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Research Article

ENHANCING THE QUALITY OF CRUDE PALM OIL BY SOLVENT EXTRACTION

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Abstract

This study aims to enhance the quality of crude palm oil by solvent extraction. The research focuses on investigating and improving the physical refining process of edible oils, specifically determining the optimal fermentation time for achieving the highest palm oil quality, and assessing the influence of temperature and heating time on the oil quality. Various experiments were conducted to achieve these objectives, including sample collection, processing of palm fruits, sterilization at different temperatures and times, determination of oil yield, and physicochemical analyses of the extracted oil. The findings revealed several significant outcomes: the optimal fermentation time was approximately 6 days, with a mean oil yield of 210.25 g for boiled samples and 173.75 g for unboiled samples. Longer heating times resulted in increased oil yield, ranging from 19.5% to 22.3% under dry heating conditions and from 22% to 25% under wet heating conditions. Higher temperatures correlated with higher oil yields, increasing from 14.3% at 70°C to 24.1% at 90°C under dry heating conditions. The effect of heating time on unsaturated fatty acid contents varied, ranging from 49.67% to 50.7% under dry heating conditions and from 50.4% to 48.5% under wet heating conditions. These findings underscore the importance of optimizing fermentation time, temperature, and heating duration to maximize oil yield and quality in the physical refining process of edible oils.

Keywords: Heating time, Solvent Extraction, Maximum yield, Temperature, Fermentation, etc.

INTRODUCTION

Currently, Nigeria, home to 220 million people, is Africa's biggest palm oil consumer. According to data spanning from October 2020 to September 2021, Nigeria was predicted to consume 1.6 million metric tons of palm oil (Sasu, 2023). Throughout the past few years, the nation's domestic use of palm oil has increased steadily. Nigeria is also among the top five producers of palm oil globally. Nonetheless, Nigeria consumes more palm oil domestically than it produces. In 2018, the country used almost three (3) million MT of fats and oils, out of which 1.34 million MT, or 44.7%, usually came from palm oil (Erhie *et al,* 2019). Production was estimated at 1.02 million MT during that time, leaving a 0.32 million supply shortage (excluding the possible impact of oil exports). According to Erhie *et al.* (2019), official CPO imports into Nigeria for fiveyears (2014–2018) were estimated at 1.7 million MT, or US$ 1.28 billion. About 23% of National Fresh Fruit Bunches (FFB) produced in Nigeria and much of West Africa are processed using large-scale (industrial) mills, with the remaining 77% being processed through antiquated, ineffective small-scale methods (Taiwo *et al,* 2010). Smallholders need six to ten days to refine palm oil, but mechanized farmers just need two to four days. It takes longer to refine palm oil, which results in a 42% decrease in yield or production. This sometimes harms the quality of palm oil produced in the nation, which reduces the variety of uses it can have, particularly in industrial processes. Free Fatty Acid (FFA), a pro-oxidant, is one of the main elements that quickens the process of oil oxidation and degrades oil quality and shelf life. Unwanted flavor molecules with low molecular weight are produced during the oil oxidation process, giving the oil a rancid flavor that is less acceptable or unfit for consumption.

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Additionally, the oxidation of oil destroys vital free fatty acids (FFA), produces harmful chemicals, and oxidizes polymers that lower edible oil's nutritional value and increase its toxicity. FFA is more likely to build on the topmost layer of edible oils due to a natural property wherein the same molecule contains both a hydrophilic carboxylic acid polar head and a hydrophobic hydrocarbon chain. This phenomenon tends to accelerate oil oxidation by decreasing the surface tension of edible oil and increasing the amount of oxygen diffused into the oil from the headspace. The presence of trace metals exacerbates the oxidation process (LU, 2021). Therefore, to produce stable and edible oil, it is crucial to decrease the amount of FFA and other unwanted components, such as trace metals. Crude palm oil was gathered and refined to remove unwanted impurities from the oil at the appropriate levels in the most effective way, turning the crude oil into high-quality edible oil. One of the main factors contributing to higher oil acidity is the microorganisms found in palm oil (Constant *et al,* 2017). By raising lipase activity, these microorganisms contribute significantly to the degradation of dietary oil quality in vegetable oils generally and palm oil specifically. We Aim to improve the quality of edible Palm oil produced through local methods. The reviewed studies collectively highlight the critical role of FFAs in determining vegetable oil quality and the various approaches physical, chemical, and enzymatic to mitigate their impact. Physical and chemical deacidification methods (Noriega *et al,* 2022; Orm *et al,* 2020) are well-studied but often lack insights into sustainability and scalability. Enzymatic methods (von der Haar, 2015; Ducret *et al,* 1992) show promise for reducing FFAs but require further exploration of cost-effectiveness and industrial feasibility. Regional studies (Olorunfemi *et al,* 2014; Ohimain *et al,* 2012; Enemuor *et al,* 2012) underscore the prevalence of high FFA levels in palm oil, particularly in smallholder processing contexts, and the associated health and quality concerns. However, these studies often lack actionable recommendations for improving pre-processing or quality control practices.

Based on the examination of these physicochemical characteristics, previous study conducted by Ngando *et al.* (2011) indicated that crude palm oil (CPO) extracted from small holders' extraction sites was of lesser quality when compared to that extracted from industrial oil mills to ensure human health and safety. Given that smallholders contribute over 70% of Nigeria's total CPO production, it is reasonable to presume that the product's quality, which is widely accessible in local marketplaces, is questionable. Numerous studies have been conducted on improving the quality of palm oil using automated procedures. Our goal is to raise the standard of crude palm oil made using conventional techniques. We'll be going over the technology and extraction procedures that are now accessible and can be readily integrated with the conventional extraction process. The current study aims to enhance the quality of CPO offered in Nigeria's key marketplaces concerning food safety.

METHODOLOGY

Materials and Equipment

Fresh palm fruits and water are required materials, and the following equipment was used: beakers, electric heater, viscometer, centrifuge, conical flask, burette, volumetric flask, water condenser, pipette, and Water Bath.

Sample Collection and Preparation

Sample Collection

Traditional production techniques were used to extract palm oil from palm fruit.

Preparation of Sample

During this procedure, bunches were picked and their size was quickly decreased. The reduced-sized palm fruits were sliced and whipped into four sections, each of which was appropriately covered for the different fermentation days.

Palm Oil Extraction

The palm fruits were hand-sorted out of the bunch following each day of fermenting. Two kilograms were divided into two portions, one of which was boiled for one hour and the other not. It was boiled, let cool, and then crushed using a mortar and pestle. To make it easier to skim the crude palm oil from the mashed fruit, cold water was added after the mashed palm fruits were poured into the large plastic bowl. To eliminate any moisture, the extracted oil was heated even further. Following a second boiling and the removal of the oil with a scoop, the oil was filtered and left to cool. The yield of the oil was measured using a measuring cylinder. The remaining unboiled portion of the palm fruit was processed in the same way, except before being pounded, the fruits were not boiled. After being measured and chilled, the palm oil was moved to a ½-liter black plastic container and stored out of heat and direct sunlight to prevent oxidative rancidity. The following day, the physiochemical characteristics of the generated palm oil were examined.

Processing palm fruitless: Experimental design

Oil palm fruit sterilization was accomplished by examining the effects of heating time and temperature. The oil palm fruits used in this study were taken from the Emohua mill and cleaned to remove any dirt. They were then heated in both dry and wet conditions using an electrical oven, respectively, for the necessary amount of time and temperature as shown in figure 1.

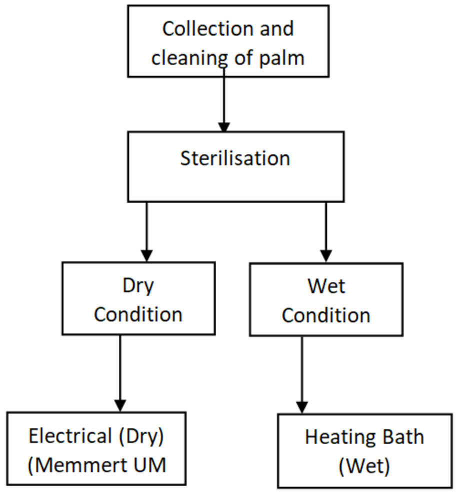

Figure 1. Processing palm fruits

Sterilization of oil palm fruits at different heating temperatures and times

For a set duration of 90 minutes, oil palm fruits were cooked to temperatures of 70, 80, and 90°C. Oil palm fruit, meanwhile, was cooked for 30, 45, 60, and 90 minutes at 90°C.

Oil yield

The nuts were extracted and the fruits' mesocarp was peeled. A fruit press expeller was used to press the peel mesocarp after it had been soaked in hexane for 24 hours at a ratio of 1:1 (v/w) between the solvent and crop. Filter paper No. 1 from Whatman was used to filter the extraction solution. Afterward, using a vacuum rotary evaporator, the filtrate's solvent was extracted from the oil at 60 degrees Celsius. Using the following equation (1), the yield of palm oil extract was calculated.

$$\%\, oil\ yield = \frac{x}{y} \times 100 \qquad (1)$$

Where; x is defined as the mass of oil extracted (g) and y is defined as the mass of oil palm fruits (g).

Physicochemical analyses of extracted oil

i. Free fatty acid

Using the MPOB test method p2.5:2004, the free fatty acid (FFA) concentration of the extracted oil was ascertained. Potassium hydrogen phthalate was used to create and standardize a sodium hydroxide solution (0.1M). After dissolving a known mass of the oil sample in neutralized isopropanol, sodium hydroxide was used to neutralize the free acids. The expression for FFA values was palmitic acid (%). Duplicate sample mean values were computed.

ii. Deterioration of Bleachability Index (DOBI)

In addition to that, the Deterioration of Bleachability Index

(DOBI) was calculated by using the MPOB test method p2.9:2004. The spectroscopic absorbance at 446 nm is referred to as DOBI, which is the ratio of that absorbance to that at 269 nm. A volumetric flask with a capacity of 25 milliliters was used to dissolve a known quantity of oil in n-hexane, which was then diluted to the desired amount. It was determined that the absorbance of the solution was measured at 446 and 269 nm by using a Hitachi U-2000 Spectrophotometer, which was manufactured in Japan. Two sets of sample mean values were calculated**.**

iii. Carotene

To determine the amount of carotene present, the MPOB test technique was used. A volumetric flask with a capacity of 25 milliliters was used to dissolve a known quantity of the oil in n-hexane, which was then diluted to the desired level. At a wavelength of 446 nm, the absorbance of the solution was measured using a Hitachi U-2000 Spectrophotometer, which was manufactured in Japan**.** Duplicate sample mean values were computed. Equation (3.2) below is used to compute the carotene content, which is given as ppm β – β-carotene.

$$\beta - carotene\ (ppm) = \frac{25 \times 383}{100W\ (as - ab)} \qquad (2)$$

in which w is the sample's weight in grams and as is the sample's absorbance. In this case, ab stands for cuvette error.

iv. Adsorbent

The commercial bleaching earth Tonsil OPT 210 FF (Süd Chemie, Germany) was utilized in the adsorption studies. With a surface area (B.E.T.) of 200 m2/g, calcium bentonite is acid-activated to create this highly acid-activated bleaching earth. A sieve examination of the dry powder was used to determine the particle size, and the average results were as follows: 60% >25 µm, 40% >45 µm, 29% >63 µm, 17% >100 µm, and 5% >150 µm.(Chemie Süd). The bleaching earth's physical and chemical characteristics are shown in Table 2.

Table 2. Physical Chemical Characterization of Tonsil OPT 210 FF (Süd-Chemie)

Apparent bulk density g/l	550
Free moisture (2 h, 110 °C) %	~ 10
Loss on ignition (predried, 2 h, 1000 °C) %	8.0
pH (10% suspension, filtered)	2.2 – 4.8
Acidity mg KOH/g	4.5
Chloride content mg Cl/g	0.5
Surface area (B.E.T.) m^2/g	200
Micropore volume	
0 - 80 nm ml/g	0.29
0 - 25 nm ml/g	0.25
0 - 14 nm ml/g	0.23

Analytical Measurements

According to Gee (2007), palm oil contains a multitude of carotenoids, with β-carotene being the most abundant among them all. To quantify the total carotene content, also referred to as β-carotene, the absorbance at 446 nm of homogenized and diluted samples in isooctane was measured using a Spectrophotometer UV-240, manufactured by Shimadzu Graphicord in Japan. In a manner comparable to this, the bulk of the phosphorus that is present in palm oil is located in the form of inorganic phosphates (Goh *et al,* 1984a), while the remaining 10–30% is situated in the form of phosphatides (Gibon *et al,* 2007). In line with the AOCS Official technique Ca 20–99 (AOCS, 1998), the phosphorus concentration in this study was expressed as total phosphorus. This was accomplished by using an Inductively Coupled Plasma (ICP) technique (Thermo Scientific, iCAP 6000 series, USA).

RESULTS

Variation of yield with fermentation time

According to the experimental findings (Figure 2), the yield of palm oil decreases for both the cooked and unboiled samples as the number of fermentation days rises. This was in line with the research that Ituen and Modo (2000) published. They discovered that the quantity and quality of oil produced are influenced by the length of time the fruits are left to ferment. We can infer that after the six days of fermentation, the oil would have shifted from special palm oil (SPO) grade to technical palm oil (TPO) grade due to a slow deterioration of the fresh fruit bunch caused by microbial reaction. The oil's commercial value is diminished due to the low quality of the TPO grade. Contrary to the belief held by the majority of small-scale palm oil processors that longer days of fruit fermentation improve oil yield, the longer fruit fermentation days had no discernible impact on oil yield (Zu *et al,* 2012). The reason for the decrease in amount is that at peak performance, which occurs after six days, the fruits would have completely softened to the point where fermentation has progressed past its peak and any remaining red outside color would have progressively turned black. With water, the reaction happens more spontaneously (Jimoh, 2011).

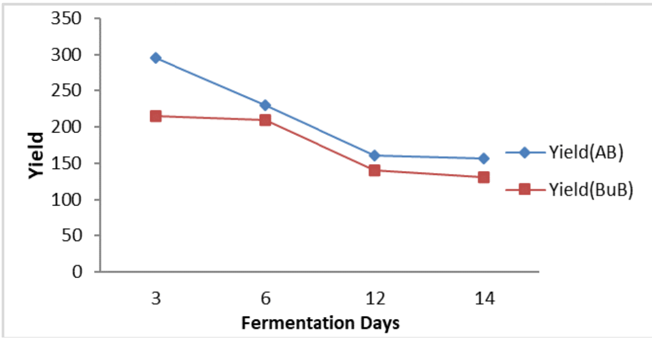

Fig. 2. A chart plotting Yield versus Fermentation Days

Effect of temperature and heating time on oil yield

At 70, 80, and 90 °C for a fixed heating time of 90 minutes, the relationship of oil yield on temperature was found. Figure 3. illustrates how temperature affects oil output. At lower temperatures, the oil output was as anticipated to be poor. The heating temperature of 90 °C used in this investigation is suitable for the highest oil output. According to Baryeh (2011), a significant finding is in agreement. Baryeh (2011) asserts that greater oil yield was a result of higher temperatures in both dry and wet heating processes. Furthermore, the results indicated that for the best yield, the heating temperature shouldn't be higher than 100°C. This is because there was just a slight increase in yield and more expenses. The key element in sterilizing palm fruitlets is heat penetration. Reduced oil production is the result of inefficient heat supply penetration. Furthermore, the length of heating was essential to guaranteeing that the heated fruit would not degrade during the process of extracting oil. The oil yield (Fig. 4) demonstrated the effectiveness of the solvent extraction procedure as well as the impact of various heating times on the oil content. The findings indicate that for both the wet (21.64% - 24.55%) and dry (18.86% - 20.99%) heating processes, the oil production rises with increasing heating time. A longer heating time resulted in a higher oil output because the heat caused more of the palm fruits' cell walls to rupture.

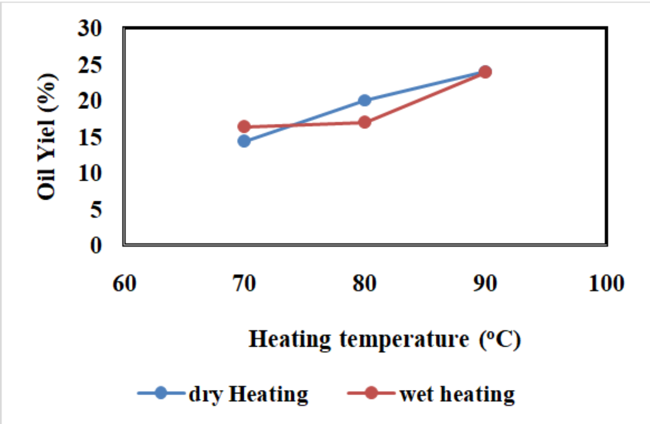

Fig. 3. Effect of temperature on oil yield at heating time of 90 min

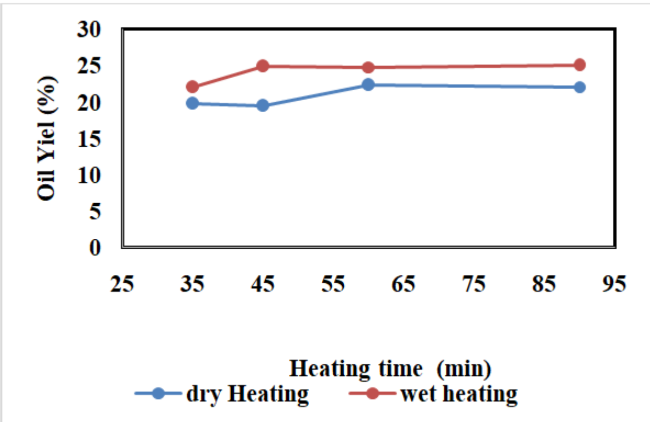

Fig.4. Effect of time on oil yield at a heating temperature of max. 90 °C

The outcomes corroborated earlier research (Cheng *et al,* 2011; Nu'man *et al,* 2012). The average oil extraction rate using traditional sterilizing and screw pressing in commercial palm oil mills was recorded as 20.21% in 2009, according to the Malaysian Oil Palm Statistic (Malaysian Palm Oil Board, 2010). An extended cooking time resulted in overcooked palm fruits, which raised the amount of burnt mesocarp produced. Conversely, as suggested by MPOB, a moderate heating duration allows for a suitable amount of time to detach the nuts from their mesocarp while maintaining a high enough yield to meet the necessary criteria. Wet heating was used to reach a maximum oil output of 24.55% after 90 minutes of heating. Nevertheless, it was shown that the ideal range of heating duration using moist heating was between 45 and 60 minutes after all studies were completed. The increase in yield is essentially negligible after 45 minutes of heating.

Physicochemical Analyses of Extracted Oil (Heating time on oil quality)

A selection of oil extracted at different heating times was made for additional characterization. Table 3 displays the extracted oil quality utilizing both dry and wet heating methods. When oil was extracted by wet heating instead of dry heating, the quality of the extracted oil was higher.

Table 3. Effect of heating time on oil quality

	Quality of Oil					
Heating Time (min)	FFA (%)		DOBI		Carotene Content (ppm)	
	Dry	Wet	Dry	Wet	Dry	Wet
30	4.97	1.20	4.52	6.25	595.31	806.78
45	2.45	1.15	5.21	5.57	588.98	791.76
60	2.37	0.93	6.06	6.10	846.09	938.42
90	1.42	0.99	6.09	5.42	930.01	763.10
Commercial CPO	< 5.0[a]		> 2.8[b]		500 – 700[c]	

Deterioration of Bleachability Index (DOBI) values

The study's findings suggested that, for all heating periods, the methods employed resulted in extracted oil of superior quality when compared to commercial CPO. The FFA value steadily dropped as the heating time was extended across the whole heating period. This is because fruits' hydrolysis enzymes have stopped working. Therefore, the reduction in FFA content led to a higher DOBI score. Regrettably, the carotene content is not rising as a result of this circumstance. Consequently, the carotene content was unaffected by the FFA or DOBI values.

Unsaturated fatty acid contents

Most of the physical properties of palm oil, including its melting point and crystallization behavior, are only partially defined by the TAG (Sambanthamurthy *et al,* 2000). The content of unsaturated fatty acids during the dry and wet heating processes is depicted in Figure 5 After 60 minutes of exposure, the amount of unsaturated fatty acids gradually decreases as a result of the prolonged heating period. For every heating duration, the fatty acid composition remained within the specified range. In commercial crude palm oil (CPO), unsaturated fatty acid content ranges from 47.5% to 51.8%.

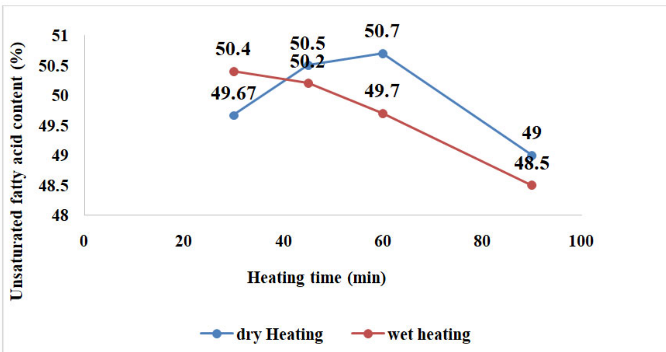

Fig.5. Effect of heating time on unsaturated fatty acid contents

Extended heating times resulted in lower levels of unsaturated fatty acid because more palm fruit cell walls broke down from the heat. In their investigation of kernel oil, Macaire *et al.* also noted a similar observation. Similar findings were observed by Owolarafe *et al.* (2007) in their investigation into the micro-structural characterisation of palm fruit. The unsaturated fatty makeup of the extracted oil varies very little between wet and dry heating procedures (between 0.11% and 2.33%).

Compared to dry heating, the oil derived by wet heating has a lower amount of unsaturated fatty acids. Water is used in the wet heating process to help break open oil cells and demolish cell walls (Owolarafe & Faborode, 2007). As a result, their unsaturated fatty acids rapidly oxidize and fix oxygen. The reason for the marginally increased fatty acid content during dry heating as opposed to moist heating is that the fatty acid stays inside the cells. The fruit was only partially penetrated by the heat from dry heating; the fruit's inside was not effectively heated. The mesocarp was thereby toughened by longer heating times. Because they lessened the likelihood of the cell content disintegrating, they prevented oxygen from reaching the location and prevented enzymes from attacking double bonds.

Conclusion

With a particular focus on enhancing the bleaching stage, figuring out the ideal fermentation time for the highest quality palm oil, and evaluating the effects of temperature and heating time on the oil's quality, this study sought to explore and improve the physical refining process of edible oils.

1. The optimal fermentation time for achieving the best palm oil quality is approximately 6 days. Beyond 6 Days, both boiled and unboiled samples showed a decrease in oil yield, with values ranging from 210.25 to 173.75.
2. At a maximum heating temperature of 90°C, longer heating times generally resulted in increased oil yield.
3. Optimum range period of heating time was between 45 to 60 min via wet heating.

These results highlight the significance of maximizing oil yield and quality throughout the physical refining process of edible oils by adjusting fermentation time, temperature, and heating duration.

Recommendation

1. To further improve the quality of palm oil, look into the best temperature ranges for the adsorptive removal of phosphate and carotenes.
2. To determine the ideal circumstances for industrial uses, investigate how various bleaching temperatures affect side reactions and overall oil quality.
3. Carry out research to determine how storing oil palm fruits for more than five days affects the quality of the oil, with a primary focus on adhering to international standards.
4. Examine how different boiling times affect oil yield and quality in order to offer evidence-based suggestions for streamlining processing methods and cutting production costs.

Author Contributions: [1]Engr. Onuabuchi Charles Uwakwe and[2]Futughe, Toju Rex: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. Prof. M. K. Oduola: Supervision, Writing – original draft, Writing – review & editing. Dr. Raheem Ademola: Writing – review & editing.

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