umerie *et al.*, 2004; Owolarafe *et al*., 2007; Hadi *et al.*, 2009). Pisifera is not used as a commercial planting material as it is mostly infertile. The Tenera is a monofactorial hybrid between Dura and Pisifera (Baryeh, 2001; Atinmo and Bakre, 2003; Abbas *et al*., 2006; Owolarafe *et al*., 2007). It is characterized by 60% - 95% thick mesocarp, 0.5 – 3 mm thin endocarp with reasonable kernel size (Teoh, 2002) and is thus used in the production of mesocarp oil and less kernel oil when compared with the dura variety (Owolarafe *et al*., 2007). Tenera constitutes most commercial plantings (Latiff, 2000; Teoh, 2002; Owolarafe *et al*., 2007).

Oil in palm fruits is stored in oil bodies found in the cytoplasm of mesocarp cells of ripe fruits. The oil content in young fruits is very little but increases rapidly prior to ripening (Baryeh, 1992: The Agronomy and Economy of Important Tree Crops of the Developing World, 2010). Polyunsaturated linolenic acid (18:3) and linoleic acid (18:2), which are components of membrane lipids are the major fatty acids in the mesocarp of young palm fruits but their levels drop as rapid oil accumulation begins (The Agronomy and Economy of Important Tree Crops of the Developing world, 2010). On harvesting, fats constitute 70 – 75% (composed of oleic 39 – 52%, palmitic 32 - 45%, linoliec 5 – 11%, stearic 2 – 6 %, myristic 1- 6 % of dry matter) (Baryeh, 1992). The percentage of palmitic acid in oil palm is higher than any other commercial vegetable oil (Sambanthamurthi *et al*., 2000).

In the mesocarp of palm fruits, certain key enzymes regulate fatty acid composition. They include: Beta-ketoacyl ACP synthase II (KAS II) which is a condensing enzyme exclusively responsible for the conversion of palmitic acid to stearic acid; Acyl ACP thioesterases which cause the release of fatty acids from ACP so that they can be exported out of the plastid into the cytoplasm where they are incorporated into triacylglycerols; Stearoyl ACP desaturase which is responsible for the formation of oleic acid; and lipase (triacylglycerol acylhydrolase), the first enzyme involved in the degradation of triacylglycerols (Sambanthamurthi *et al*., 2000). The degradation of triacylglycerols produces free fatty acids that results in rancidity and impairment of oil quality. Therefore the increase in FFA levels in palm fruits is often attributed to the action of lipases (Sambanthamurthi *et al*., 2000).

2.4 Palm Oil Extraction

Palm oil extraction entails processing palm fruits to obtain palm oil. This process varies due to the equipment available and the level of mechanization involved in the extraction process. Palm oil extraction is therefore categorized into small scale, medium scale (semi-mechanized) and large scale (mechanized) (Taiwo *et al.*, 2000; Owolarafe *et al*., 2002; Orji and Mbata, 2008).

2.4.1 Palm Oil Extraction Process

Generally palm oil processing involves certain basic steps which are fruit boiling or sterilization, stripping, digestion and oil extraction. Across the different scales of production, processing steps differ due to differences in equipment used and the level of mechanization. In industrial mills the unit operations involved in palm oil processing are; sterilization, stripping, digestion, oil extraction and clarification. While in most medium and small scale set ups the unit operations are quartering/sectioning, heaping/fermentation, stripping, cooking (sterilization), digestion, extraction and clarification. The differences in the steps are as a result of the differences in mechanization.

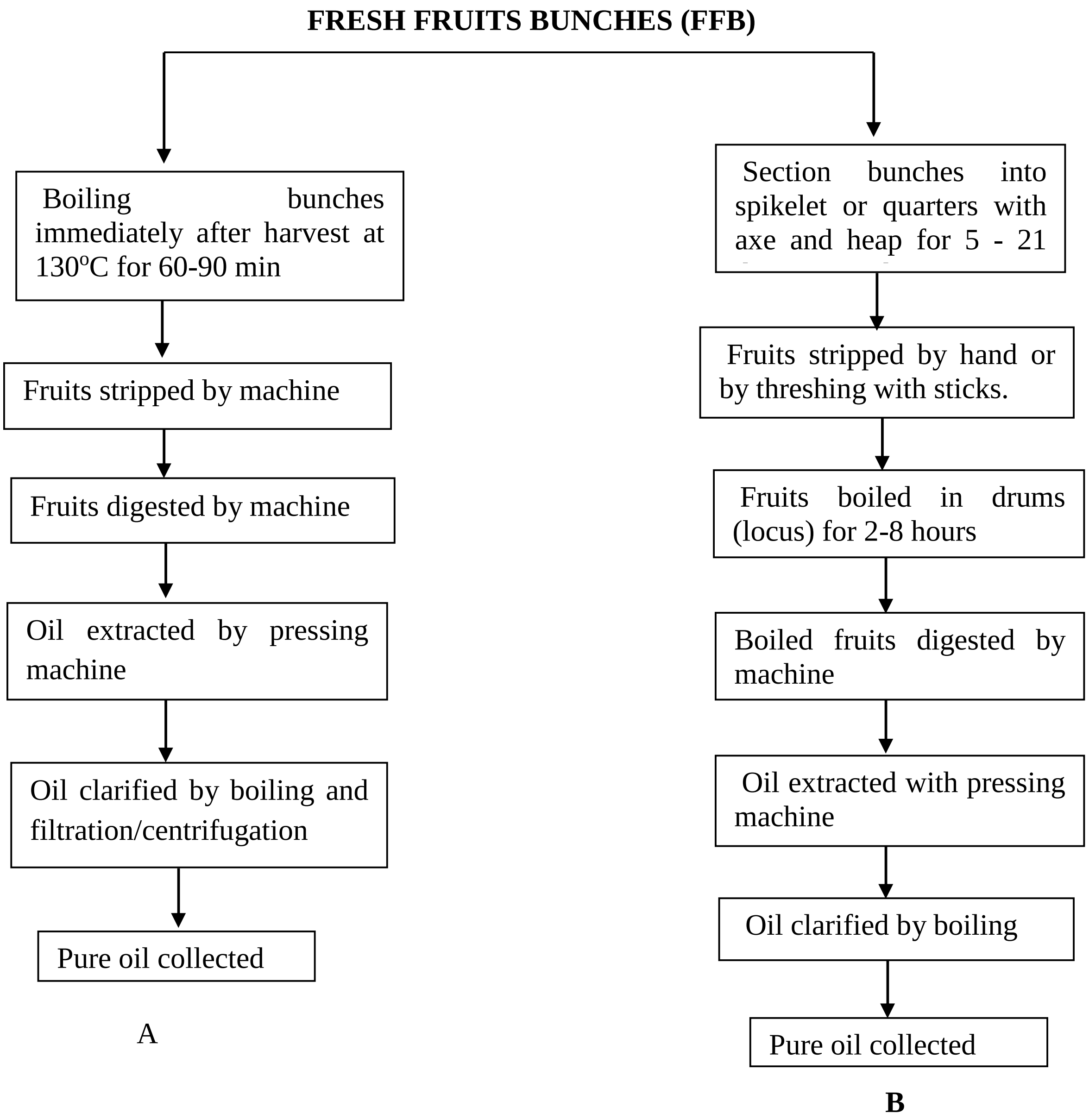

Figure 1.1: Process flow diagram of large scale (A) and small scale (B) palm oil processing

2.4.1.1 Sterilization

Sterilization or cooking or fruit boiling is often the first step carried out in many industrial palm oil mills. Fresh fruit bunches are often subjected to steam pressure of 3 kg/cm^2 at a temperature of 143^{o}C for approximately 60 min (Basiron, 2005). The objectives of sterilization according to Basiron (2005) are;

i. to prevent further rises in the FFA of the oil due to enzymatic reaction,
ii. facilitate mechanical stripping,
iii. prepare the pericarp for subsequent processing and,
iv. precondition the nuts to minimize kernel breakage.

In small and most medium scale mills, fruit sterilization which is done in the form of boiling the fruits is done after quartering, fermentation and stripping. Whereas sterilization in large scale is done under controlled conditions of temperature and pressure, sterilization in small scale is controlled at the processors own discretion since the process is not mechanized. Sterilization in small scale processing according to Owolarafe *et al.* (2002) takes about 1 – 3 hours and it depends on the volume of fruits and the burning efficiency of the wood.

Small scale processors in Ghana boil their fruits in big metal containers called *loco* for a period of about 1- 4 hours depending on the amount of fruits (Osei-Amponsah *et al*., 2012). Boiling of fruits is often done overnight in open fire using empty fruit bunches, fibre and lorry tyres as a source of fuel, while others use only empty bunches and fibre as source of fuel for boiling fruits during the day (Osei-Amponsah *et al*., 2012).

Although sterilization according to Orji and Mbata (2008) serves to first of all prevent FFA build-up in oil as a result of the destruction of the thermolabile lipase or fruit enzyme and arrests hydrolysis and autoxidation, and secondly, soften the palm fruit on the bunch to facilitate stripping, it appears that the latter is not applicable in small scale processing since the fruits are stripped prior to sterilization or cooking. However many authors (Baryeh, 2001; Owolarafe and Faborade, 2008; Taiwo *et al.*, 2000) agree that the sterilization process improves extraction efficiency and the quality of the oil.

2.4.1.2 Quartering

Quartering is often the first unit operation done in most small and medium scale palm oil processing mills. This is a process of sectioning or quartering the fresh fruit bunches into smaller units (spikelets). Quartering is done using an axe or cutlass. Since most processes in the small scale are not mechanized, quartering is done for convenience as it reduces the size of bunches into smaller and workable bits especially for hand stripping. However quartering exposes the fruits to bruises and thus the quality of the fruits are compromised since FFA would accumulate.

2.4.1.3 Heaping/fermentation

In the small and medium scale, FFB or loose fruits are often stored for some time before oil extraction. Storage of fruits is done in the open on the bare ground often under shade. This processing step is believed by many (Purseglove, 1985; Orji and Mbata, 2008; Hadi *et al.*, 2009; Frank *et al.*, 2011; Zu *et al.*, 2012) to be the sole source of poor oil quality produced by the small and medium scale processors. Storage of fruits for longer periods results in the growth of moulds which can contribute a significant amount of lipases during processing. Figure 2.2 shows fruits stored for different periods of time.

Figure 2.2: Palm fruits stored for 5 days (A) and 14 days (B)

Osei-Amponsah *et al.* (2012) studied the processing practices of small scale palm oil producers in the Kwaebibirem district. They reported that storage of fruits ranges from 1 – 4 weeks and this range depended on the intended use of the oil. Processors in Asuom, Otumi and Subi stored fruits for 1- 5 days because these areas produced a special palm oil for cooking called *zoomi*. However, processors in Kade and Kusi stored their fruits for 1- 2 weeks, while those processors in Takorase stored fruits for 2 – 4 weeks because their oils were meant for soap making. Getting rid of water, enhancing extraction and making pressing of digested fruits easier were the reasons given for fruit storage. Fruit storage according to some processors as reported by Osei –

Amponsah *et al.* (2012), increased oil yield but reduced quality. Many processors however disagreed with this claim.

Similar studies by Zu *et al.* (2012) in the same district found that the duration of storage of fruits had no significant effect on oil extraction rate or oil yield contrary to perception by most small-scale palm oil processors that oil yield and extraction rate increased with duration of storage of palm fruits. The reason given was that the mesocarp tissue becomes softer with increasing time of fruits storage thereby making pressing of oil easier. They also noted the belief by most small scale processors that storing fruits for a period of time helps to reduce the moisture content of the oil.

Fruit storage may be a necessary step in the small and medium scale because it helps in the stripping of the fruits. Without fruits storage, stripping would be difficult since there are no machines involved in this process at the small scale. However fruit storage after stripping of fruits is done for the perceived higher oil yield.

2.4.1.4 Stripping

The purpose of stripping is to separate the fruit from the bunch stalks. In the small and medium scale, stripping is done after fermentation as fermentation makes it easy to detach the fruits from the stalks. Stripping of fruits in small and medium scale is achieved through hand picking, or threshing where sticks are used to knock off the fruits from the stalks. The former is done mostly by women (Osei – Amponsah *et al.,* 2012). Fruits that are often threshed do not go through the process of quartering because the bigger size is easier to thresh. Hand picking though slow results in clean fruits whereas threshing is faster but causes the bruising of fruits (Orji and

Mbata, 2008). Stripping by threshing may require an additional process of winnowing (Orji and Mbata, 2008).

Stripping in many industrial settings is done after sterilization (Taiwo *et al.*, 2000; Orji and Mbata, 2008). The process is mechanized and two basic actions are involved in separating the fruits: a small vigorous shaking and beating (Basiron, 2005). Over the years, several machines have been designed but only the ‘‘drum’’ type is in general use (Basiron, 2005). The drum stripper consists of a long horizontal drum made up of small channel section or T bars spaced far enough apart to permit the escape of the fruit yet close enough to prevent the passage of the stalks or spikelets so that fruits are effectively separated from stalks or spikelets (Basiron, 2005).

2.4.1.5 Digestion

This process involves breaking down the boiled fruit pericarp thus breaking down the oil cells. Digestion is probably the only mechanized process in many small scale and some medium scale set ups. Digestion is an important process as it is the key process that determines oil yield at extraction (Badmus, 1991; Baryeh, 2001; Owolarefe *et al.*, 2002; Orji and Mbata, 2008). For instance a drum of fruits digested mechanically gives an oil yield of about 50 litres whereas that digested manually would yield less than 25 litres of oil (Taiwo *et al*., 2000; Owolarafe and Faborode, 2008). This also suggests that even different mechanical digesters would differ in their oil throughput.

Digestion in the industrial scale involves reheating the sterilized fruits to loosen the pericarp from the nuts and to break the oil cells before passing to the oil extraction unit (Basiron, 2005). According to Basiron (2005), optimum digestion conditions can be obtained by mixing the fruits at a temperature between 95 and 100°C for approximately 20 min. Baryeh (2001) adds that heating time of more than 20 and 30 minutes may decrease oil yield but insist that heating temperatures below or above 100°C do not increase oil yield appreciably. Digesting the fruits at high temperature according to Orji and Mbata (2008) aids in reducing the viscosity of the oil, destroys the fruits' exocarp, and completes the disruption of the oil cells which already begun in the sterilization phase. Digesters are mostly cylindrical vessels fitted with a central shaft that carry a number of radial arms and heated by steam from a steam jacket or by direct steam injection (Basiron, 2005).

2.4.1.6 Oil Separation/Pressing

This is a separation process that yields two products; (1) a mixture of oil, water, solids, and (2) a press cake containing fibers and nuts (Basiron, 2005). Oil extraction is an important determinant of oil yield. Oil yield increases with increasing extraction pressure but pressures above 25MN/m according to Baryeh (2001) do not increase yield significantly.

In small scale palm oil processing, pressing is the other mechanized operation besides digestion (Osei – Amponsah *et al.*, 2012). Several equipment are involved and these include the hand spindle press, hydraulic press and digester-screw press. The digester screw press is the only extraction machine that combines the process of digestion and pressing into a single process (Owolarafe *et al.*, 2002).

In mechanized systems, oil extraction is generally carried out using continuous screw presses comprising a perforated horizontal cage in which two screws or worms run with a cone at the discharge end of the cage that controls the pressure to ensure a minimum of residue oil in the press cake with an acceptable amount of broken nuts (Basiron, 2005). Oil extraction may be designed to operate batch system where small amounts of material is extracted at a time or a continuous system (Owolarafe *et al.*, 2002; Owolarafe and Faborode, 2008).

2.4.1.7 Clarification

Clarification is often the last process in oil extraction. It is a cleaning process that removes dirt and water from the oil. According to Basiron (2005), crude oil from the press (sludge) has an average composition of 66% oil, 24% water, and 10% non-oily solids (NOS).

In small scale processing, clarification is achieved by boiling and skimming of the oil. Sludge from the press is boiled for about 1 – 2 hours under low heat (Osei-Amponsah *et al*., 2012). During boiling, more water is added to push down solid particles. After boiling for a while, the pure oil settles at the top and it is scoped out until a point that the water which is beneath is seen. The clarification process if well done in the small scale can effectively minimize the amount of water and solids in the pure oil. However processors during the later periods of scoping the oil may scope some water along.

Clarification in many small scale processing operations according to Osei-Amponsah *et al.* (2012) is often omitted to reduce operational cost and because processors believe that storing fruits for some weeks before processing helps to get rid of water thus making clarification unnecessary. Where clarification is not done, crude oil is drawn off after allowing the extracted oil to stand for 2 – 3 hours to allow the sludge to settle (Osei-Amponsah *et al*., 2012).

Clarification in the industrial mills is mechanized and involves several processing operations. These have been described by Basiron (2005) as follows: the crude oil is diluted with water to obtain satisfactory settling because of its high solid proportion. The crude oil is then screened to remove fibrous materials and then pumped to a continuous settling tank where it separates into two parts - oil and sludge. The oil which settles at the top is skimmed off and passed to a centrifugal purifier and then a vacuum dryer and finally a cooler before being pumped to the storage tanks. The sludge which has an oil content of about 10% is reclaimed and fed back to the main settling tank. At the end of the clarification process, the oil has moisture content between 0.1 and 0.12% and impurities less than 0.02% (Basiron, 2005)

The clarification process can thus be seen as an important process that determines both oil yield and quality. Hence whereas clarification in the small and medium scale involves only separating the pure oil from the sludge, additional operations of centrifuging and drying done in the large scale minimizes the impurities and moisture content of the final oil. Also the practice of reclaiming oil from the sludge in the industrial mills is a practice that increases the oil yield.

2.5 Palm Oil Composition and Chemistry

Palm oil like many other oils consist of mainly triacylglyerides (TAGs). Over 95% of palm oil consists of mixtures of TAGs (Sambanthamurthi *et al.*, 2000). TAGs are made of glycerol molecules, each esterified with three fatty acids. Different placement of fatty acids and fatty acid types on the glycerol molecule produces a number of different TAGs (Sambanthamurthi *et al.*, 2000).The fatty acid chains present in the palm oil TAG could vary in the number of carbons present in the chain (chain length) and in structure (presence of double bonds, i.e., unsaturation). The chain lengths of the fatty acids present in the TAG of palm oil fall within a very narrow range from 12 to 20 carbons. It is the variations in the structure and number of carbons in these fatty acid chains that largely define the chemical and physical properties of palm oil (Basiron, 2005).

Palm oil, contains about 50% saturated fatty acids, 40% monosaturated fatty acids, and 10% polyunsaturated acids. The even balance between saturation and unsaturation in palm oil makes it semi solid at room temperature and confers some stability against oxidation to the oil as compared to other vegetable oils (Teoh, 2002, Basiron, 2005, Njoku *et al*., 2010). Palmitic acid and oleic acid are the dominant fatty acids in palm oil. The fatty acid composition of palm oil is shown in table 2.1. The ratio of palmitic/stearic acid in palm oil can vary according to a number of factors one of which is geographical influences (The Agronomy and Economy of Important Tree Crops of the Developing World, 2010).

Table 2.1: Fatty Acid Composition of Palm Oil

Name	**Acid**	**(%) Mean**
Lauric	C 12:0	0.2
Myristic	C 14:0	1.1
Palmitic	C 16:0	44.0
Stearic	C 18:0	4.5
Oleic	C 18:1	39.2
Linoleic	C 18:2	10.1
Others	Others	0.9

Source: Njoku *et al.* (2010)

2.5.1 Minor components of Palm Oil

The minor components in palm oil are the metabolites from the biosynthesis of TAGs and products from lipolytic activity. The minor constituents can be divided into two groups. The first group consists of fatty acid derivatives, monoacylglycerols (MAGs), diacylglycerols (DAGs), FFAs, phosphatides, esters and sterols. The second group includes classes of compounds not related chemically to fatty acids. These are the hydrocarbons, aliphatic alcohols, free sterols, tocopherols, pigments and trace metals (Sambanthamurthi *et al.*, 2000, Basiron, 2005).

MAGs, DAGs and FFAs which are known collectively as partial glycerides are however the major metabolites of TAGs in palm oil from enzyme activity. Partial glycerides according to Sambanthamurthi *et al.* (2000) and Basiron (2005) are artifacts of the extraction process, especially the stages prior to sterilization. Thus oil extracted from unbruised and sterilized fruits show trace levels of partial glycerides. Partial glycerides are important as they are known to affect the crystallization behaviour of the oil (Basiron, 2005).

The minor components, such as partial glycerides and phosphatides, are saponifiable by alkaline hydroxide. The other minor components found in palm oil are unsaponifiable fraction and these include carotenoids, vitamin E (tocopherols and tocotrienols), sterols, phospholipids, glycolipids, terpenic and aliphatic hydrocarbons, and other trace impurities (Sambanthamurthi *et al.*, 2000). Though the unsaponifiable fraction altogether is less than 1% in palm oil, nevertheless they, especially carotenoids and vitamin E play a significant role in the stability, refinability and nutritive value of the oil (Basiron, 2005, Njoku *et al.*, 2010).

Tocopherols and tocotrienols are fat-soluble vitamin E isomers and the major antioxidants of vegetable oils. Crude palm oil contains tocopherols and tocotrienols in the range of 600 – 1000 ppm, however refined palm oil contains about 50% (350-630 ppm) of these products (Basiron, 2005, Njoku *et al.*, 2010). As natural antioxidants, tocopherols and tocotrienols provide some natural oxidative protection and stability to palm oil.

2.5.1.1 Pigments in Palm Oil

Carotenoids are important pigments in many organisms. They are developed at fruit maturity and are responsible for the yellow, orange and red colours of ripe fruits and vegetables. Chlorophyll which is a green pigment is the dominant colour in unripe palm fruits but as the fruits ripen, carotenoids form the dominant colour (Njoku *et al.*, 2010). Crude palm oil contains between 500 and 700 ppm of carotenoids mainly in the forms of α-and β-carotenes, the precursor of vitamin A (Basiron, 2005; Njoku *et al.*, 2010). The depth of colour of palm oil therefore depends on the amount of carotenoids present (Baryeh 2001; Hadi *et al*., 2009; Tan *et al.*, 2009). Carotenoids composition and concentration differ in the different varieties of oil palm (Table 2.2). Carotenoids are thermally destroyed during the deodorization stage in order to produce the desired colour for refined oil (Basiron, 2005).

In crude palm oil, the presence of carotenoids offers some oxidative protection to the oil through a mechanism where they are oxidized prior to the triglycerides (Basiron, 2005). Carotenoids are however sensitive to oxygen and light, and may undergo oxidative reactions which include photoxidation, autoxidation and antioxidation. The oxidation of carotenoids leads to discoloration and bleaching and it is catalyzed by hydroperoxides generated from lipid oxidation (Sambanthamurthi *et al.*, 2000).

Table 2.2: Carotene Profiles of Palm Oil Extracted from *Elaeis guineensis*

Carotenoid	**Percentage (%)**		
		Palm fruit type	
	Pisifera	Dura	Tenera
Phytoene	1.68	2.49	1.27
Cis-β-carotene	0.10	0.15	0.68
Phytofluene	0.90	1.24	0.06
β-carotene	54.39	56.02	56.02
α-carotene	33.11	54.35	35.16
Cis- α- carotene	1.64	0.86	2.49
ζ- carotene	1.12	2.31	0.69
γ-carotene	0.48	1.10	0.33
δ-carotene	0.27	2.00	0.83
Neurosporene	0.63	0.77	0.29
β-zeacarotene	0.97	0.56	0.74
α-zeacarotene	0.21	0.30	0.23
Lycopene	4.50	7.81	1.30
Total carotene(ppm)	428	997	673

Source: Yap *et al*. (1997).

2.6 Quality Characteristics of Palm Oil

The quality characteristics of palm oil like many other oils may be assessed through physical and chemical (Physico-chemical), microbiological or sensory methods. In industry and international trade, physico-chemical methods are used to establish quality of palm oil.

2.6.1 Physico - Chemical Quality Indices of Palm Oil

The main indices used in determining palm oil quality are the FFA, moisture and impurities. However parameters that help determine the composition of the palm oil such as iodine and saponification value and parameters of oxidation like peroxide value are often added. Depending on the intended use of the oil, several other parameters such as colour, melting point, flush point, fire point, smoke point, tocophenol and tocotrienol contents may be used (Edem, 2002).

Free fatty acid is a very important indicator of oil quality. This is because they increase the oil's susceptibility to oxidation, can contribute bitter/soapy flavors, and can cause a decrease in the oil's smoke and flash points (Wrolstad *et al.*, 2005). The presence of FFA moieties arises from the activity of lipases present in the mesocarp of the oil palm fruit which hydrolysis triacylglycerols (Ngando *et al.*, 2006). Lipases are activated at maturity when the palm fruits are bruised during harvesting, transportation or processing. According to Berger (2010), it is possible to obtain oil with 0.8% FFA if freshly harvested palm fruits are taken directly to the laboratory from the field, cooked and pressed immediately but this is not practicable on a manufacturing scale. The maximum standard for FFA in CPO is therefore 5% (Codex Alimentarius, 1992; Corley and Tinker, 2003; Hadi *et al.*, 2009; Berger, 2010). The standard for FFA in palm oil is higher than in other vegetable oils because palm fruit contains a very active lipase (fat splitting) enzyme, which rapidly breaks down the triglycerides to a mixture of FFA, monoglycerides and diglycerides (Onyeka *et al*., 2005; Berger, 2010). For refined, bleached, and deodorized oil (RBDO) the FFA should be lower than 0.1 % (Berger, 2010).

Moisture and impurities are important parameters that determine oil oxidative stability especially during storage (Ngando *et al.*, 2006; Orji and Mbata, 2008). The presence and amounts of moisture and impurities in palm oil are attributed to the extraction process and the equipment involved in the extraction (Orji, 2006). The breakdown of fibres followed by an ineffective clarification process contributes to impurities while the absence or ineffectiveness of the drying contributes moisture to palm oil (Orji and Mbata, 2008). The limit for moisture and impurities in CPO is 0.2% and 0.05% maximum respectively (Codex Alimentarius, 1992; Ping 2007; Berger, 2010). Oils contain a mixture of fatty acids, both saturated and unsaturated. The iodine value (IV) measures unsaturation in a lipid system. The iodine value is the number of grams of iodine needed to react with the double bonds in 100g of oil. It is a useful index in determining the identity of oil. The greater the degree of unsaturation (high IV), the greater the susceptibility of the oil to oxidation (Wrolstad *et al.,* 2005). Oils being natural products show variations due to variety and growing conditions and the specification for iodine value for a particular oil is therefore put in a range to accommodate these variations (Berger, 2010). The iodine value specification for CPO ranges from 50.0 to 55.0 Wij's is (Codex Alimentarius, 1992).

Saponification is a measure of the mean molecular weight of the fatty acids in a lipid system. The smaller the saponification value, the longer the fatty acids on the glycerol backbone; conversely, a high value indicates shorter fatty acids. For palm oil the value ranges from 190 –

209 mg KOH / g (Codex Alimentarius, 1992). Triglycerides of the same or close chain lengths have little difference in saponification value (Wrolstad *et al.*, 2005).

Peroxide value is a measure of lipid oxidation. It is a direct measure of the amount of oxygen that has combined at the double bonds of the fatty acids (Ekpa and Ekpa, 1996; Anhwange *et al.*, 2010). In time these oxidised bonds are broken, resulting in short chain volatile compounds and residues of oxidised glycerides. The residues are measured by another parameter known as the Anisidine Value (Berger, 2010). The standard value for peroxide in CPO is 10 meq / Kg maximum (Codex Alimentarius, 1992). A high figure is an indication that oxidation has taken place in the past, and there has been a loss of quality. The formation of peroxides in oil depends on the extraction process, with moisture and impurities been underlying causes and also the storage condition of the oil (Ihekoronye and Ngoddy, 1985; Orji and Mbata, 2008).

2.6.1.1 Extraction Method and Oil Quality

The methods of oil extraction greatly affect the quality of palm oil produced. The level of mechanization involved and the type of processing equipment available, dictates the processes which the oil will go through and this goes a long way to affect oil quality. Studies by Aletor *et al*. (1990) in Nigeria, revealed that distinct variability existed among samples of traditional processing and those mechanically processed in all parameters (FFA, PV, moisture and impurities) due to differences in processing techniques. They observed that mechanically processed oil had better quality than traditionally processed ones especially with respect to FFA and impurity level. Mechanically processed oil however recorded high moisture content than the traditionally processed oil. Both traditional and mechanically processed oils fell outside the accepted levels for all parameters except PV. They attributed the poor quality especially in the traditional process to the fermentation of the palm fruits before processing.

Similar findings by Orji and Mbata (2008) also in Nigeria show that the moisture, impurities, FFA and microbial counts of oil samples obtained from different extraction methods in Nigeria varied greatly from one extraction method to the other. They noted that all the oil samples (from traditional, semi mechanized and mechanized) except the ones produced in the laboratory had values higher than the international standards for edible palm oil in all parameters. Oil samples obtained through the traditional extraction methods, especially those obtained through the fermentation methods had the poorest quality. Findings by Frank *et al.* (2011) in Cameroon are consistent with those of Orji and Mbata (2008). However oil from the mechanized process met the standards for moisture and impurities in Frank *et al*. (2011) studies.

The poor quality of oil due to fermentation is affirmed by Zu *et al.,* (2012). They found that the FFA, moisture and impurities content of oils from different extraction equipment increased significantly as fruits fermentation period increased from 6 to 15 days. Several studies (Onwuka and Akaerue, 2006; Owolarafe *et al.,* 2008; and Tan *et al.*, 2009) have also shown that storage of palm fruits leads to high build-up of FFA resulting in the production of poor quality palm oil. The underlying cause for FFA build up has been identified by many authors (Purseglove, 1985, Sambanthamurthi *et al*., 2000; Ngando *et al.*, 2006) to be lipases, an active enzyme contained in the mesocarp of ripe oil palm fruits. The activity of the endogenous lipase of the oil palm fruit mesocarp as studied by Ngando *et al. (*2008) was very variable within palms with different genetic background, and the low lipase phenotype was positively correlated to low acidity level of the extracted oil. Zu *et al.* (2012) attributed the accumulation of dirt and mould during storage of fruits to be the cause of increasing impurity content of oils whose fruits where stored for longer periods. Zu *et al*. (2002) also noted that processing equipment affected the FFA content of the oil. Earlier work by Owolarefe *et al.* (2002), however suggest that processing equipment did not.

2.6.1.2 Oil storage and Oil Quality

The quality of palm oil is affected as is it stored. Environmental conditions such as temperature, moisture and light have been found to be the major factors that affect the quality of oil during storage. The storage container of the oil is seen as a key player in oil storage as it influences the way the environmental factors aforementioned interact with the oil. The quality of oils in different packaging material (opaque blue plastic, green bottle, opaque white plastic, transparent plastic and transparent bottle) was assessed by Okonkwo *et al*. (2012). They found exponential increases in FFA, acid value and saponification values in all treatments (packaging material) throughout the 12 months of storage. However there were no significant differences among treatments. Thus the packaging material in this study did not affect the storage quality of the oil.

Orji and Mbata (2008) studied the effect of storage on the quality palm oil extracted through different methods in Nigeria. They found remarkable increase in FFA and a mild increase in PV of oil samples stored for eight months. However, there was no increase in FFA of oil sample produced in the laboratory after storage. Njoku and Onwu (2010) made similar findings with FFA, acid value, PV and SV values increasing and IV declining after 4 weeks of storage. Frank *et al.* (2011) also reported increases in FFA and PV during the first 4 weeks of storage. They however obtained a decrease in FFA and PV after the fourth and sixth weeks respectively to values even lower than values obtained from the fresh oil especially for FFA. Frank *et al.* (2011) explained that unsaturated FFA may undergo subsequent chemical reactions such as peroxidation and generate secondary products which could not be detected while assaying oil acidity to be the possible cause of the decrease in FFA.

Most of these studies have established that palm oils from small scale processing deteriorate faster than those of the industrial scale. Moisture and impurities have been the underlying cause of increases in FFA and PV as reported by most studies (Orji and Mbata, 2008; Njoku and Onwu, 2010; Frank *et al*., 2011). However these studies failed to measure the moisture and impurities during the storage period to support their claim.

2.6.2 Sensory characteristics of oils

The preceding two paragraphs suggest that chemical quality of oil is affected by both extraction methods and storage. The sensory attributes of oils are dictated by the chemical constituents of the oils hence extraction method and storage has an effect on sensory characteristics of oil. CPO from the traditional oil extraction method Ngando *et al.* (2011) is highly sought after in local markets, due to its better sensory qualities (red color, taste, smell) which make it an irreplaceable ingredient of many local recipes. In contrast, studies by Orji and Mbata (2008) found no significant differences in the taste and aroma of fresh palm oils produced from different extraction methods but differences existed among them after 8 months of storage except for the oil produced in the laboratory. Sensory evaluation results by a trained panelist in studies by Orji and Mbata (2008) were consistent with the FFA values obtained in the chemical analysis of the oils as only the oil prepared in the laboratory did not change in FFA value after storage.

Several studies have concentrated on the chemical attributes of the CPO. Studies on sensory characteristics are rather limited as most studies have been on finished products derived from palm oil. Descriptive sensory analyses have been used in other oils to establish sensory characteristics and may also be useful in determining sensory properties of palm oil.

2.7 Uses of Palm Oil

Palm oil is used widely as edible oil. The chemical composition of palm oil makes it versatile and this is exploited in food application to make a wide array of products (Akpanabiatu *et al.*, 2001; Baryeh, 2001). It is used to make margarine, shortening and cooking oil. In West Africa and especially those in the coastal and forest zones, palm oil constitutes the single most important source of edible oil (Baryeh, 2001) where it is used in the preparation of many dishes. However, nonedible application of palm oil is gaining substantial grounds especially in its use as automobile energy as an alternative source because of depleting fossil fuel reserves (The Agronomy and Economy of Important Tree Crops of the Developing World, 2010). It also finds use in the cosmetic industry where is used widely in making soaps, and oleochemical production.

2.8 Concluding remarks

The literature reviewed brings to bear extraction process as the major determinant of oil quality. Fruit storage has been particularly singled out as the major cause of poor oil quality as FFAs tend to accumulate during fruit storage. Other processing operations such as oil clarification and oil drying have been identified to influence the amount of impurity and moisture respectively in oil. Although several studies have been done comparing crude palm oils from different scales of processing, very little attention has been given to the specifics of the different unit operations in processing and how they influence the quality of the oils.

The chemical composition of fresh crude palm oil affects its storage properties. Initial FFA, impurity and moisture content of fresh palm oils would influence the quality of stored palm oil with higher amounts resulting in poor oil quality during storage. However, information on moisture and impurity content of palm oils during storage is limited. This work would among others assess the moisture and impurity contents during storage to understand how they influence storage quality of crude palm oils. The storage conditions in this work would also be averagely higher than the normal room temperature of about 26^{o}C to mimic the storage conditions in which palm oils are often subjected to during sale under the sun, or at home in the kitchens both of whose temperature are averagely higher. This study will also establish a descriptive profile for crude palm oils to complement the impact of differences in chemical quality as a result of processing methods, on the sensory characteristics of the oil.

3.0 METHODOLOGY

3.1 Materials

3.1.1 Palm fruits

Fresh fruit bunches (FFB) of the Tenera variety were obtained from the Oil Palm Research Institute (OPRI) of the Council for Scientific and Industrial Research (CSIR) at Kusi in the Eastern Region of Ghana. The FFB were processed under the supervision of the researcher using a digester screw press as outlined in Figure 3.1. to obtain improved traditional process (ITP) oil.

3.1.2 Palm Oil Samples

Freshly processed crude palm oil samples were obtained from small scale processors. One sample each was obtained from processors using the hand spindle press, hydraulic press and the digester screw press respectively. Two samples each were also obtained from the medium and large scale processors. Samples were put in 500 ml sterile, opaque and airtight rubber bottles and stored on open shelves at a temperature of 31 ± 2ºC. Each sample was put into 8 bottles for analysis every other week for 12 weeks.

3.2 Experimental design

A purposive randomized design was used to include crude palm oil (CPO) from different scales of processing (small, medium and large) and different extraction equipment.

3.3 Sample preparation

Thirty eight fresh fruit bunches of Tenera variety weighing 500Kg were sectioned into spikelets using an axe and heaped on the bare ground under a shed for two days. The fruits were removed from the spikelets by hand and processed into oil. The flow chart below shows the improved traditional process (Figure 3.1). A total of 5 days was used for processing from the time of harvest to extraction.

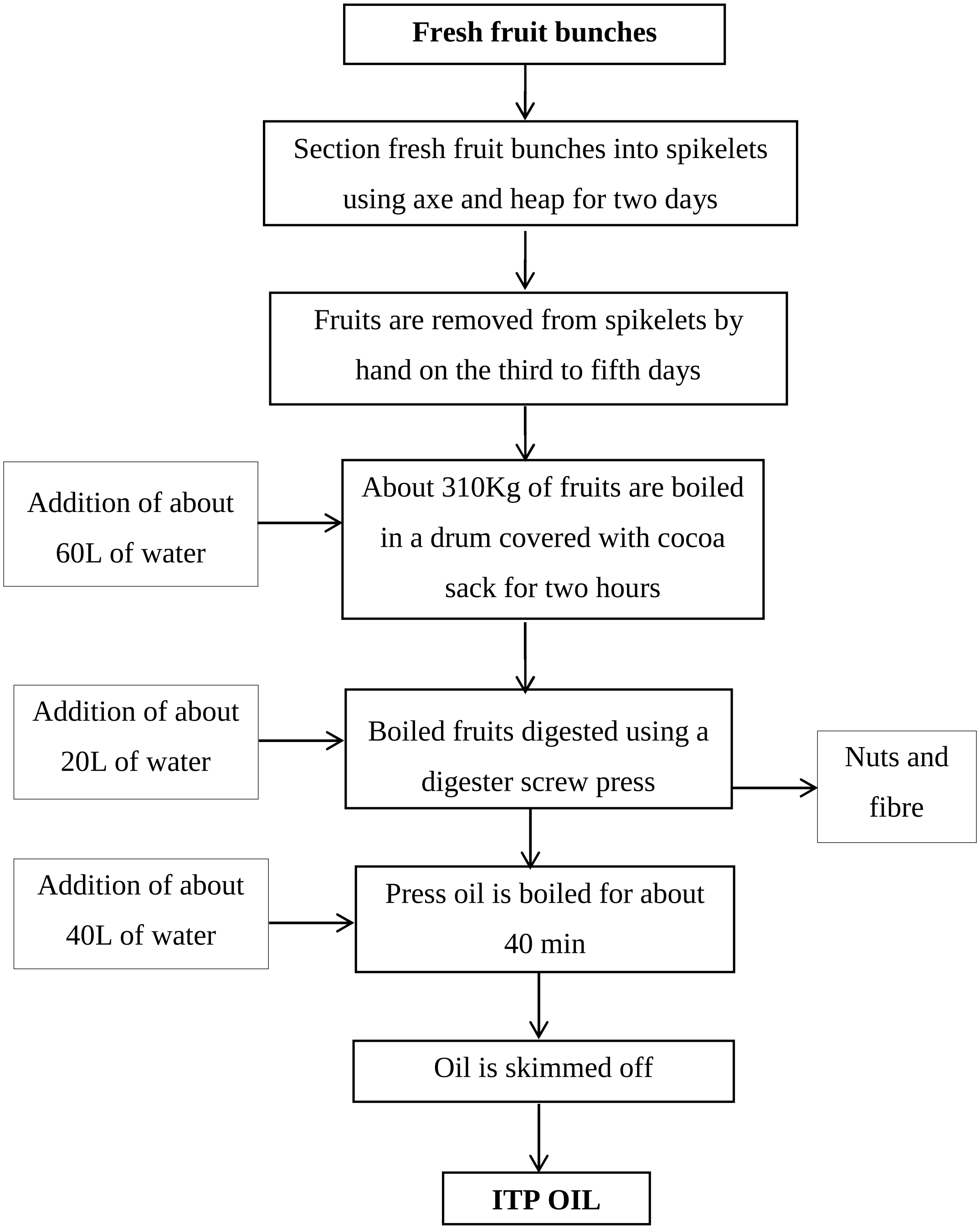

Figure 3.1: Process flow diagram for improved traditional process

3.4 Methods

3.4.1 Physico-Chemical analyses

The following physico-chemical quality indices in palm oil were analyzed according to AOCS (1997).

- Moisture (Ca 2c-25)
- Impurities (Ca 3a-46)
- Free fatty acids (Ca 5a-40)
- Peroxide value (Cd 8-53)
- Iodine value (Cd 1-25)
- Saponification value (Cd 3-35)

3.4.1.1 Determination of Palm Oil Colour

The colour of palm oil samples was measured using the Hunter Lab Colour Difference Meter (CDM), Model CR-300 (Minolta Camera Co. Ltd. Inc., Tokyo, Japan). Colour Measurements were described according to the following coordinates: lightness (L*), redness (a*, ±red-green) and yellowness (b*, ± yellow – blue)

3.4.2 Sensory Evaluation

The generic descriptive method (Lawless and Heymann, 1999), was used to train 10 panelists and to evaluate 8 fresh crude palm oil samples in a total of 3 test sessions in 3 days

3.4.2.1 Panel Selection

A total of 10 trained panelists (6 female and 4 male) ages 20 to 33 years old participated in the evaluation. All panelists were recruited from the Department of Nutrition and Food Science, University of Ghana. They were recruited on the basis of their previous experience in descriptive sensory analysis, availability, interest and consumption of palm oil at least once a week.

3.4.2.2 Panel Training

Five training sessions of 3 hours duration each day were held. On the first day of training, panelists were given an overview on sensory evaluation and basic sensory attributes (appearance, texture, aroma, taste and flavor). Each panelist was then given 4 sample oils that included a sample each from the small, medium and large scale and a rancid sample. The panelists were then asked to identify key perceivable attributes (descriptors). The descriptors identified were then discussed by the whole panel to see their relevance. A consensus was reached on which descriptors to use and each descriptor was defined (Table 3.1). Where there was difficulty in coming up with descriptors or their definitions, the panelists were guided to identify their descriptors or definitions with available literature such as those by Munoz and Civille (1998), and other relevant literature. After the descriptors were finalized, the panelists identified standards by which each descriptor could be compared with. Again where there was difficulty, possible standards from literature were used to guide the panelists.

Table 3.1: Definition of attributes used by the trained panel to describe crude palm oils obtained from different scales of processing.

Attribute	Definition
Appearance	
Orange - red colour	Colours associated with carrots (orange) and flesh of ripe watermelon (red)
Turbid	Appearance associated with cloudiness
Aroma	
Fresh palm oil	Aroma associated with freshly processed palm oil
Rancid	Aroma from old and spoilt oil
Smoky	Aroma associated with smoke from burnt wood and hide
Burnt	Aroma associated with burnt banku and other burnt foods
Taste	
Sweet	Taste associated with sugar and sugary products
Bitter	Taste associated with quinine or caffeine
Mouth feel	
Rough	The degree of fineness of particles felt between the tongue and upper pallet
Mouth coating	A drag feeling of residual oil on the tongue after swallowing or expectoration

During the second day of training, panelists were trained on the use of a 150 mm line scale with no anchors. Each panelist rated the attribute intensity of each reference by first evaluating the reference for a particular attribute. The mean intensity rating for each reference was calculated and used as the attribute intensity rating for that particular reference (Table 3.2). The panel was calibrated by first obtaining an average panel rating and those panelist not within ±10 points of the average rating were asked to re-evaluate the sample and adjust their rating until a consensus was reached.

On the third day of training, panelist were given a warm up palm oil sample to evaluate. The mean intensity ratings for each attribute were obtained and panelists whose rating fell outside ±10 points of the average rating for a particular sample were again asked to re-evaluate the sample and adjust their rating until a consensus was reached. Calibration of the panel continued on the fourth and fifth days of training using 8 warm-up palm oil samples on a 150 mm line scale. Techniques for the evaluation of the oils were also finalized.

Table 3.2: Standard reference ratings used in descriptive sensory analysis of crude palm oils obtained from different scales of processing

Attribute	Reference	Intensity (mm)
Appearance		
Colour	0.1g orange colour/100ml water	10
	0.5g orange colour/100ml water	50
	0.5g red colour/100ml water	90
	2g red colour/100ml water	130
Turbid	0.5g potato starch/100ml water	40
	2g potato starch/100ml water	110
Aroma		
Rancid	Rancid oil (Symrise)	95
Smoky	Smoke aroma (Symrise)	120
Burnt	Burnt aroma (Symrise)	100
Taste		
Sweet	2g sugar/100ml water	20
	5g sugar/100ml water	50
Bitter	0.05g caffeine/100ml water	20
	0.08g caffeine/100ml water	50
Mouth feel		
Rough	Salad cream (Heinz)	20
Mouth coating	Salad cream (Heinz)	40

3.4.2.3 Sample evaluation

Each panelist was presented with 2 sets of 4 palm oil samples in 30 ml plastic opaque cups with lids coded with 3 digit random numbers. Each cup contained 15 ml of palm oil that was maintained at 30 ± 2^0C in an oven for an hour. Samples were presented in a random balanced nomadic order with water, a spit cut for expectoration, paper napkin and cracker for palate cleansing. The panelists evaluated 8 samples a day for 3 days using a 150 mm line scale. All evaluations were conducted between 10am – 12pm and 2pm – 4pm

3.5 Statistical Analysis

The data was entered into Minitab software version 16 and analyzed using different procedures. Firstly, one-way Analysis of Variance (ANOVA) was carried out to establish the effects of the extraction method on physico-chemical parameters (FFA, PV, IV, SV, moisture content, colour, impurities) and sensory attributes. Secondly, two-way ANOVA was used to determine the effects of extraction method and storage period on the variables studied. Fisher's Least Significant Difference (LSD) test was performed to determine which treatment means were significantly different ($p<0.05$). Principal Component Analysis (PCA) was performed to identify major sensory attributes. Bar and line graphs were drawn using Microsoft Office Excel 2010. All measurements were conducted in triplicates and their means and standard deviations reported.

4.0 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents results obtained per the specific objectives of this work. It compares the findings of this work to similar works and discusses the underlying factors leading to the results obtained and the implications of the results. Flow charts describing the processing procedures for the oil samples from the various scales of processing are shown in Figures 4.1a and 4.1b. The scale of processing refers to the level of mechanization involved in the processing of a sample while processing method refers the to the different unit operations that takes place to obtain a sample. The differences in the processing methods arise mainly from the extent of mechanization involved.

Digestion in the small scale is mechanized. However different equipment is used in the digestion and pressing operations. Oil samples SDP and ITP were obtained from a digester screw press which combines the digestion and pressing operation into a single unit, while oil samples SSP and SHP were obtained from digester with separate hand spindle press and hydraulic press respectively. The difference between SDP and ITP were from the period of fruit storage. ITP fruits were stored for 5 days while SDP fruits were stored for 14 – 21 days. SSP and SHP were differentiated from SDP and ITP by the use of separate digestion and pressing machines and absence of a clarification process. The pressing equipment in SSP was a hand operated spindle press while SHP was from a hydraulic press.

In the medium scale, the digestion and pressing stage was mechanized and performed as a single operation. There was also the presence of conveyor pipes to move oil after pressing for clarification and to move oil from the clarifying tanks into storage tanks. The main difference between M1 and M2 were the use of a mechanical stripper in M2 whereas fruits in M1 were stripped by hand. There was also a second clarification process in M2 to further clarify the oils.

Large scale processing involves complete mechanization from the point where FFB are sterilized to the storage of oil in the tanks. The main points of difference between L1 and L2 are as follows:

- Fruits from L1 were processed immediately upon reception whereas fruits from L2 were stored for between 1 to 5 days before processing
- Oil from L1 was centrifuged after clarification whereas oil from L2 was not
- Oil in L1 was dried using vacuum drier while a heat exchanger was used to dry L2

Table 4.1: Key to sample codes

Sample code	**Scale**
SSP (Hand spindle press)	Small
SHP (Hydraulic press)	Small
SDP (Digester screw press)	Small
ITP (Improved traditional process)	Small
M1 (Hand stripping)	Medium
M2 (Fruit stripper)	Medium
L1 (No fruit storage)	Large
L2 (Fruit storage)	Large

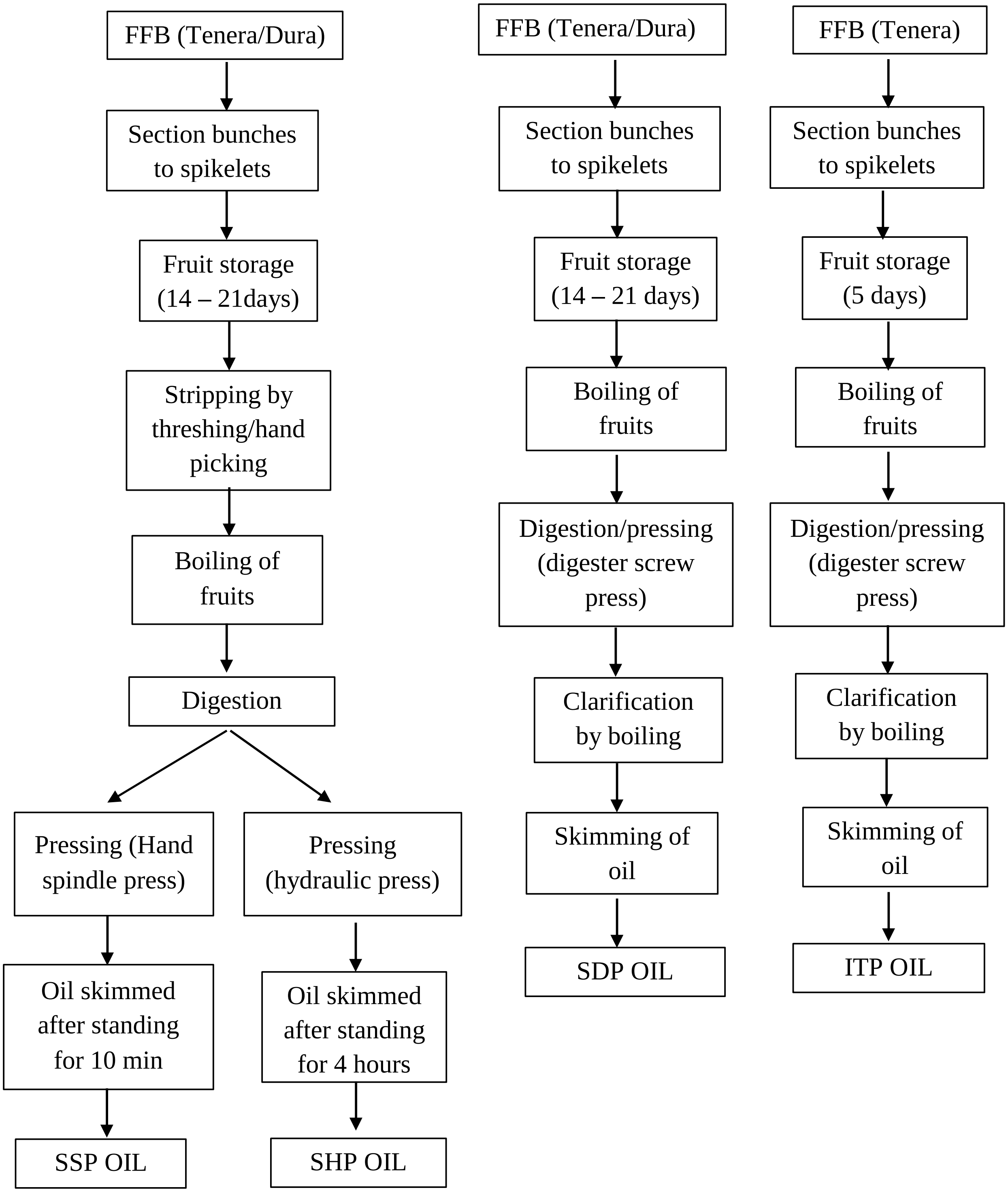

Figure 4.1a: Process flow diagram of crude palm oils from the small scale and ITP

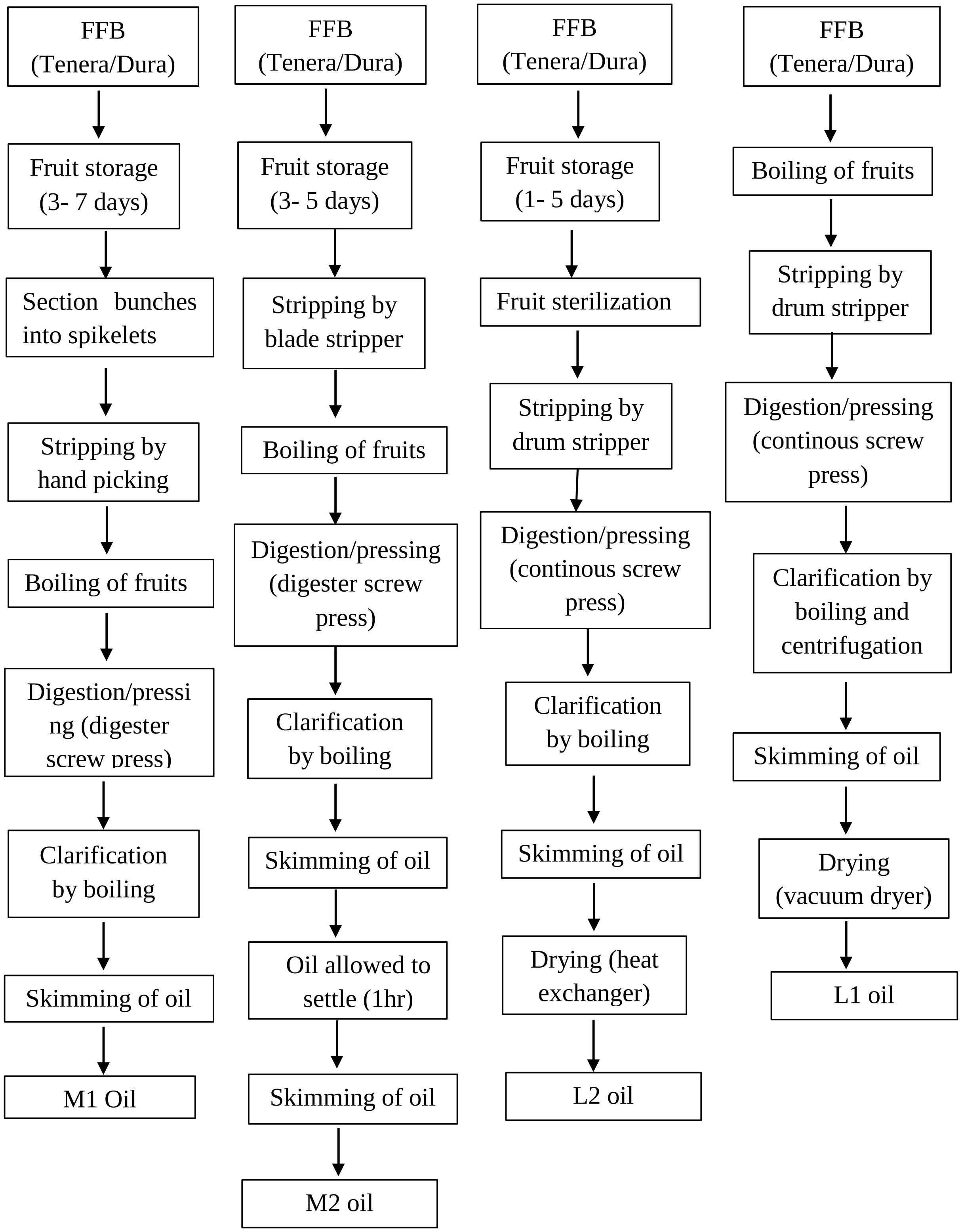

Figure 4.1b: Process flow diagrams of crude palm oils from the medium and large scale

4.2 Effects of extraction method on oil quality

Fresh palm oils from the eight (8) different processes were assessed for the following physico-chemical quality parameters: moisture content, impurities, colour, free fatty acids, peroxide value, iodine value and saponification value. The results of each parameter are presented below.

4.2.1 Moisture content

There were significant differences ($p<0.05$) in the moisture content of the oil samples among the different scales of processing. The lowest moisture content recorded (0.16%) was from oil from the large scale process in which fruits were not stored (L1) while the highest, 1.15% was from the medium scale process in which fruits were hand stripped (M1) (Figure 4.2). The extraction process has been shown to influence the amount of water in palm oil after processing (Orji, 2006; Orji and Mbata, 2008). Of all the oil samples, only oil samples from the large scale underwent a drying process during extraction. Oil drying is a process that involves heating the oil so that moisture in the oil can evaporate. The absence and ineffectiveness of a drying process according to Orji and Mbata (2008) results in high moisture content of palm oil. The low moisture content (0.16%) of L1 can thus be attributed to an effective drying system - vacuum dryer. However, L2 which also undergoes a drying process using a plate heat exhannger had a moisture content of 0.66% which is comparable to those of the small scale (0.74 and 0.58% for ITP and SHP respectively) and higher than that of M2 (0.50%) all of which do not undergo drying. The drying process in L2, which was done using a heat exchanger, may therefore be ineffective. A defective heat exchanger especially when it is corroded or leaky may introduce some moisture into the oil resulting in high moisture content.

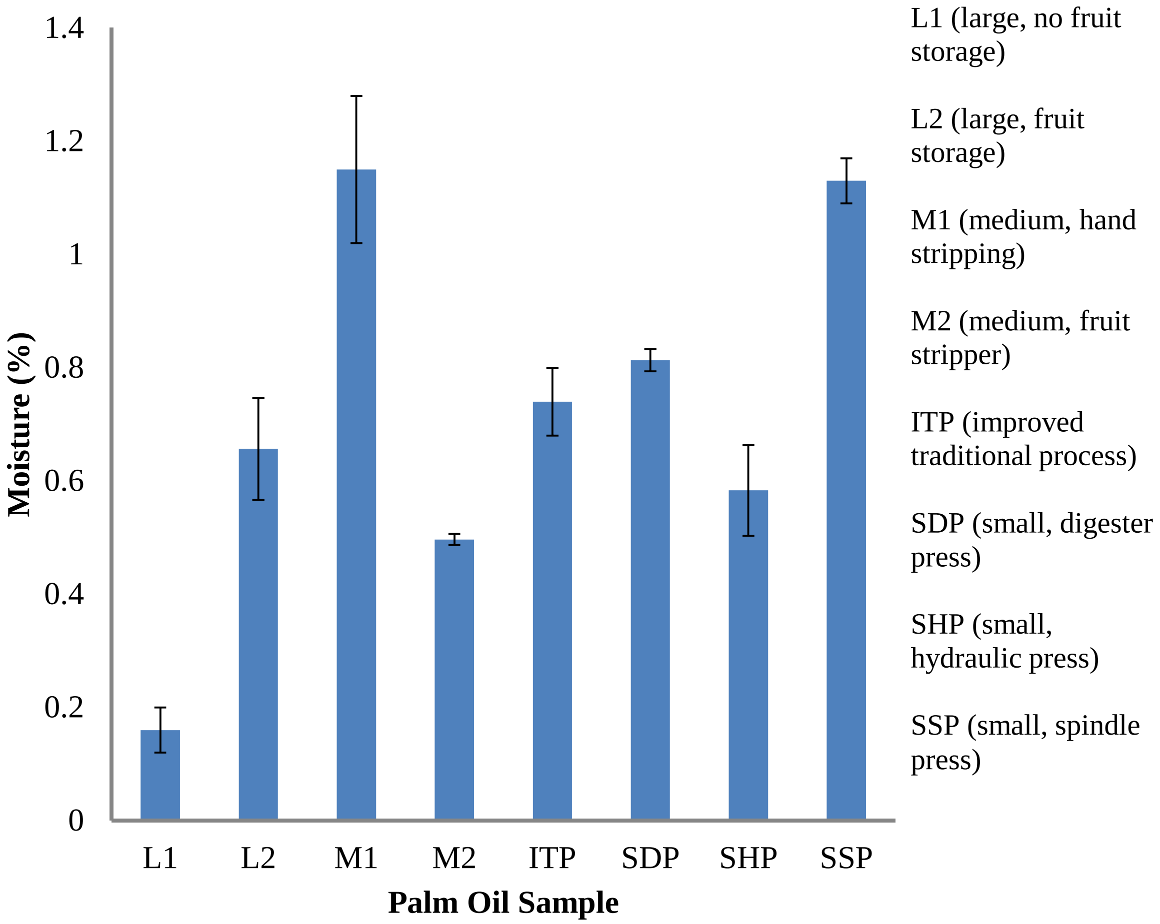

Figure 4.2: Moisture content of fresh crude palm oil samples from different scales of processing

Studies by Zu *et al* (2012) indicated that moisture content of palm oil increases with duration of storage of fruits while Tagoe *et al*. (2012) reported that the length of storage of fruits did not affect moisture content. There were no clear distinctions in the moisture content of oils from the different fruit storage periods (0 for L1; 1 – 7 days for L2, M1, M2 and ITP; and 14 – 21days for SHP, SDP and SSP) in this study, which is similar to the findings of Tagoe et al. (2012)

The variation in processing methods and conditions in this study may better explain the results obtained rather than the duration of storage of fruits. Processing temperatures especially in sterilization, digestion and clarification can influence the moisture content of the oil. This is because the oil in palm fruits are formed in emulsions and higher temperatures are needed to break the oils free especially during clarification where the oil has to be separated from a sludge which contains a mixture of oil, water and solids. Lower temperatures of processing may therefore be the cause of very high amounts of moisture in M1 (1.15%) and SSP (1.13%).

The amount of moisture in the oil may also be affected by the skimming or decantation process during clarification. This process if not well done can introduce significant amount of water into the clarified oil as it is a process that separates the oil from the water and sludge. Where clarification is not done, the period the press oil is allowed to stand before the oil is skimmed can also affect the moisture content of the oil as is the case for SHP and SSP. Oil from SHP was made to stand for more than 5 hours after pressing before skimming while oil from SSP stood for about 10 minutes resulting in moisture contents of 0.58 and 1.13 % respectively. Press oil often obtained immediately after pressing contains a large amount of water dispersed in the oil. Therefore allowing the oil to stand for longer periods allows the dispersed water in the oil which is denser than oil to settle to the bottom by gravity leaving oil with less water at the top which can then be skimmed off.

4.2.2 Impurities

Impurities are artifacts from the extraction process and these include kernels, mucilaginous matter, fibres and metals. There were variations in the amount of impurities of the palm oils among the various scales of processing (Figure 4.3). The amount of impurities in palm oil depends on the extraction process and the equipment involved in the process (Orji, 2006). Clarification of oil is particularly an important process in reducing the amount of impurity in palm oil. This clearly explains why all oil samples that were clarified (L1, L2, M1, M2, ITP and SDP) with impurity levels ranging from 0.01 – 0.11% were significantly different ($P< 0.05$) from those that were not clarified (SHP and SSP) both with impurity level of 0.45%.

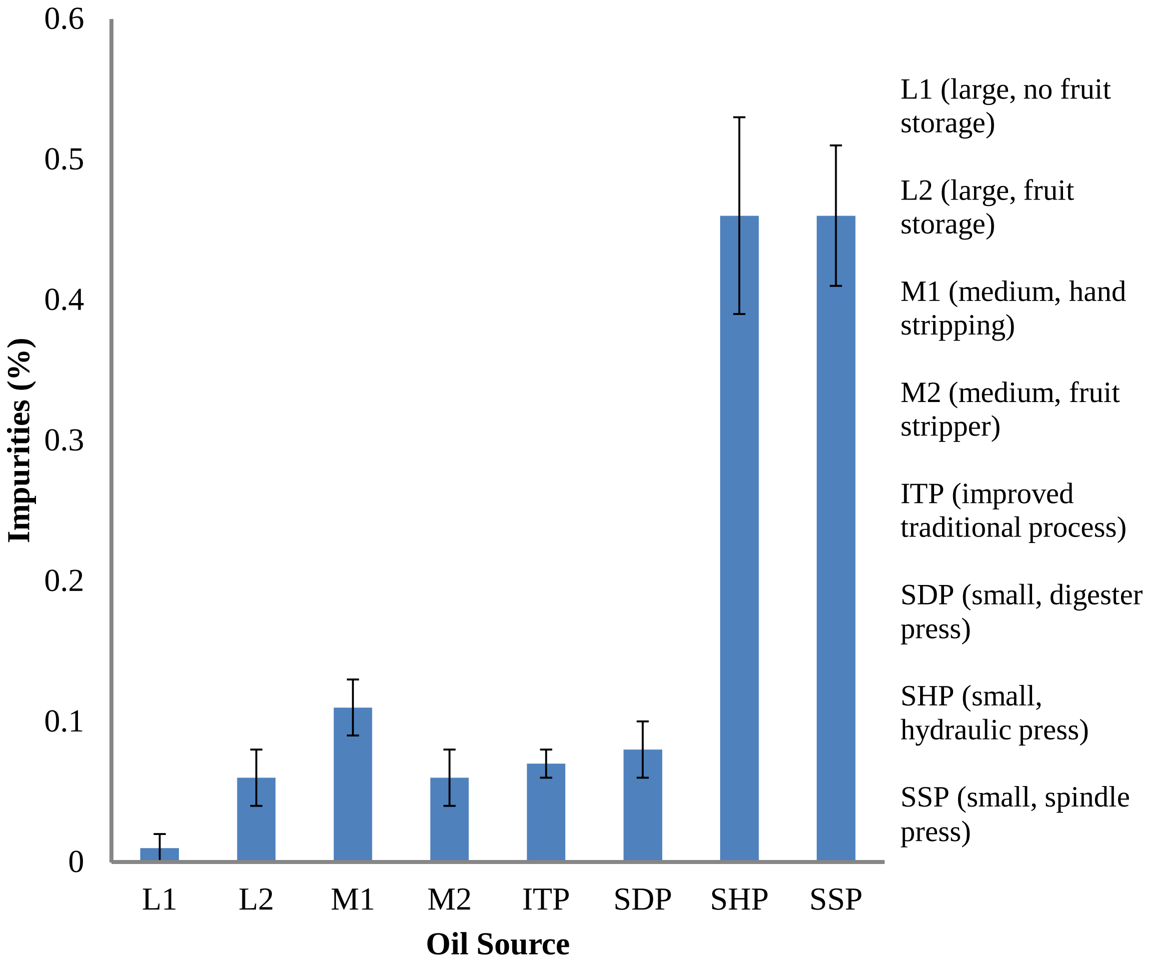

Figure 4.3: Amount of impurity of fresh crude palm oils obtained from different processing procedures

Within the oil samples that were clarified, sample L1 had the least impurity content (0.01%). This is because sample L1 goes through an additional clarification process of filtration and this process removes excess impurity that may have persisted after the ordinary clarification process which typically involves boiling and skimming. Oil sample M1 also had the highest amount of impurity (0.11%) among oil samples that were clarified during processing. This significantly higher amount of impurity can be attributed to the heat involved in clarification process. Clarification in M1 is done under low heat. This makes it difficult for some oil to dissociate from the solids and water it forms emulsions with thus resulting in clarified oil that contains a significant amount of impurity and water.

Impurities play a major role in the stability of oil especially during storage. Codex alimentarius thus specifies a maximum of 0.05% impurities. Impurity levels higher than this tend to increase rancidity. Only oil sample L1 meets this criterion while oils from SHP and SSP may be more prone to oxidative deterioration than the rest. Studies by Aletor *et al*. (1990) and Frank *et al*. (2011) have found variations in the impurity content across the different processing scales. They pointed out that mechanised and semi – mechanised processes produce oils with a lower impurity content than the traditional processes. This is because many traditional or small scale processes do not have an oil clarification step as part of the process. Results obtained for the impurity content of the large and medium scale in this work are similar to those of Frank *et al*. (2011). The lower impurities levels in the digestor press (SDP) than the hydraulic press (SHP) and spindle press (SSP) in this study were also observed by Zu *et al*. (2012) after fruits were stored for 15 days.

4.2.3 Colour

The colour measurements are presented in lightness (L*), redness (a*) and yellowness (b*) in Table 4.2. The lightness of the oils from the different scales of processing ranged from 45.58 – 50.78. This range indicates that the oils were slightly dark. There were significant differences ($p<0.05$) in lightness across samples except samples L2, SDP and SHP.

Table 4.2: Colour measurements of fresh crude palm oil samples from different processing procedures

Sample	L* ±STD	a* ± STD	b* ± STD
L1	45.58 ± 0.14^{e}	11.94 ± 0.07^{g}	7.59 ± 0.32^{g}
L2	49.63 ± 0.12^{c}	12.51 ± 0.10^{e}	8.94 ± 0.02^{f}
M1	50.78 ± 0.16^{a}	15.15 ± 0.16^{a}	15.86 ± 0.05^{a}
M2	48.79 ± 0.15^{d}	14.37 ± 0.08^{d}	12.47 ± 0.06^{d}
ITP	50.16 ± 0.10^{b}	14.95 ± 0.04^{b}	15.33 ± 0.10^{b}
SDP	49.71 ± 0.21^{c}	12.20 ± 0.12^{f}	12.38 ± 0.07^{d}
SHP	49.66 ± 0.10^{c}	14.67 ± 0.13^{c}	13.42 ± 0.04^{c}
SSP	48.54 ± 0.22^{d}	8.90 ± 0.09^{h}	11.36 ± 0.06^{e}

Values are expressed as mean of a triplicate ± standard deviation. Means followed by the same superscript in a column are not significantly different ($p < 0.05$). L*= Lightness, a* = Redness, b*=Yellowness. L1 (large, no fruit storage), L2 (large, fruit storage), M1 (medium, hand stripping), M2 (medium, fruit stripper), ITP (improved traditional process), SDP (small, digester press), SHP (small, hydraulic press), SSP (small, spindle press).

The lightness of the oils is dependent on the proportions of redness and yellowness of the oils. Redness and yellowness of oils from the different scales of processing ranged 8.90 -15.15 and 7.59 – 15.86 respectively. Both redness and yellowness were significantly different ($p<0.05$) across all samples. The colour of palm oils is influenced by the amount of carotenoids in the oil. The amount of carotenoids in palm oil has been found to differ with fruit variety with Dura having carotenoids concentration of 997 ppm while that of Tenera is 673 ppm (Yap *et al*., 1997; Sundram *et al*., 2003; Njoku *et al.,* 2010). The higher value in lightness of ITP (50.16) may therefore be attributed to the Tenera variety used as opposed to the mixed varieties (Dura and Tenera) used in the other samples. The extraction procedure including fruit storage, digestion and clarification may all influence the colour of the oil and may explain why M1 (50.78) though an oil obtained from mixed fruit variety is lighter than ITP (50.16). Carotenoids are sensitive to light and oxygen, and may undergo oxidative reactions which include photoxidation, autoxidation and antioxidation which lead to bleaching and discoloration (Sambanthamurthi *et al.*, 2000). Oil sample L1 which is produced under highly mechanised conditions, recorded the darkest colour (45.58) probably because conditions in processing the oil may have prevented or controlled for light and oxygen and resulted in less or no oxidation. Oxidation leads to bleaching which results in lighter colours.

4.2.4 Free Fatty acids

Free fatty acid (FFA) is the major index used in determining oil quality. FFA values for the oils samples ranged from 2.51 to 34.81 (Figure 4.4). The differences in the FFA values of the oils could be attributed largely to the duration of storage of fruits before processing. This can be seen in the pattern of FFA values obtained - FFA values for oil obtained from fresh fruits (L1) was 2.51%, that for fruits stored for 3 – 7 days (L2, M1, M2 and ITP) was 5.93 – 10.57%, while those stored for more than 14 days (SDP, SHP and SSP) ranged from 31. 04 – 34.81%. The increase in FFA with increasing storage in this study is consistent with that of Zu *et al.* (2012).

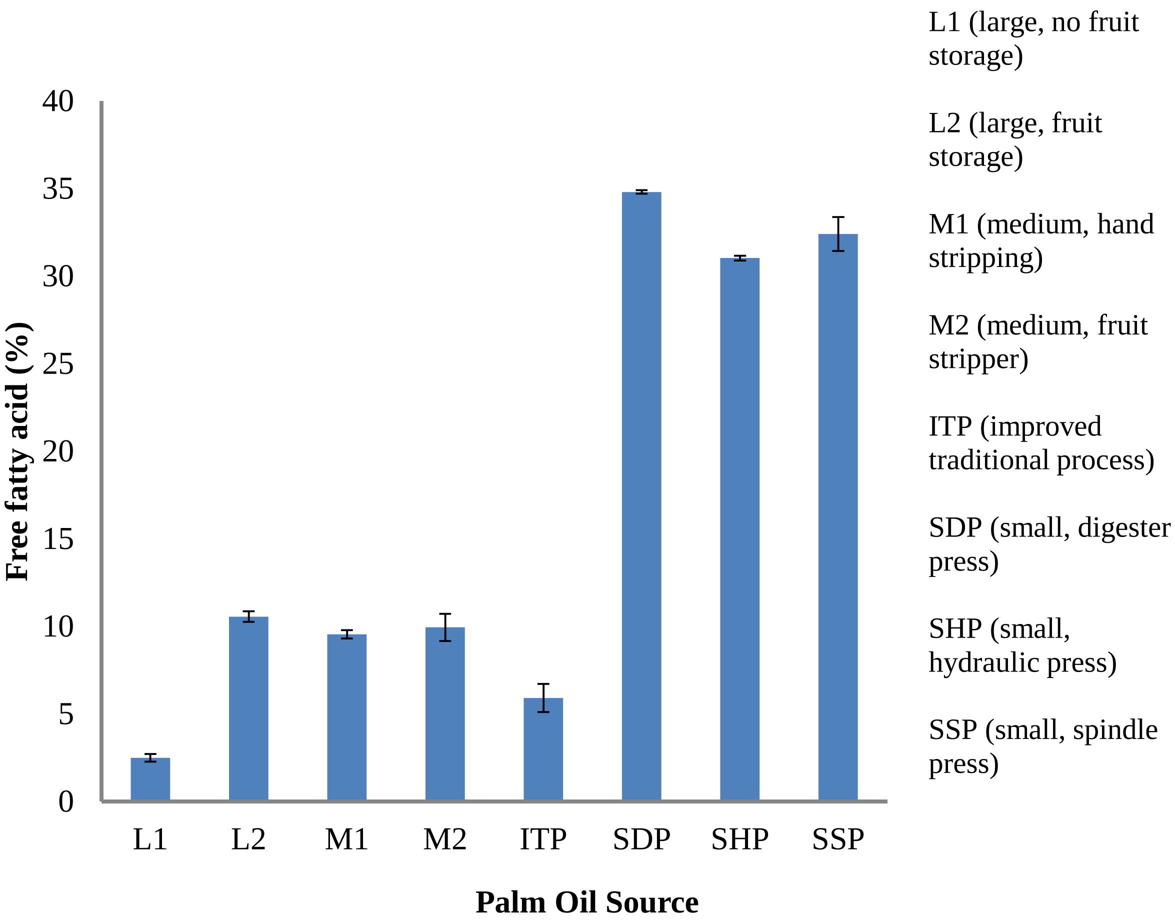

Figure 4.4: Free fatty acid content of fresh crude palm oil samples from different processing procedures.

The storage of palm fruits has long been recognised by many authors as the major cause of FFA build up in palm oil. (Sambanthamurthi *et al.*, 2000; Onwuka and Akaerue, 2006; Owolarafe *et al.*, 2008; Tan *et al.*, 2009). This is due to active lipases in the fruit mesocarp that break down triglycerides into DAGs, MAGs and FFAs (Purseglove, 1985, Sambanthamurthi *et al.*, 2000; Ngando *et al.*, 2006). Lipase (triacylglycerol acylhydrolase) is an endogenous enzyme located in the oil body fraction of the mesocarp with an optimal activity at pH 7.5, is stable in hydrophobic environments and loses activity in a non – polar environment (Sambanthamurthi *et al.*, 2000).

Lipases may also come from contaminating moulds growing from fruits that have been stored for long periods. Lipases are activated by cold treatment (Sambanthamurthi *et al.*, 2000) therefore the sterilization or cooking phase of palm oil extraction which is a heat treatment phase inactivates lipases. It is thus necessary to heat treat fruits immediately after storage to deactivate lipase activity which would lead to the generation of FFA. This explains why sample L1 whose fruits were sterilized immediately after harvest had the lowest FFA.

Although oil samples from one of the large scale (L2), the medium scale (M1 and M2) and ITP had similar fruit storage periods (3 – 7 days), ITP oils had a significantly ($p< 0.05$) lower FFA (5.93%) value than L2, M1 and M2 (10.57%, 9.56% and 9.96% respectively). The higher FFA in M1 (9.56%) may be as a result of the higher storage period (3 – 7 days) as compared to 5 days of ITP. However, the higher FFA of L2 (10.57%) and M2 (9.96%) both with fruit storage of 3 – 5 days may be due to differences in extraction method rather than the storage period. The extraction process in M2 involves the use of a mechanical stripper. The stripping of fruits is done after the fruits have been stored for 3 – 5 days. The fruits at this stage are still held tightly to the fruits stalks and therefore more force is needed to strip the fruits. This results in bruising of the fruits by the blades of the stripper.

Fruit bruising activates lipase activity which leads to the formation of FFA (Ngando *et al*. 2008; Berger, 2010). Therefore lipases are rapidly activated and they catalyze the formation of FFA as a result of the bruising of fruits and by the time the fruits are sterilized, a considerable amount of FFA has been formed. This accounts for the higher FFA values in M2 in comparison to ITP. The higher FFA value in L2 (10.57%) than ITP (5.93%) may result from the drying of the oil before storage. Oil from L2 is dried by heating the oil through a heat exhanger at temperatures of about 60^{o}C for about 3 hours. Elevated temperatures increase oxidative deterioration of oil as such temperatures are ideal for autocatalysis of FFA in the presence of water to generate more FFA**.** Hence this may account for the increase in FFA of L2.

Oil from the small scale (SDP, SHP, SSP) had the highest FFA values (31.04 – 34.81%). Similar findings were made by Aletor *et al*. (1990) and, Orji and Mbata (2008). Also the FFA values in all the three extraction equipment used in the small scale were significantly different ($P< 0.05$). Although the exact number of days fruits were stored for these samples (SDP, SHP, SSP) were not known, the differences in FFA may be attributed to the differences in equipment rather than the storage period. Zu *et al.*, (2012) reported differences in FFA values for the different extraction equipment used in the small scale however their findings were contrary to earlier work by Owalorefe *et al*. (2002). All oil samples were significantly different except samples L2 and M2, and M2 and M1. Only the oil from the large scale whose fruits are not stored (L1) met the FFA specification of less than 5% used in world trade. While sanctions may be imposed on the other oils (L2, M1, M2 and ITP), FFA values from the small scale are far too high for industrial processing and this may be the reason oils from the small scale are limited to the local markets.

4.2.5 Peroxide value

Peroxide is a measure of lipid oxidation. Results from Figure 4.5 show that the peroxide values of the oils from the different extraction procedures were below 1 meq / Kg, which is far below the 10 meq / Kg specification. The very low values obtained indicate that lipid oxidation had not begun. This was expected because the oils were fresh. Peroxides are mostly formed as primary products of oxidation.

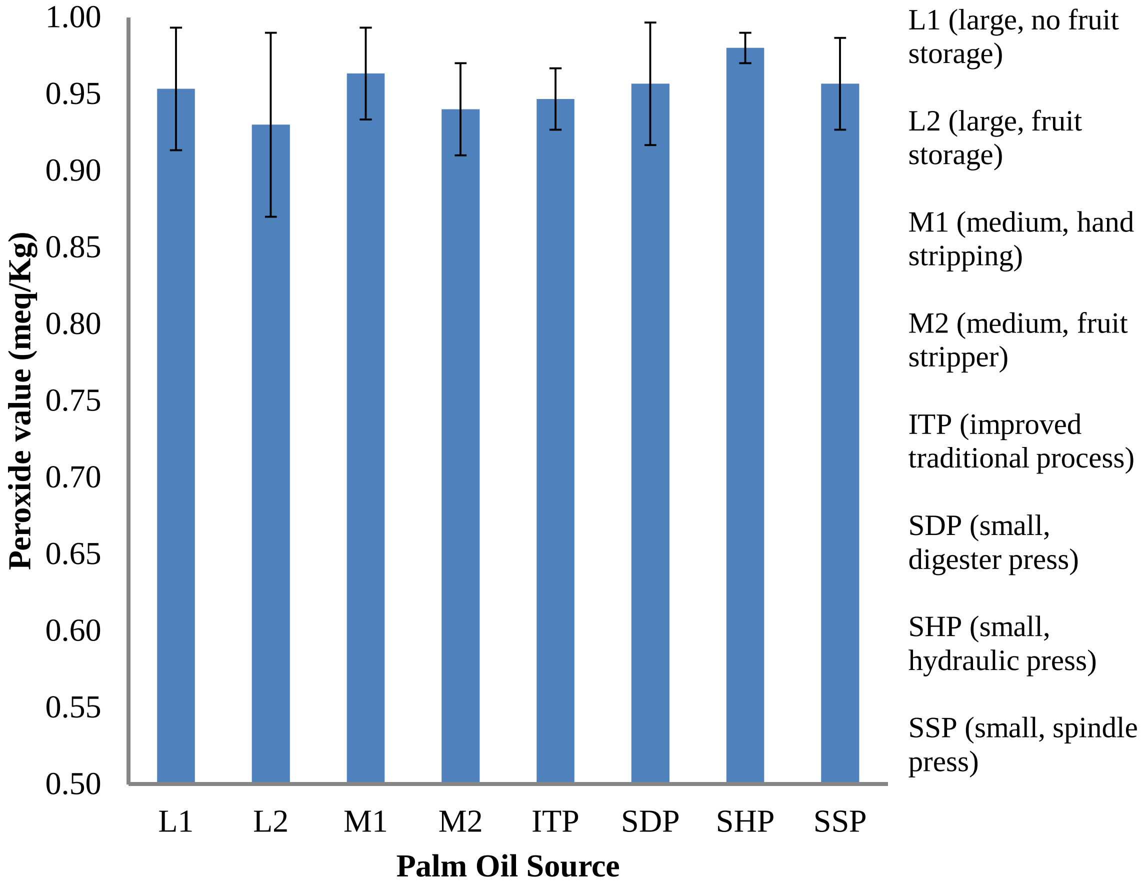

Figure 4.5: Peroxide values of fresh crude palm oil samples from different processing procedures

The formation of peroxides in oils depends on the extraction process when metals and steam catalyzes the absorption of atmospheric oxygen (Orji and Mbata, 2008). Metals serve as pro-odixants that catalyse the absorption of oxygen to form hydroperoxides. These metals are produced from the wear of machine parts especially machines involved in digestion. Very low peroxide values are an indication that there were very little metal residues. Hence all equipment used from the various processing methods were in good shape. The peroxides values obtained also imply that the oils from the various processing scales showed very little oxygen absorption during oil extraction. This is because all oils from the different processing scales were cooled before storage thereby preventing the formation of steam which also catalyses the absorption of oxygen to form hydroperoxides. There were no significant differences in the peroxides values from the different scales of processing which is in contrast with results from Orji and Mbata (2008) and Frank *et al*. (2011) although their values were also below the 10 Meq/kg specification.

4.2.6 Iodine value

Iodine value is the measure of amount of unsaturated fatty acids in an oil. Iodine values of oils from the different scales of processing ranged from 50.93- 54.63 (Figure 4.6) thus falling within the Codex Alimentarius acceptable range of 50 – 55% which identifies an oil as palm oil. Even though all oils fell within the range, there were significant differences ($p < 0.05$) in the IV of the oils. Apart from oils samples L1 and M2, and samples L2 and M1 which were not significantly different, all other samples where significantly different.

The differences in iodine values in the different samples shows a pattern that can be linked to the extraction process. For instance, the highest IV obtained were samples SSP and SHP (54.62 and

54.14 wijs respectively) and these two samples were not clarified. Because of the absence of a clarification process in SSP and SHP, the oils were allowed to cool before skimming the pure oil off. It is likely that the unsaturated fats which are more likely to be liquid upon cooling were mostly the portion skimmed off with a little portion of the saturated oil which is more likely to be semi -solid. Thus a greater portion of the saturated oil was retained in the remaining sludge which is also semi solid.

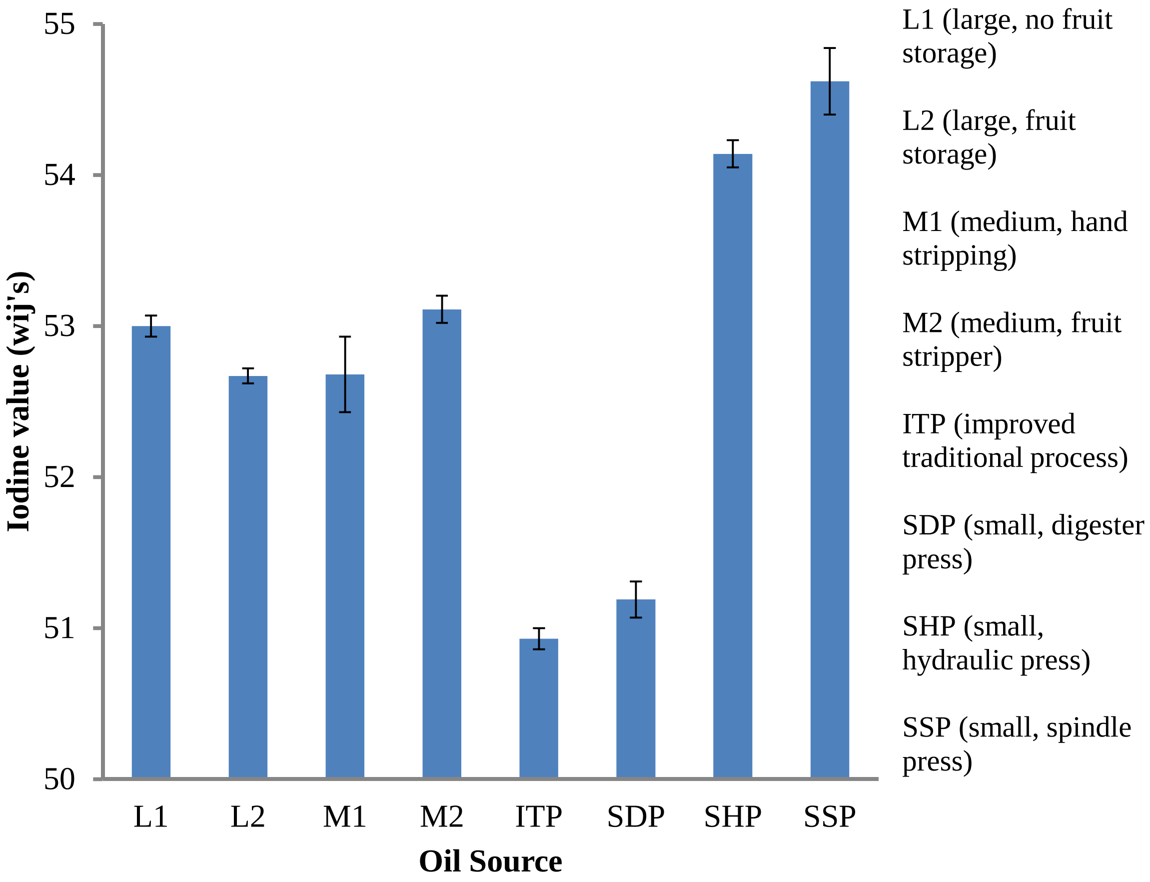

Figure 4.6: Iodine values of fresh crude palm oil samples from different processing procedures

The least IV values obtained were from ITP and SDP (50.96 and 51.19 Wijs respectively) and these two were processed using the digester screw press and were clarified. The significant difference ($p<0.05$) in IV of ITP and SDP from the other clarified oils (L1, L2, M1 and M2) may have resulted from the turbid or cloudy water used in the processing of ITP and SDP. Turbid or cloudy water as shown in Appendix 5, would contain metals and these metals can react with unsaturated fatty acids to produce peroxides, thus reducing the amount of unsaturation in ITP and SDP. Therefore the lower IV of ITP and SDP may not suggest stability during storage. Hence the extraction methods especially the clarification process may be an important process that influences the IV of palm oil. Studies by Njoku and Onwu (2010) revealed that palm oils from cold method of extraction (extraction without boiling fruits) had higher IV values than palm oils extracted using the normal method (boiling fruits before extraction). Heating increases reaction rates therefore content of unsaturated fatty acids which tend to be more prone to degradation reactions than saturated fatty acids would be reduced. The differences in the IV of the different samples obtained in this work may therefore be attributed to the heating processes and the temperatures involved, thus extraction procedures that involved more heating processes results in lower IV and the vice versa.

Apart from processing conditions, varietal differences may also be a possible cause of variations in IV and may explain why although ITP and SDP undergo the same processing, ITP oil which is obtained from only Tenera fruits is significantly different ($p< 0.05$) from SDP oil which is obtained from a mixture of Tenera and Dura palmfruits. Berger (2010) identifies varietal differences and growing conditions as sources of variation in the IV of oil samples. Iodine value is a measure of unsaturation and the higher the iodine value, the greater the unsaturation and the more prone the oil to oxidative deterioration. Hence SHP and SSP are more susceptible to oxidative deterioration and the addition of antioxidants may be necessary to maintain stability especially during storage.

4.2.7 Saponification value

Saponification measures the mean molecular weight of the fatty acids in a lipid system. Codex Alimentarius specifies saponification values of 190-209 mg KOH/g for palm oil. Saponification values obtained from the different scales of processing ranged from 190.65 - 201.61 mg KOH/g (Figure 4.7) and thus are within the acceptable levels. Saponification value of oil obtained from the spindles press (SSP) was the highest (201.61 mg KOH/g) and differed significantly ($p < 0.05$) from all the oils. The higher saponification value of sample SSP is an indication of short chain fatty acids.

Partial glycerides and phosphatides are the major components of saponifiable matter. Partial glycerides which include monoacylglycerides (MAGs), diacylglycerides (DAGs) and free fatty acids (FFAs), according to Sambanthamurthi *et al.* (2000) do not occur naturally in significant amounts except in palm oil obtained from damaged fruits. Oil produced from damaged fruits would undergo partial hydrolysis to produce partial MAGs, DAGs, water and FFA. Therefore the significantly higher saponification value of sample SSP (201.61mgKOH/g) suggests that more damaged fruits were used in to produce sample SSP. It was expected that samples with higher FFA content; SDP, SHP and SSP with FFA values of 34.81, 31.04 and 32.42% respectively (Figure 4.4) would have also recorded higher SV but this was only observed in sample SSP, while sample SHP in contrast had the lowest SV of 190.65mgKOH/g. It is thus likely that the bulk of saponifiable matter formed in samples SDP and SHP were mostly FFA, that for SSP was a combination of FFAs, MAGs and DAGs while that of the other samples (L1, L2, M1, M2 and ITP) were more of MAGs and DAGs.

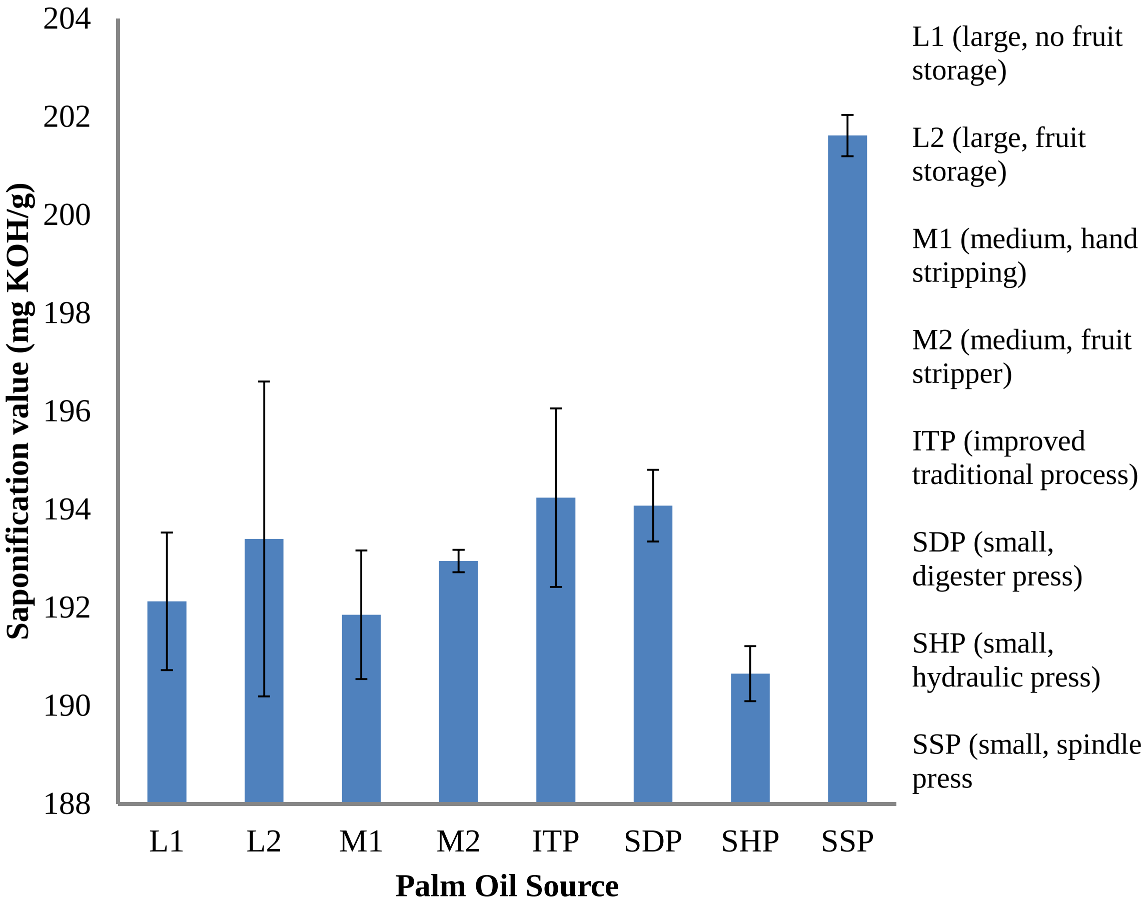

Figure 4.7: Saponification values of fresh crude palm oil samples from different processing procedures

4.3 Effects of storage on the physico-chemical characteristics of palm oils

The changes observed in all physico-chemical parameters over the 12 week storage period were all significant different ($p<0.05$). The peak of differences occurred between the 4th and 8th weeks of storage.

4.3.1 Moisture

Water is key in the oxidation of oils. The moisture content during storage shows a zigzag trend which is more pronounced in the first 4 weeks of storage (Figure 4.8). This trend may be attributed to the chain of hydrolytic reactions involving moisture. Hydrolysis can come from microbial lipolysis, enzymatic lipolysis, or autocatalysis. During storage of palm oils, the most autocatalysis is most likely to occur. Autocatalysis involves the reaction between water and TAG catalyzed by FFA to generate products such as partial glycerides, FFA and glycerol depending on how far the reaction goes. The rate of hydrolytic reactions therefore depends on temperature, moisture and initial FFA. Hence the trend in moisture content is directly related to the FFA. FFA increased significantly in the first four weeks and complements the significant changes in moisture during the first four weeks of storage. Thus moisture is used up in week 2 and regenerated for further reactions with triacylglycerol by week 4. There is generally a marginal decline in moisture throughout the storages period which signifies the use of moisture in the hydrolytic process.

There is a reduction in moisture content from week zero (0) to week 2 in all samples except sample M1. the deviation in trend of sample M1from all the other samples after the first 2 weeks of storage suggests that the initial moisture content (moisture content at week zero) of sample

M1 might have been higher than the 1.15% reported. Should the initial moisture content of sample M1 be higher than that reported, then the evaporation of moisture into the head space of the rubber container of fresh oil and its subsequent loss upon opening may be the possible cause.

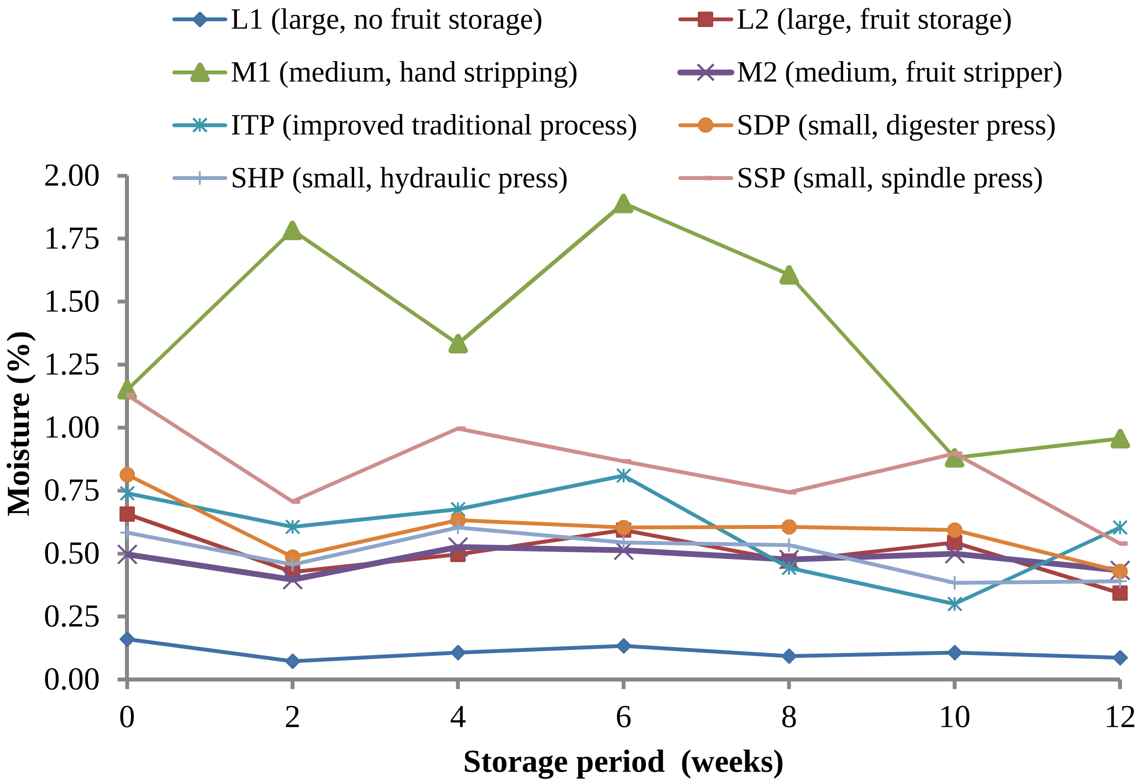

Figure 4.8: Changes in moisture content of crude palm oil samples during storage at room temperature over a 12 week period

The moisture content of sample M1 is seen to be significantly higher ($p<0.05$) than sample SSP during storage although both samples had the same moisture content at week zero. This difference may be attributed to the FFA of both samples since autocatalysis depends on initial FFA and moisture of the oil. FFA for sample M1 at week zero was 9.56% while that for SSP was 32.42% (Figure 4.12). Since FFA which acts as the catalyst in autocatalytic hydrolysis was low in sample M1, the extent of hydrolysis in sample M1was thus low resulting in less moisture been used up in the reaction and may account for the higher moisture content of sample M1 than sample SSP during storage.

4.3.2 Impurities

Impurities during storage showed two trends- marginal decline for samples that were clarified and dramatic decline for samples that were not clarified (Figure 4.9). Thus, there is generally a decline in impurities during storage. This may be attributed to the degradation of some impurities into soluble matter. Impurities in palm oil are mainly from the fibres and nuts from the palm fruits and metals from the wear of extraction machines (Baryeh, 2001; Owolarafe *et al.*, 2008).

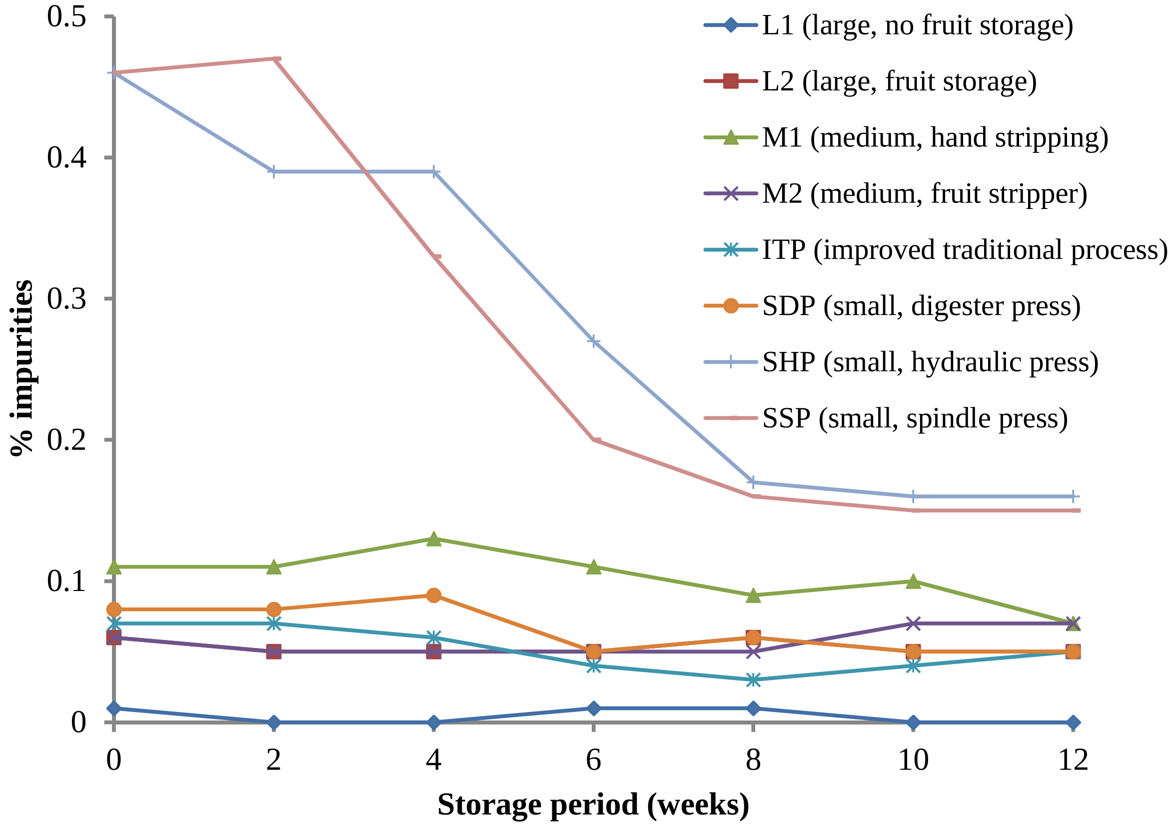

Figure 4.9: Changes in amount of impurity of crude palm oil samples during storage at room temperature over a 12 week period

Impurities from the palm fruits may be degraded. There is a significant reduction in the amount of impurities in sample SSP and SHP in the first 8 weeks of storage after which there is stabilization from the 8th to 12th week. Decomposition of impurities in sample SHP and sample SSP may be prominent as impurities from these samples were more likely to be fibres and mucilaginous substances which are easily degradable.

Trace metals form an important group of impurities in crude palm oil. They may be present as complexes surrounded by proteins, phospholipids and lipids or non-lipid carriers

(Sambanthamurthi *et al.*, 2000). Trace metals, especially transition metals such as iron and copper, act as pro-oxidants to catalyse the decomposition of hydroperoxides to free radicals such as FFA. Trace metals may be found in crude palm oil as suspended solid impurities or soluble impurities. This study measured only insoluble impurities. Hence the decline in impurities may not necessarily reduce pro-oxidants and subsequently oxidation because trace metals are not easily degraded. Thus though impurities are declining, the functional impurities involved in lipid oxidation (trace metals) may remain virtually the same.

4.3.7 Colour

The most important colour parameters in palm oils are the redness and yellowness. Redness of all oil samples decreased from week zero to four (Figure 4.10). The significant decrease ($p<0.05$) occurs between the 2nd and 4th weeks. Redness of oil samples stabilizes after the 4th week through to the end of the storage period. The red colour of palm oils is attributed to carotenes. Carotenoids undergo oxidation reactions catalysed by hydroperoxides generated by lipid oxidation and it leads to discoloration and bleaching (Sambanthamurthi *et al.*, 2000). The decline in redness after 4 weeks of storage may therefore be attributed to the oxidation of carotenoids.

Yellow colours are attributed to xanthophylls which are oxygenated carotenoids. Yellowness in the oil samples remained virtually constant except in the 2nd week where there was a decline in yellowness (Figure 4.11). The trend in yellowness is comparable to that of moisture and may be dependent on the moisture reactions for oxygenation.

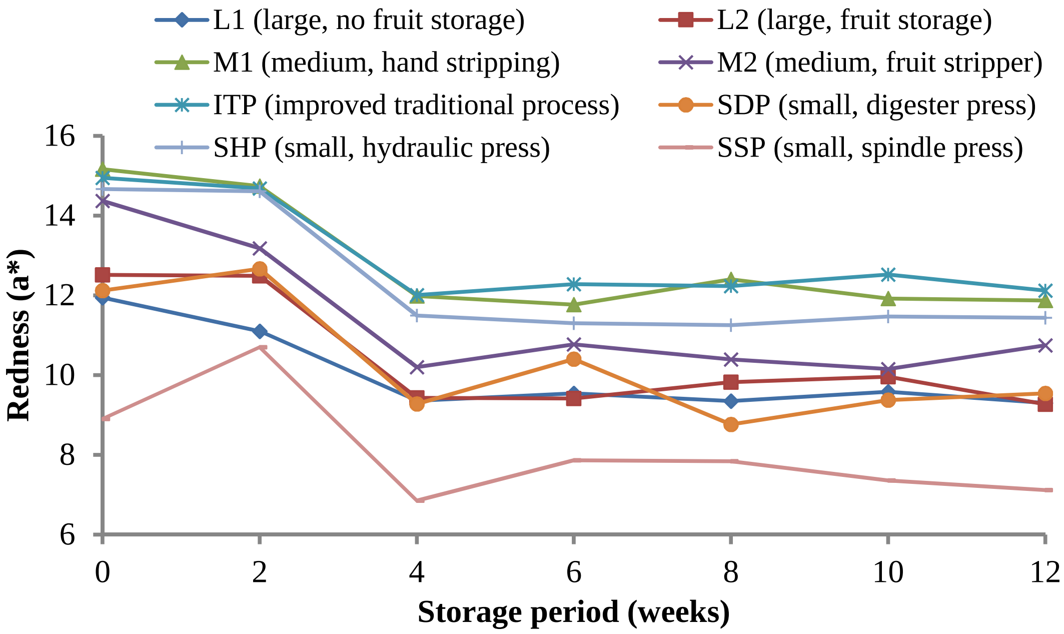

Figure 4.10: Changes in Redness of crude palm oil samples during storage at room temperature over a 12 week period

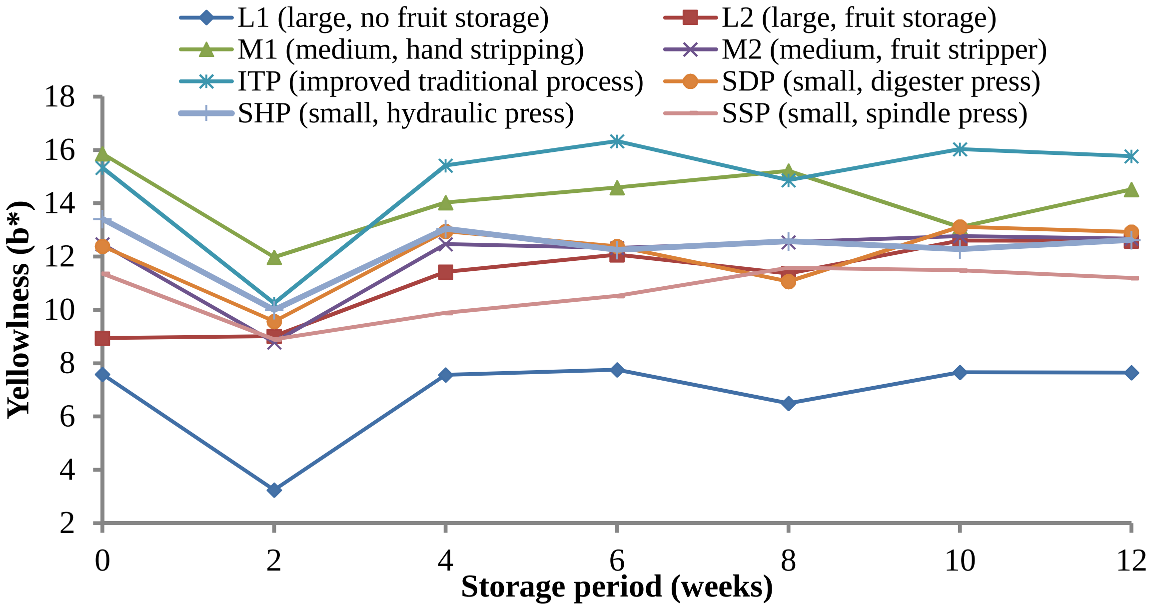

Figure 4.11: Changes in yellowness of crude palm oil samples during storage at room temperature over a 12 week period

4.3.4 Free fatty acids

Free fatty acids increased gradually from week zero (0) to week 4 and then declined drastically to week 6 after which it stabilized up to the 12th week (Figure 4.12). The gradual increase in FFA during the first four weeks of storage is attributed to the autocatalytic hydrolysis. FFAs act as a catalyst to convert triacylglycerol and water to generate more FFA. The very mild increase in sample L1 during the first four weeks is a result of the limited moisture in that sample. Therefore limiting FFA and moisture prior to storage according to Frank *et al*., (2011) is important as autocatalytic hydrolysis would hardly occur at moisture content below 0.1%.

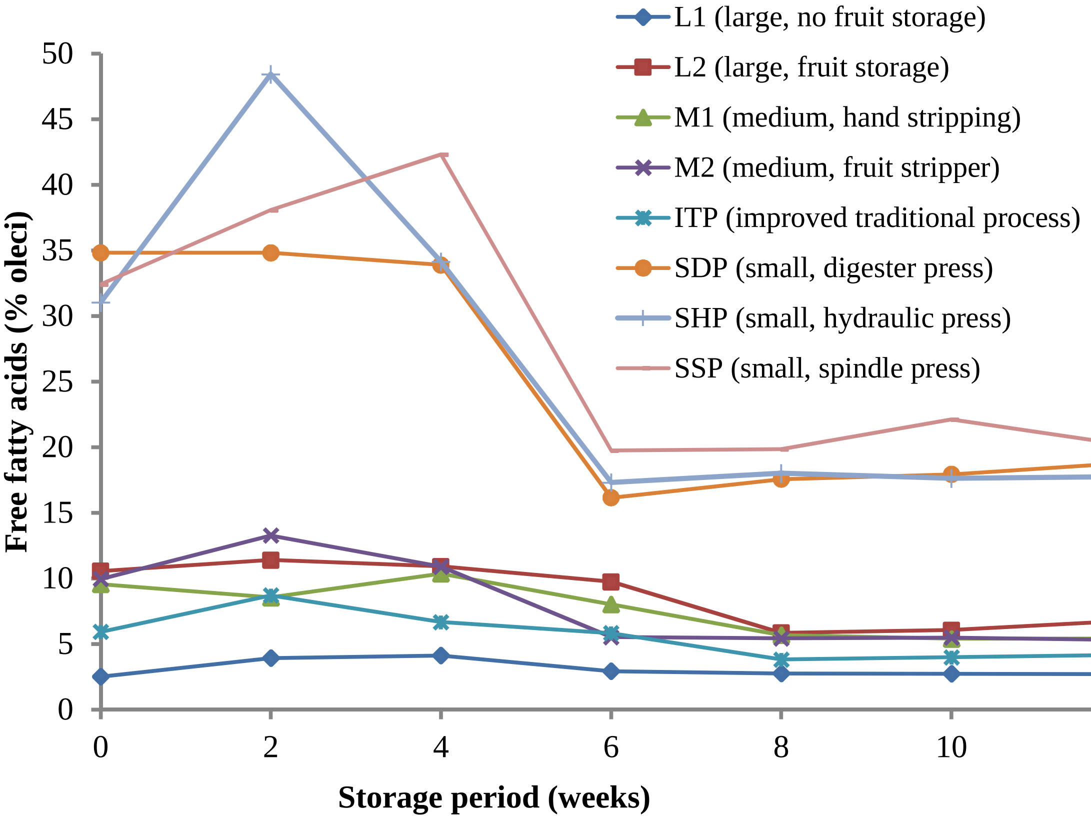

Figure 4.12: Changes in free fatty acid content of crude palm oil samples during storage at room temperature over a 12 week period

Free fatty acids, especially the unsaturated ones are likely to decompose into peroxides (Frank *et al*., 2011) and may explain the drastic decline in FFA from the 4th to 6th weeks. The stability from the 6th to the 12th week may be a result of the depletion of unsaturated FFA leaving the saturated FFAs which are more stable. Therefore the decline in FFA after the 4th week does not necessarily mean an improvement in the quality but it could rather suggest a decline in quality as further oxidation products such as peroxides, aldehydes, ketones and other secondary and tertiary oxidation products.

The rise in FFA in the first 4 weeks and its subsequent decline after the 4th week as seen in Figure 4.12 are similar to those of Frank *et al*., (2011) but contrary to results by Orji and Mbata (2008) and Njoku and Onwu (2010) who found exponential increases in FFA throughout the period of storage. Many reactions rates are influenced by temperature. FFAs are particularly influenced by factors such as temperature and containers of storage and these may be the underlining causes of the differences.

4.3.5 Peroxide value

Except for sample L1, there were significant differences ($p<0.05$) in the peroxide values of the oil samples during storage. The change in peroxide values of all samples except sample L1 (Figure 4.13) followed the Gaussian distribution that is characteristic of peroxide values during storage. There was a gradual increase in peroxide value from week zero (0) to week 4 and a sharp increase from the 4th to 6th week. The sharp rise in peroxides from the 4th to 6th week compliments the sharp decline in FFA from Figure 4.12 as a result of the degradation of FFAs into peroxides. There is a decline in peroxides from 6th to 12th week. This is attributed to the degradation of peroxides which are primary oxidation products to secondary oxidation products such as aldehydes, ketone and epoxydes.

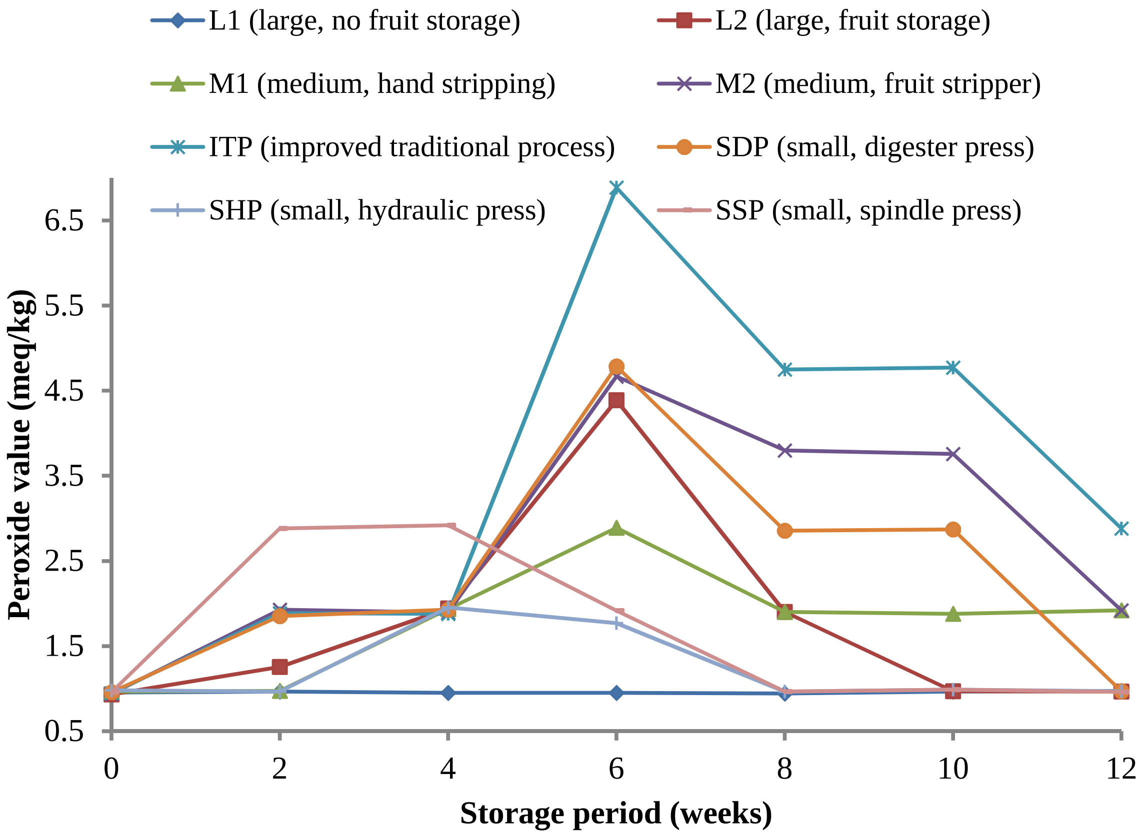

Figure 4.13: Changes in peroxide value of crude palm oil samples during storage at room temperature over a 12 week period

Peroxide values measured during storage period fall within the 10 meq/kg specified by Codex Alimentarius. This seems to suggest minimal impairment in oil quality. However given the unstable nature of peroxides, and the averagely high temperature of storage, a quicker degradation of peroxides may have occurred resulting in lower values. The higher values in peroxides for ITP could be attributed to the Tenera variety used. Studies by Njoku *et al*. (2010) show that tocopherol concentration in Dura is one and a half fold higher than that of Tenera. Tocopherols act as antioxidants. The lower concentration of tocopherols in ITP predisposes the oil to oxidation during storage and explains why ITP had significantly higher peroxide values during storage. Conversely, the very low values of sample L1 throughout the storage period indicate the oil is very stable.

Peroxides values were found by Frank *et al*. (2011) to also follow the Gaussian shape. However, values rose beyond 10 meq/kg to a peak of 40 meq/kg. Other studies (Orji and Mbata, 2008; Njoku and Onwu, 2010) found exponential increases in peroxide values during storage. Again differences in storage conditions such as temperature, containers of storage as well as inherent chemical differences in the oils as a result of the processing methods may be the cause of these differences.

4.3.6 Iodine value

Iodine values declined during oil storage with a prominent decline occurring between week 4 and 8 (Figure 4.14). This decline was expected because unsaturated fatty acids are easily prone to oxidation than saturated fatty acids. Thus as oxidation advanced during storage, the iodine value which is a measure of unsaturation declined. The prominent decline between the 4th and 8th weeks may be a result of the peak in peroxides within this period suggesting that more unsaturated fatty acids are broken down. Beyond the 8th week, a marginal decline is observed and this may be due to the decline in several reactions including peroxidation leading to fewer breakdowns of unsaturated fatty acids.

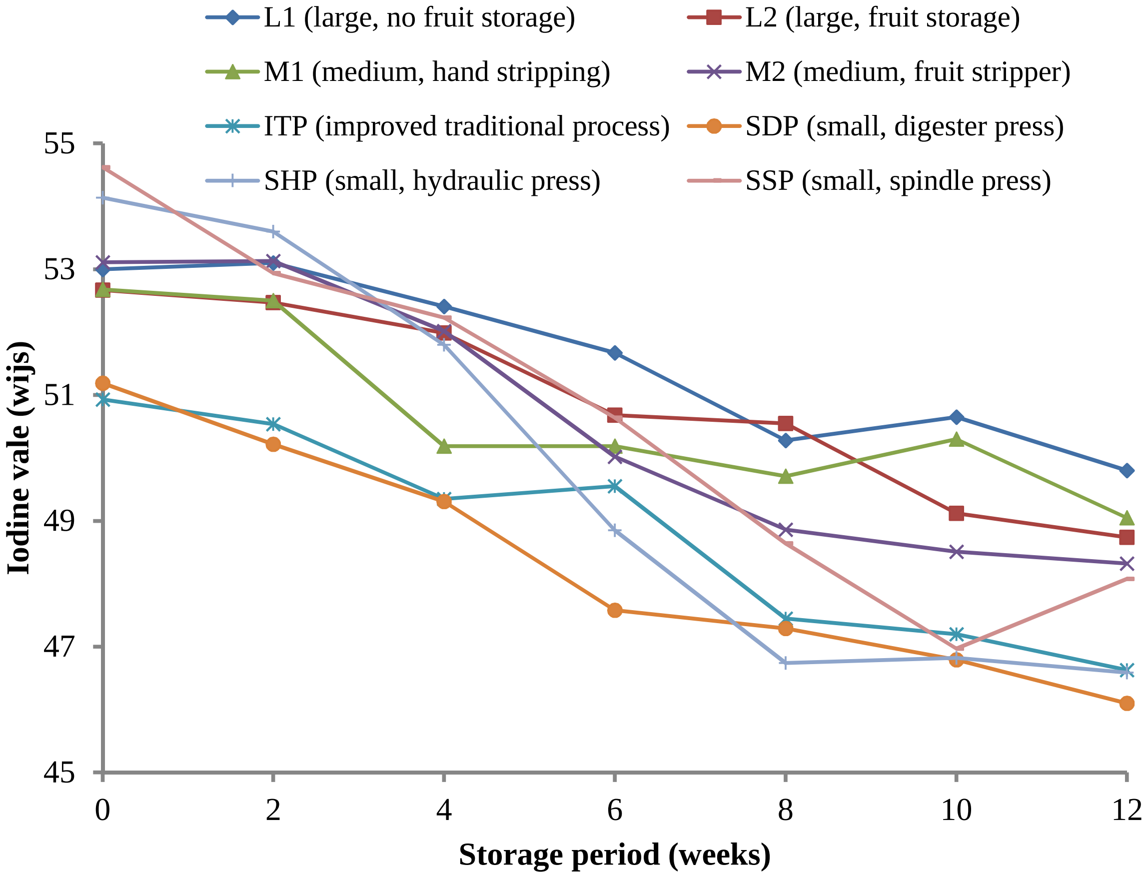

Figure 4.14: Changes in Iodine value of crude palm oil samples during storage at room temperature over a 12 week period.

The initial iodine values (at week zero) play an important role in determining the stability of the oils during storage. This is because higher iodine values of the fresh oil suggest higher unsaturation and subsequently higher oxidative deterioration as was the case of SHP and SSP. Therefore it was expected that samples ITP and SDP that had a lower iodine value (lower unsaturation) would have shown less degradation during storage. This was not the case, because the oils were probably already degraded by the turbid water used in the extraction. Turbid water is a source of pro-oxidants which catalyses the breakdown of unsaturated fatty acids.

At the end of the storage period, only sample L1 fell within 50 – 55 wijs limit for iodine value as given by Codex Alimentarius. This indicates a very high stability of sample L1. The combination of low moisture, impurities, FFA and PV in sample L1 in the fresh sample (week zero) and during storage contributed to maintaining the quality of oil (sample L1).The decline in IV of CPO samples from the different scales of processing during storage was also reported by (Njoku and Onwu, 2010).

4.3.7 Saponification value

Molecular weight or chain length of the triacylglycerol is measured by the saponification value.. Results from Figure 4.15 show an increase in saponification value with a dramatic increase between weeks 4 to 8. The shorter the chain length, the higher the saponification value. Hence the increase in saponification value with storage signifies the shedding of fatty acids on the glycerol backbone making it small and is indicative of oxidative deterioration.

The dramatic rise in saponification in the 4th to 8th week may be attributed to the peak of a myriad of oxidative reactions notably peroxidation reactions occurring during this period. Beyond the 8th week, saponification is seen to reduce and stabilize. Partial glycerides which are the major components of saponifiable matter are produced from the breakdown of unsaturated fatty acids. Therefore the stabilization of SV after the 8th week suggests that unsaturated fatty acids are no longer been broken down due probably to reduced or limiting reactants such as water and impurity.

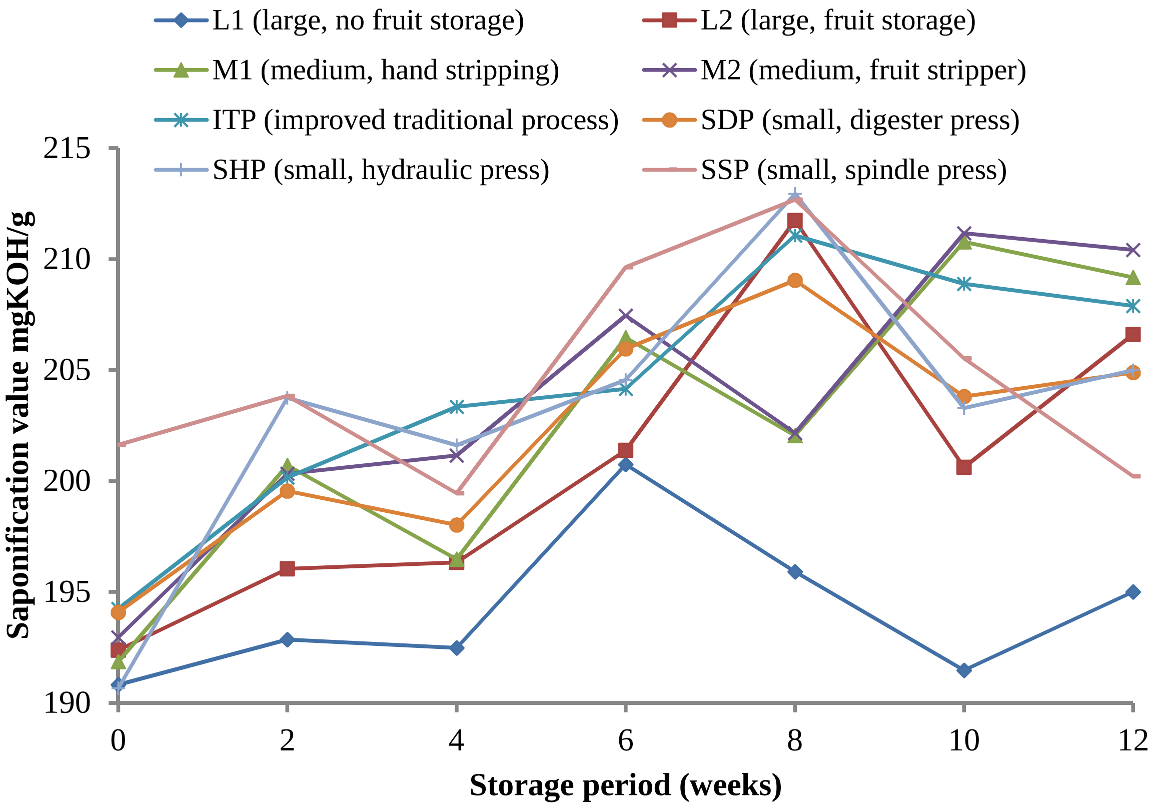

Figure 4.13: Changes in saponification value of crude palm oil samples during storage at room temperature over a 12 week period

Again throughout the storage period, only sample L1 falls within the standard 190 - 210 mgKOH/g and shows very little change throughout the storage period. It implies inherent chemical properties of sample L1, such as FFA, moisture and impurity which were all very low helped in maintaining the stability of the oil.

4.4 Sensory description of palm oils

Descriptive sensory analysis was conducted on all fresh palm oil samples obtained from the different processing methods to identity, describe and quantity perceivable appearance, mouth feel, taste and aroma characteristics. Data from seven (7) trained panelists were used after eliminating outliers by visual inspection and those who could not discriminate according to one way ANOVA ($p<0.05$). Results (Table 4.3) show that there were significant differences in all attributes among the samples except for sweet taste and bitter taste.

Table 4.3: Mean descriptive scores of crude palm oil samples from different processing procedures

SAMPLE	Appearance		Aroma			Taste		Mouthfeel	
	Colour (Redness)	Turbid	Rancid	Smoky	Burnt	Sweet	Bitter	Rough	Mouth coating
L1	84.4 ± 5.5^{a}	6.1 ± 2.1^{e}	11.0 ± 2.7^{e}	2.4 ± 1.1^{d}	11.2 ± 3.6^{d}	2.2 ± 1.2^{ab}	11.4 ± 3.0^{b}	2.5 ± 0.8^{c}	5.6 ± 1.8^{e}
L2	22.7 ± 4.5^{d}	105.9 ± 4.7^{c}	14.3 ± 3.6^{d}	3.8 ± 1.5^{cd}	16.6 ± 5.1^{c}	2.4 ± 1.4^{ab}	12.5 ± 1.9^{b}	27.2 ± 4.6^{a}	27.6 ± 4.4^{b}
M1	34.7 ± 5.2^{c}	110.4 ± 8.7^{b}	13.4 ± 2.9^{d}	76.4 ± 5.1^{a}	37.6 ± 5.8^{a}	2.2 ± 1.4^{ab}	16.6 ± 5.6^{a}	25.8 ± 2.6^{a}	31.1 ± 4.8^{a}
M2	84.1 ± 6.7^{a}	5.6 ± 1.5^{e}	14.1 ± 3.6^{d}	30.9 ± 5.5^{b}	22.2 ± 6.0^{b}	2.9 ± 1.8^{a}	15.7 ± 3.9^{a}	2.2 ± 1.0^{c}	4.9 ± 2.0^{e}
ITP	20.7 ± 4.7^{de}	116.3 ± 5.7^{a}	12.7 ± 3.3^{de}	30.4 ± 6.1^{b}	16.1 ± 7.1^{c}	2.4 ± 1.3^{ab}	8.6 ± 3.0^{c}	25.9 ± 5.2^{a}	32.6 ± 4.3^{a}
SDP	74.5 ± 6.2^{b}	19.2 ± 3.6^{d}	59.6 ± 5.4^{b}	4.5 ± 1.9^{cd}	11.1 ± 4.4^{d}	2.9 ± 1.4^{a}	15.2 ± 4.0^{a}	7.3 ± 4.2^{b}	15.5 ± 5.3^{c}
SHP	84.3 ± 5.9^{a}	6.8 ± 3.2^{e}	73.1 ± 4.5^{a}	5.4 ± 2.5^{c}	18.1 ± 4.8^{c}	2.2 ± 1.1^{ab}	17.3 ± 6.3^{a}	3.1 ± 1.8^{c}	10.3 ± 4.6^{d}
SSP	17.6 ± 6.0^{e}	112.5 ± 8.6^{b}	39.2 ± 5.0^{c}	4.7 ± 1.9^{cd}	8.2 ± 4.0^{d}	2.1 ± 0.8^{b}	12.0 ± 3.0^{b}	26.4 ± 4.3^{a}	32.9 ± 5.7^{a}

Means followed by the same superscript in a column are not significantly different ($p < 0.05$). Intensity ratings are based on a 150 mm unstructured line scale where 0 is least and 150 is highest intensity. L1 (large, no fruit storage), L2 (large, fruit storage), M1 (medium, hand stripping), M2 (medium, fruit stripper), ITP (improved traditional process), SDP (small, digester press), SHP (small, hydraulic press), SSP (small, spindle press).

4.4.1 Appearance

Colour and turbidity which were the major appearance attributes had contasting trends in intensity (Table 4.3). Samples L2, M1, ITP and SSP with an intensity range of 17.6 -34.7 had a distinctively orange colour accompanied with very high turbidity (105.9 – 116.3) while samples L1, M2, SHP, SDP appeared red (74.5 - 84.4) and very clear (not turbid) with intensity range of 5.6 to 19.2. This indicates that the appearance of palm oil was not affected by the scale of processing as the trends cut across the various scales of processing, but was affected by inherent components of the various oils. Moisture in oils is a key component that dictates physical properties of oils (Bennion, 1972). High moisture content in oils changes the physical state of the oil into permanent emulsion which is accompanied with high viscosity (Paul and Palmer, 1972). Viscous palm oils, as a result of high moisture contents, tend to have lighter colours (orange) while the less viscous oils appear dark (red). Also, the emulsions in the oils appears particles and explain why samples with orange colours were turbid, while oils with red colours were clear. Colour and turbidity were highly negatively correlated (-0.99). Therefore appearance of the palm oils was influenced by the moisture content of the oils

4.4.2 Aroma

There were distinct differences in aroma of oils from the different scales of processing (Table 4.3). Fresh crude palm oil has a typical nutty aroma. Oils from the large scale processors (L1 and L2) had a predominantly fresh (nutty) palm oil aroma as they should very low intensities (below 20 for all aroma attributes, while oils from the medium scale (M1 and M2) and ITP, had perceivable smoky (30.4 – 76.4) and burnt aromas, and oils from the small scale (SDP, SHP and SSP) were predominantly rancid as they had high intensities (39.2 – 73.1) for rancidity . These distinct differences according to the scale of processing suggest that aromas in the oils are a direct effect of the level of mechanization.

The storage of palm fruits for extended periods of time increases the FFA which causes rancidity in oils (Orji and Mbata, 2008; Frank *et al.* 2011). This explains why oils from the small scale whose fruits were stored for over 14 days were rated significantly higher ($p<0.05$) in rancidity than the rest of the oils whose fruits were stored for less than 7 days. There were significant differences ($p<0.05$) in the rancidity of oils within the small scale although the chemical analysis (FFA) did not. This is because FFA exists in different forms. Chemical assays measure the total FFA. However, short chain fatty acids such as butyric, caproic and capric are volatile at room temperature and their offensive aromas may be detected by smell even when present in very small amounts (Bennion, 1972). Thus although the oils may have the same quantity of FFA, the composition of these fatty acids as short chain or long chain may differ. Therefore the possible differences in composition of the FFA may explain why there were significant differences in rancidity of oils from the different oils in the small scale. The absence of fruit storage in L1 also accounts for the reason it was rated least in rancidity suggesting that it had a high fresh palm oil aroma followed closely by ITP whose fruits where stored for 5 days. Therefore rancidity in the oils was a result of extended fruit storage.

The presence of smoke as perceived in samples M1, M2 and ITP (Table 4.3) may be attributed to the smoke generated from the burning fuel, mainly charcoal and empty bunches. Except oils samples from the large scale, all other samples were processed using fuel that generated smoke. However, samples from the small scale had comparable smoky ratings (less than 6) to those of the large scale which suggest the absence of smoky aromas in these samples. It is imperative to note that the perceivable levels of rancidity present in oil samples from the small scale masked the smoky aromas and therefore made it difficult to perceive the smoke aroma in the oils from the small scale. This accession is clearly explained by the presence of smoke in ITP and absence of smoke aroma in SDP although both samples were processed in the same processing centre with the same processing equipment, similar processing conditions except the period of storage of fruits which was longer in SDP and led to rancid aroma in SDP.

Burnt aromas were perceived in samples from the medium scale. These perceived burnt aromas may be as a result of the presence of smoke aroma in these very oils. Smoke is an exudate of burnt products, in this case burnt charcoal and empty bunches. Therefore while perceiving smoke aroma, the burnt aroma from the charcoal and empty bunches was perceived as well. Smoke and burnt aromas were highly correlated (0.92).

4.4.3 Taste

Two basic tastes were identified in the palm oil samples – sweet and bitter. However, the ratings (Table 4.3) indicate that all samples did not taste sweet while samples M1, M2, SDP and SHP tasted bitter. The presence of FFA, the underlining cause of rancidity in oils can contribute to bitter/ soapy flavours (Wrolstad *et al.*, 2005). This explains why samples SDP and SHP which had the highest rating for rancidity (59.62 and 73.14 respectively), tasted bitter. The bitter taste of oil samples from the medium scale (M1 and M2) may be attributed to the perceived burnt aromas in these samples.

4.4.4 Mouth-feel

Roughness and mouth coating were the mouth feel attributes rated. The two attributes showed trends similar to those for colour and turbidity. Samples L1, M2, SHP and SDP had roughness rating in the range of 2.52 to 7.33 (Table 4.3) which clearly indicates they were smooth while samples M1, ITP, SSP and L2 rated in the range of 25.81 - 27.19 and are thus very rough. Correspondingly, M2, L1, SDP and SHP had mouth coating values ranging from 4.86 – 15.48 which is indicative of an oily mouth coating. L2, M1, ITP and SSP showed a waxy mouth coating as rating ranged from 27.62 – 32.91. An oily mouth coating signifies very thin film of residual oil on the tongue after swallowing while a waxy mouth coating signifies thick residual oil on the tongue. Smooth oils with less mouth coating are desirable than rough oils with waxy mouth coating.

3.5 Correlation and redundancy of terms

Principal component analysis (PCA) was done on the mean attribute scores of samples across all attributes. The first three PCs had eigenvalues greater than 1 representing 48.4, 20.4 and 12.6% respectively and accounted for 79.8% of total variation (Figure 4.16). Factor loadings from Table 4.4 suggests that PC1 was heavily influenced by appearance and mouth feel properties, PC2 by aroma attributes (smoky and burnt) and PC3 by taste attributes and rancidity. The PCA indicates that all attributes accounted for variability in the oil samples therefore all sensory lexicons generated to describe the sensory profile of palm oils were important.

A high correlation (0.89 – 0.97) existed between appearance and mouth feel attributes. Roughness, mouth coating and turbidity were positively correlated while they were negatively correlated with sensory colour. This high correlation could be attributed to an underlying inherent property of the oil - moisture. Smoky and burnt were also highly correlated (0.79) suggesting burnt aromas were heavily influenced by smoke or the vice versa. Correlation of chemical and sensory attributes show that moisture was highly correlated (>0.70) with roughness, mouth coating and turbidity. FFA and rancidity were also correlated (0.91). It implies that the sensory profile of the palm oils was affected by the FFA and moisture content of the oils.

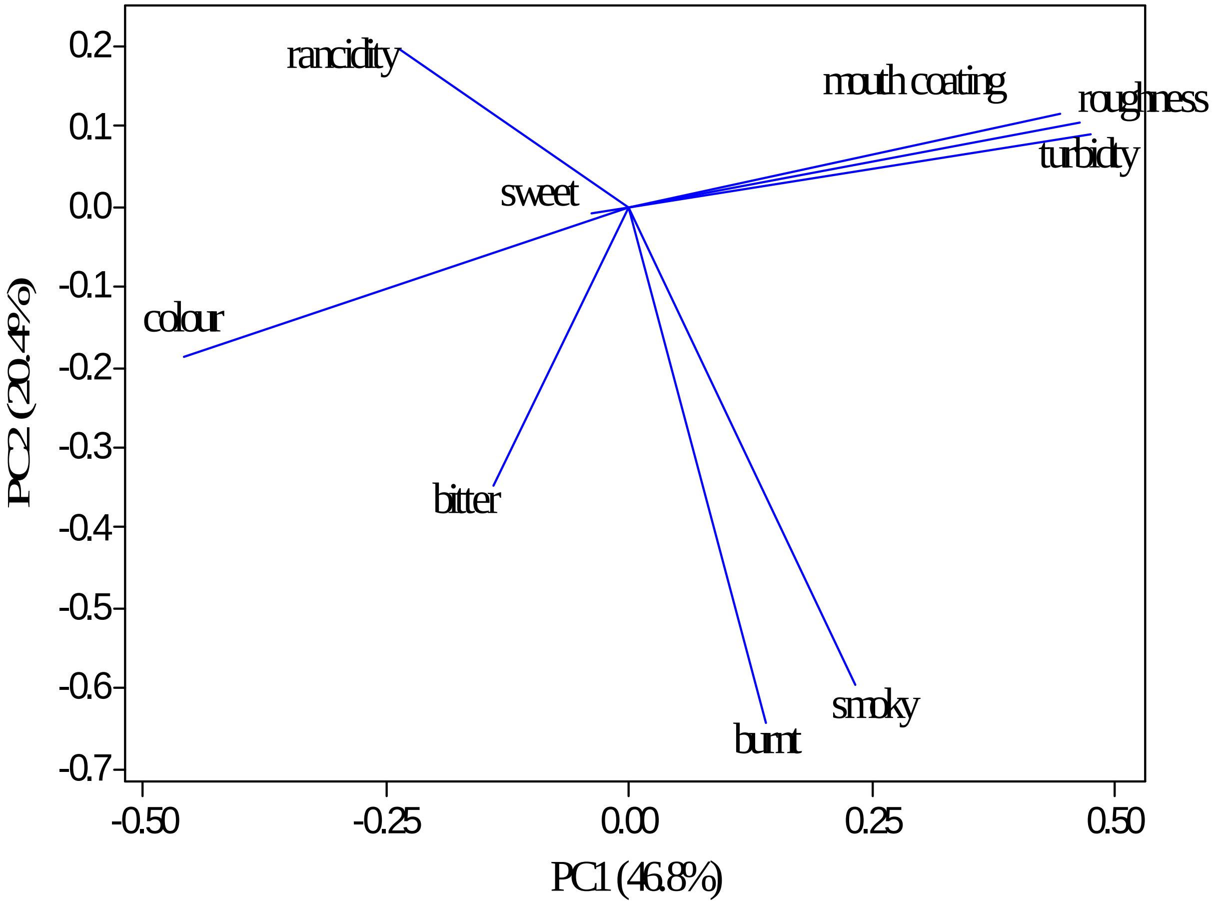

Figure 4.16: Principal component analysis (PC1 and 2) of the mean attribute scores of fresh crude palm oil samples

Table 4.4: Principal component analysis factor loadings for sensory attributes of palm oil samples

Variable	**PC1**	**PC2**	**PC3**
Colour	-0.458	-0.185	-0.079
Turbidity	0.476	0.094	0.075
Rancidity	-0.237	0.199	0.540
Smoky	0.234	-0.597	-0.063
Burnt	0.142	-0.644	-0.002
Sweet	-0.038	-0.008	-0.542
Bitter	-0.138	-0.348	0.591
Roughness	0.464	0.106	0.088
Mouth coating	0.444	0.116	0.205

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The quality of palm oil produced from the various scales of processing varied. The differences in quality may not be attributed directly to the scale of processing but how individual unit operations in the processing of the oil are done in the various scale of processing. FFA and moisture were the major indices that influenced both the sensory characteristics of oil and the quality characteristics of oil samples during storage.

The quality indices that varied most were the basic quality indices used to determine oil quality (FFA, moisture and impurities). The most important factor that militated against oil quality was the duration of fruit storage. Fruit storage for longer periods resulted in higher FFA while fruits not stored had the lowest FFA. Absence of a drying process in the medium and small scale and ineffective drying process in L2 resulted in very high moisture contents while the absence of clarification in hydraulic and spindle pressed oils resulted in very high impurities. Only oil sample L1 (oil from the large scale whose fruits are not stored) met all the oil quality standards while ITP oil was second to L1 in terms of FFA with FFA content 5.9% slightly above the 5% maximum standard.

Oil quality deteriorated with storage and the peak period of deterioration occurred between the 4th and the 8th week. There was minimal deterioration in oil obtained from the large scale processors whose fruits were not stored (L1) and it met the quality standards throughout the storage period. Higher moisture content of the oils was the predisposing factor to oil deterioration during storage. Effective drying of oil would thus be necessary to prolong shelf life of oil during storage.

Processing method had a pronounced effect on sensory quality of the oil. Most of the differences in the sensory quality were found in the appearance and mouth feel attributes of the oils which were influenced by the moisture content of oils. Oils from the various scales or processing had distinct aromas. The oils obtained from the large scale processors had a predominant fresh palm oil aroma, whilst that from the medium scale processors and improved traditional processing (ITP) had smoky aroma. Oils obtained from the small scale processors had rancid aroma.

Oil sample from the large scale processors whose fruits are processed immediately upon reception (sample L1) had superior physico-chemical and sensory quality, and showed very little deterioration during storage. This is due to the absence of fruit storage and the use of efficient machinery in the extraction process. Thus elimination or minimization of fruit storage, careful clarification of oils and the introduction of a drying process would be necessary in ameliorating the quality of oils produced in the small and medium scales.

5.2 Recommendations

Based in the findings in this study, the following processing recommendations would be necessary in the small and medium scale to improve both physico-chemical and sensory quality and extend the shelf life of palm oil:

- Fresh fruit bunches should be sectioned and boiled immediately. Sectioning of FFB would eliminate stalks and reduce the bulk to be boiled while boiling would facilitate loosening so that fruits can be easily stripped by hand picking or threshing. Thus fruit storage which is done to facilitate stripping would be eliminated.
- Temperatures of processing especially in fruit boiling, digestion and clarification should be higher to prevent the formation of emulsions which results in high moisture contents and consequently viscous oils which feel rough and leave undesirable residual oil on the tongue (mouth coating).
- A drying process by way of boiling the oil at higher temperatures to reduce the amount of residual water in palm oil should be done.
- Clean water should be used to prevent the introduction of pro-oxidants which increase the rate of oxidation.

The following recommendations are also made for further research

- The deep frying properties of palm oils from the different scales of processing should be assessed to determine the suitability of the oils for deep frying.
- Further work should be done to determine the fatty acid profiles of oils from the different scales of processing for both fresh oils and during storage. This will help in

understanding how the scales of processing affect the composition of the oils and how fatty acids are affected during storage.

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APPENDICES

Appendix 1: Screening questionnaire for descriptive sensory analysis of crude palm oils

Name…………………………………………………………

Age…………

Sex……………

Contact……………….

Please tick the choice applicable to you

1. Are you available on weekdays between 9am and 4pm? Yes………... No…………

2. Do you have any of the following;

Nasal disease	Yes………... No…………
Visual impairments	Yes………... No…………
Food allergies	Yes………... No…………
Frequent colds or sinus conditions	Yes………... No…………
Dentures	Yes………... No…………

3. How often do you consume palm oil?

At least once a week……….

At least once a month………

Never…………..

4. Have you participated in a descriptive sensory analysis before? Yes……. No…..

5. Are you interested in participating in a descriptive sensory analysis? Yes……. No…..

Appendix 2: Work sheet for descriptive sensory analysis of crude palm oil

Type of sample: Crude palm Oil

Type of test: Descriptive analysis

Sample coding: codes are written with the middle numeral representing sample.

-1- represents L1 (large, no fruit storage)
-2- represents L2 (large, fruit storage)
-3- represents M1 (medium, hand stripping)
-4- represents M2 (medium, fruit stripper)
-5- represents ITP (improved traditional process)
-6- represents SDP (small, digester press)
-7- represents SHP (small, hydraulic press)
-8- represents SSP (small, spindle press)

Test day 1								
Panelist no.	Codes and order of presentation							
1	519	047	251	980	161	320	275	036
2	228	761	543	274	650	481	532	018
3	131	518	427	257	664	872	049	381
4	943	324	582	130	715	371	260	658
5	057	162	480	345	910	638	372	925
6	462	774	318	650	127	045	338	884
7	174	827	031	563	447	380	715	952
8	980	553	166	218	073	249	028	134
9	533	617	258	048	364	277	284	725
10	015	723	230	582	371	960	553	642

Test day 2								
Panelist no.	Codes and order of presentation							
1	943	324	582	130	715	371	260	658
2	057	162	480	345	910	638	372	925
3	462	774	318	650	127	045	338	884
4	174	827	031	563	447	380	715	952
5	980	553	166	218	073	249	028	134
6	533	617	258	048	364	277	284	725
7	015	723	230	582	371	960	553	642
8	519	047	251	980	161	320	275	036
9	228	761	543	274	650	481	532	018
10	131	518	427	257	664	872	049	381
Test day 3								
Panelist no.	Codes and order of presentation							
1	057	162	480	345	910	638	372	925
2	462	774	318	650	127	045	338	884
3	174	827	031	563	447	380	715	952
4	980	553	166	218	073	249	028	134
5	533	617	258	048	364	277	284	725
6	519	047	251	980	161	320	275	036
7	228	761	543	274	650	481	532	018
8	131	518	427	257	664	872	049	381
9	943	324	582	130	715	371	260	658
10	057	162	480	345	910	638	372	925

Appendix 3: Ballot sheet for descriptive sensory analysis of crude palm oil

Name…………………………………………………………… **Date……………………..**

Sample code **A. Colour**

Orange Red

______________ ____
______________ ____
______________ ____
______________ ____
______________ ____
______________ ____
______________ ____
______________ ____

B. Turbidity

Clear Turbid

______________ ____
______________ ____
______________ ____
______________ ____
______________ ____
______________ ____
______________ ____
______________ ____

C. Rancidity

Fresh palm oil aroma rancid

______________ ____
______________ ____
______________ ____
______________ ____
______________ ____
______________ ____
______________ ____
______________ ____

Name………………………………………………………… **Date……………………..**

Sample code **D. Smoky aroma**

None Strong

__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________

E. Burnt aroma

None Strong

__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________

F. Sweet taste

None Very

__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________

Name………………………………………………………………… **Date……………………..**

Sample code

G. Bitter taste

None Very

__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________

H. Roughness

Smooth Rough

__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________

I. Mouth coating

Oily coating Waxy coating

__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________
__________ ______________________________

Comments…………………………………………………………………...................................

Appendix 4: Means of all physicochemical parameters used to assess crude palm oil

sample	Storage period (week)	moisture	Impurity	L*	a*	b*	FFA	PV	IV	SV
L1	Fresh(0)	0.16	0.01	45.58	11.94	7.59	2.51	0.95	53.00	190.82
	2	0.07	0.00	45.45	11.10	3.24	3.93	0.96	53.10	192.85
	4	0.11	0.00	45.83	9.36	7.56	4.12	0.95	52.41	192.47
	6	0.13	0.01	46.09	9.54	7.75	2.93	0.95	51.67	200.75
	8	0.09	0.01	45.51	9.35	6.49	2.76	0.94	50.28	195.91
	10	0.11	0.00	45.96	9.58	7.66	2.73	0.97	50.65	191.46
	12	0.09	0.00	45.68	9.30	7.65	2.71	0.97	49.80	195.00
L2	Fresh(0)	0.66	0.06	49.63	12.51	8.94	10.57	0.93	52.67	192.37
	2	0.43	0.05	48.99	12.49	9.02	11.41	1.25	52.47	196.04
	4	0.50	0.05	47.86	9.43	11.42	10.92	1.94	51.99	196.32
	6	0.59	0.05	48.61	9.41	12.07	9.75	4.39	50.68	201.38
	8	0.47	0.06	48.17	9.82	11.37	5.86	1.90	50.55	211.75
	10	0.54	0.05	48.58	9.96	12.60	6.07	0.97	49.12	200.61
	12	0.34	0.06	48.80	9.27	12.59	6.76	0.96	48.74	206.60
M1	Fresh(0)	1.15	0.11	50.78	15.16	15.86	9.56	0.96	52.68	191.86
	2	1.78	0.11	50.32	14.74	11.98	8.55	0.97	52.50	200.71
	4	1.33	0.13	49.34	11.98	14.03	10.38	1.93	50.19	196.47
	6	1.89	0.11	50.19	11.77	14.59	8.03	2.89	50.19	206.45
	8	1.61	0.09	50.69	15.40	15.22	5.69	1.90	49.71	2020.05
	10	0.88	0.10	48.74	11.92	13.11	5.41	1.88	50.30	210.78
	12	0.96	0.07	48.80	11.87	14.52	5.41	1.92	49.05	209.17
M2	Fresh(0)	0.50	0.06	48.79	14.37	12.47	9.96	0.94	53.11	192.95
	2	0.40	0.05	48.45	13.18	8.79	13.27	1.93	53.13	200.33
	4	0.53	0.05	48.94	10.20	12.47	10.89	1.89	52.02	201.15
	6	0.51	0.05	48.71	10.77	12.32	5.53	4.67	50.02	207.45
	8	0.48	0.05	48.68	10.39	12.54	5.43	3.80	48.86	202.17
	10	0.50	0.07	48.73	10.15	12.77	5.49	3.76	48.51	211.17
	12	0.43	0.07	47.01	10.75	12.67	5.31	1.92	48.32	210.41
ITP	Fresh(0)	0.74	0.07	50.16	14.95	15.33	5.93	0.95	50.93	194.24
	2	0.61	0.07	49.48	14.68	1.25	8.71	1.89	50.54	200.16
	4	0.68	0.06	50.58	12.01	15.42	6.67	1.88	49.35	203.35
	6	0.81	0.04	51.50	12.28	16.33	5.83	6.89	49.55	204.15
	8	0.44	0.03	50.61	12.23	14.87	2.82	4.75	47.45	211.06
	10	0.30	0.04	50.63	12.52	16.03	3.99	4.77	47.20	208.88
	12	0.60	0.05	49.61	12.12	15.77	4.17	2.88	46.63	207.88
	Fresh(0)	0.81	0.08	49.71	12.12	12.38	34.81	0.96	51.19	194.08

SDP	2	0.49	0.08	49.03	12.67	9.57	34.81	1.85	50.22	199.54
	4	0.63	0.09	49.45	9.28	12.95	33.89	1.93	49.31	198.01
	6	0.60	0.05	48.9	10.40	12.39	16.15	4.79	47.58	205.95
	8	0.61	0.06	47.87	8.76	11.06	17.56	2.85	47.29	209.04
	10	0.59	0.05	49.30	9.37	13.12	17.93	2.87	46.79	203.80
	12	0.43	0.05	46.4	9.54	12.92	18.79	0.97	46.10	204.88
SHP	Fresh(0)	0.58	0.46	49.66	14.67	13.42	31.04	0.98	54.14	190.65
	2	0.46	0.39	49.37	14.61	10.00	48.42	0.97	53.60	203.75
	4	0.60	0.39	49.0	11.49	13.05	34.14	1.95	51.80	201.61
	6	0.54	0.27	49.23	11.30	12.25	17.33	1.77	48.85	204.55
	8	0.53	0.17	48.74	11.25	12.58	18.03	0.97	46.74	212.94
	10	0.38	0.16	48.91	11.47	12.28	17.63	0.99	46.82	203.28
	12	0.39	0.16	47.02	11.44	12.62	17.75	0.97	46.59	204.99
SSP	Fresh(0)	1.13	0.46	48.54	8.9	11.36	32.42	0.96	54.62	201.62
	2	0.71	0.47	48.94	10.7	8.89	38.08	2.88	52.94	203.83
	4	1.00	0.33	47.50	6.85	9.89	42.31	2.92	52.23	199.44
	6	0.87	0.20	48.56	7.86	10.53	19.76	1.92	50.64	209.64
	8	0.74	0.16	48.54	7.84	11.58	19.85	0.97	48.64	212.67
	10	0.90	0.15	48.02	7.36	11.48	22.12	0.99	46.97	205.53
	12	0.54	0.15	48.80	7.12	11.20	20.22	0.96	48.08	200.21

Appendix 5: Water used in processing ITP and DSP oils