FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 7 No. 1, February, 2023, pp 126 - 135
DOI: https://doi.org/10.33003/fjs-2023-0701-1263

NIGERIAN PALM OIL: QUALITY DISPARITY, CONTAMINATION AND PROCESSING WASTES HANDLING

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ABSTRACT
The review article intended to provide an overview of quality variation and various contaminants in locally processed palm oil (PO). The paper also deliberates on the pros and cons of wastes generated during PO processing. There is a serious concern about the quality and safety of crude PO in Nigeria resulting from poor quality raw materials, inadequate processing know-how, inappropriate packaging and storage facilities, poor handling and transportation system and more importantly adulteration by producers and marketers. Wide disparities in the chemical and physical composition were reported in the literature. This may result from the variations in the chemical composition of the palm fruit, environmental factors, variation in processing operations which is determined by the location and abuse during handling and transportation. Microbial contamination is the foremost safety challenge in Nigerian crude PO processing. Higher microbial counts and the presence of toxic microorganisms including aflatoxins-producing fungi were reported by many researchers. Oil palm production in contaminated soil account for PO heavy metals contamination, though, heavy metals contamination below permissible limits was reported in most cases. Wastes generated from PO processing can be detrimental to the environment. Alternately, various benefits can be derived from the proper handling and utilisation of PO processing wastes. Palm oil mill effluent (POME) is a good substrate for the production of organic manure, biomolecules and amendment of oil-contaminated soil. Recommendations on how to tackle various challenges along the PO supply chain were presented at the end of the paper.

Keywords: adulteration, soil contamination, soil amendment, organic manure

INTRODUCTION

Oil palm is among the commonly used oil-bearing plant with diverse uses, it thrives pleasantly in the tropical and sub-tropical regions (Izah and Ohimain, 2016b). Palm oil (PO) is extracted from oil palm fruit and is among the most important and most utilise vegetable oils (Andoh *et al*., 2019). The consumption and economic value of PO are growing in Nigeria due to its numerous nutritional benefits (Ndidi *et al*., 2020) and it is numerous applications beyond food (Gourichon, 2013; Ohimain and Izah, 2015). In addition to it is used as cooking oil and as material for margarine production, PO and its by-products are also used in the manufacturing of soaps, cosmetics, detergents, lubricants, biofuels, etc. (Ibiyemi *et al*., 2022). Four palm oil products commonly marketed and consumed in Nigeria are (1) the low-quality crude PO which is also known as Technical Palm Oil, (2) the good quality (usually refined) PO produced purposely for industrial use (3) fully refine PO and (4) palm kernel oil (Gourichon, 2013).

In addition to its good glycerides composition, PO also contains other functional ingredients with positive health implications (Olafisoye *et al*., 2017). The major constituents of PO are palmitic acid methyl ester (31.5%) and oleic acid methyl ester (31.5%) (Ogundare *et al*., 2019). Different oil possesses different and unique fatty acids profile (Lim *et al*., 2020). Free fatty acid (FFA) is the most reliable quality indicator used in PO (AbdullRani, 2015).

There is alarming criticism about the quality of commercial crude PO vended in most Nigerian markets (Odoh *et al*., 2017). Poor handling and ignorance of the activities of contaminating microorganisms and their associated dangers on food quality and human health contributed extensively to the poor quality of PO (Ngangjoh *et al*., 2020). Contamination due to poor processing, inadequate storage facilities and post-processes adulteration hurt the qualities of PO and may negatively affect the future of the oil palm industry in Nigeria (Aphiar and Raphael, 2019).

Poor funding, lack of good planting materials, improper milling, inadequate technology (Amadi and Wogborama, 2016; Gourichon, 2013; Shehu et al., 2021), poor extraction processes, high cost for plantation rent (Bello *et al*., 2015), bad roads, higher transportation fare and poor storage facilities (Oluwatusin, 2017), poor linkages and extension services delivery (Urhibo, 2022) are among the major challenges facing PO industry in Nigeria. The processing methods in most rural areas are still very rudimentary with many manual works that are associated with many dangers including burning injuries and other occupational-related illnesses (Bamidele, 2015). Novel techniques were reported to extend the keeping qualities of palm oil. Spray drying and encapsulation using sodium caseinate significantly improved the oxidative stability of PO (Dhiman *et al*., 2021).

Local production of PO accounts for only 55 % of the total demand (Izah and Ohimain, 2016b). Despite the deficit in self-sufficiency in PO production in Nigeria, oil palm production is contributing enormously to the economic development of Nigeria (Abdul-Qadir *et al*., 2016). About 80 % of Nigerian PO is produced locally through the traditional ancient extraction methods that are extremely inefficient, grievously unhygienic (Izah and Ohimain, 2016a) and less profitable (Onu *et al*., 2022).

Lack of inceptive from governments at various levels also contributed to the poor quality finished products that cannot compete at international markets (Amadi and Wogborama, 2016). It is sad to report that Nigeria lost its position as PO leading producer and exporter in the 1960s to a net importer of refined PO and its by-products (Oluwatusin, 2017). The poor yield resulting from failure to embrace modern farming techniques continues to hinder agricultural development in Nigeria. For instance, United Nations data reported on oil palm fruit production in 2020 shows that Nigeria produced only 9.5 million tonnes in 3.7 million hectares of land while Malaysia produced 97 million tonnes in only 5.2 million hectares of land (FAOSTAT, 2022).

In recent years, Nigeria is occupying 5^{th} in global PO production with a domestic supply of 930,000 metric tonnes (Izah and Ohimain, 2016a). Failure to meet international food safety standards creates an additional hurdle to PO acceptance in the global market. The issue of food safety is of great concern to Europe and other developed countries. Their concern about agrochemical residues accounts for the rejection of Nigerian commodities in the international market and this forces producers to sell their harvest at cheaper prices in local markets (Akanni, 2018). As a matter of urgency, the government should recognise the economic importance of traditional palm oil mills in Nigeria and come up with a workable policy that will transform the sector into a revenue and livelihood generation venture(Filusi *et al*., 2022).

Quality Disparity

Harvesting methods, fruit handling and processing methods (Omotoso *et al*., 2018), extraction methods, supply systems (Constant *et al*., 2017), personnel and environmental hygiene, quality of the palm fruit (Aphiar and Raphael, 2019), ripening stage, mechanical damages during harvesting, exposure to sunlight (Abiodun *et al*., 2019) and geographical location of the palm tree (Jolayemi *et al*., 2018) are important to the quality of PO.

The quality variation was reported in Nigerian crude PO by many researchers (Table 1). Comparing the data in Table with the National Agency for Food and Drug Admiration and Control (NAFDAC) stands shows that Peroxide, iodine and saponification values in most of the reported values are within the acceptable limits while free fatty acid (FFA) contents exceeded the recommended level in all the reported findings.

The PO samples reported to comply with the overall quality standard of the Standard Organisation of Nigeria (SON) are those collected from Minna in Niger State (Ajai *et al*., 2016), Isialangwa in Abia State (Kenechi *et al*., 2017), Enugu in Enugu State (Chigbogu *et al*., 2015). It is only FFA, peroxide value, iodine value and moisture content that meet SON standard in the analysed samples from Jos, Plateau State (Odoh *et al*., 2017).

Chinakwe and Ogbuagu (2019) reported a broad disparity in the quality parameters of crude PO sold in the major South-Eastern Nigeria markets. The chemical qualities of PO produced in Imo State fall below the recommendations of SON and Nigerian Industrial Standard (Ebere *et al*., 2018). The saponification value, FFA, specific gravity, moisture and impurity levels in market samples collected from Yenagoa, Bayelsa States exceeded the maximum permissible limits recommended by NAFDAC (Ohimain and Izah, 2015). Moisture content above the permissible limit was also reported by Enyoh *et al*. (2017a) in PO samples collected from Okigwe, Imo State.

The oxidative stability of locally processed PO is seriously affected during storage. Chuku and Chuku (2016) and Akinola *et al.* (2019) reported a decrease in moisture content and an increase in free fatty acids, iodine value and peroxide value during storage of locally processed PO. Similarly, Enyoh *et al*. (2017a) reported an increase in free fatty acid during 10 days of storage. Exposure to sunlight during retailing also accounts for many quality changes (Akinola *et al*., 2019).

Table 1: Quality variations in Nigerian Crude Palm Oil

Location	Moisture (%)	Peroxide value (meq/kg)	FFA (mg KOH/g)	Iodine value (Wij/s)	Saponification value (mgKOH/g)	Relative Density(g/ml)	Specific Gravity (g/mL)	Refractive index (°Bx)	Melting point	Smoke point (°C)	Flash point (°C)	Reference
Minna, Niger State		0.37		57.50	198.76	1.42	0.96	1.44				(Ajai *et al.*, 2016)
Lagos, Lagos State	0.38- 2.48	7.15-10.35	14.70-21.45	84.94-179.71	157.20 - 212.84				33.40 - 35.00		232.00 - 232.60	(Abiodun *et al.*, 2019)
Oyo, Osun and Ondo states	1.51 - 2.46	3.186-5.450	0.719 to 1.090	45.57 to 50.60	199.22-203.55		0.8980-0.9140	1.465-1.469	31.11-34.03			(Rafiu *et al.*, 2022)
Kwali, Abuja	0.34-1.29	4.80-32.11	189-210	35.35-48.14								(Idoko *et al.*, 2018)
Calabar, Cross Rivers		3.60-0.03	9.26-12	45.78 to 21.40								(Ekpo *et al.*, 2022)
Kano, Kano State	0.97-1.77		0.86-0.90	30.20-35.37	182.97-192.07							(Samuel *et al.*, 2018)
Isialangwa, Abia State	0.14-0.24	6.89-8.80	2.73-3.26	29.56-44.60	179.80-203.50		0.768-0.903			117-129	175-188	(Kenechi *et al.*, 2017)
Yenagoa, Bayelsa States	0.55-2.43	2.60 - 9.28	4.503 - 8.467		191.50– 203.05		0.9250 - 0.9875					(Ohimain and Izah, 2015)
Enugu, Enugu State	0.13-0.20	4.25– 6.80	2.68–2.96	52.46–53.74	194.90–198.57		0.844–0.896		34.75–35.55	115.35–117.80		(Chigbogu *et al.*, 2015)
Imo State	0.26-0.33	0.01410-0.0248	10.38-18.80	0.48-2.84	192.49-202.73	0.8700-0.9100	0.8900-0.9250	1.4615-1.4640		114.0-116.2		(Enyoh *et al.*, 2017b)
Isoko, Delta State	0.26-0.86	18.8124-18.9068	15.60-16.90		192.49-202.73							(Aphiar and Raphael, 2019)
Jos, Plateau State	0.44-0.72	6.96-13.63	3.43-6.88	39.7-67.5								(Odoh *et al.*, 2017)
Benin, Edo State		0.83-5.35	6.33-21.33									(Omotoso *et al.*, 2018)
NAFDAC Standard		Not > 10	Not > 0.6	50 – 55	190 – 209	0.891 – 0.899		1.454 – 1.456				(NAFDAC, 2020)

Contamination

Microbial Contamination

The rudimentary methods and techniques involved in the processing, handling and storage and poor environmental hygiene account for the contamination and proliferation of microorganisms in locally manufactured PO (Izah and Ohimain, 2016a). Obire and Hakam (2015) associated faecal contamination in locally processed PO with poor personnel and poor environmental hygiene. The open-pan cooking commonly used allow the sporulating organisms to develop spore and withstand the thermal treatment, they letter germinate in the PO and initiate the deterioration process (Obire and Hakam, 2015).

Previous report indicated that fresh PO samples collected from Ile-Ife are grossly contaminated with microorganisms beyond the SON and FAO recommended level of 10^4 (Akinola *et al*., 2019). Market samples also collected from Yenagoa, Bayelsa States possessed microbial loads within permissible limits (Ohimain and Izah, 2015). Mean mould count between 3.18×10^4 and 4.56×10^4 cfu/mL was observed in commercial samples collected from Jos markets (Odoh *et al*., 2017). Total heterotrophic bacterial counts in the range 9.7-39.0 x 10^6 cfu/ml were reported by Ahmed and Wagini (2018) in market samples collected from Katsina.

Bacterial isolates found in PO include *Bacillus cereus*, *Bacillus subtilis*, *Escherichia coli*, *Klebsiella* sp., *Serratia marcescens*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Staphylococcus epidermidi* (Obire and Hakam, 2015). Ahmed and Wagini (2018) isolated *Staphylococcus aureus* and *Escherichia coli* from commercial samples. Akinola *et al*. (2019) isolated *Bacillus pasteurii*, *Staphylococcus aureus, Enterobacter aerogenes, Micrococcus* sp*., Escherichia coli, Pseudomonas aeruginosa and Serratia marcescens* in freshly milled PO collected from traditional milling stations in Ile-Ife, Osun state.

Obire and Hakam (2015) reported the presence of *Aspergillus fumigatus*, *Aspergillus niger*, *Mucor* sp. *Penicillium* sp. and *Saccharomyces cerevisiae* in freshly extracted PO. Nwachukwu *et al*. (2019) also isolate aflatoxin-producing *A. flavus* in commercial samples of PO collected from South-Eastern Nigeria. *Candida* sp. *Aspergillus* sp. and *Fusarium* sp. were reported by Odoh *et al* (2017) in commercial samples collected from Jos, Plateau State. Chuku and Chuku. (2016) isolated *Rhizopusstolonifer, Fusarium oxysporum, Sclerotium rolfsii, Aspergillus niger* and *Neurospora crassa* during 12 months of PO storage.

In addition to indigenous lipases found at the mesocarp of palm fruit, fungi such as *Mucor* sp, *Aspergillus* sp, *Candida* and *Penicillium* and bacteria such as *Bacillus*, *Micrococcus*, *Pseudomonas*, *Enterobacter* and *Staphylococcus* also produce lipases that catalyse the breaking down of lipids (Constant *et al*., 2017).

Heavy Metals Contamination

The concentrations of heavy metals reported in PO by most researchers fall below the permissible limits recommended by various regulatory bodies. These include the concentrations Cu, Zn, Mn, Fe and Ni reported in samples collected from Yenagoa, Bayelsa State (Omozemoje *et al*., 2017), Cd, As, Hg and Pb reported in samples collected from Kano markets (Samuel *et al*., 2020), Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn in samples collected from Benue and Taraba states (Raphael *et al*., 2017), Cd and Ni in samples collected from Calabar, Cross Rivers State (Ekpo *et al*., 2022). However, it is worth mentioning that frequent consumption of contaminated oil can lead to the accumulation of metals in body fluids and vital organs.

Higher concentrations of Zn and Cd were found in palm oil extracted from oil palm produced at Nigeria Institute for Oil Palm Research and its substations in South-Western Nigeria, the oil samples sourced from these places are unfit for human consumption due to the bioaccumulation of toxic metals from contaminated soil which leads to Accumulation Factor and Health Risk Index values above 1 (Olafisoye *et al*., 2020). Ekpo *et al* (2022) reported Co and Pb above WHO permissible limits in commercial PO samples collected from Calabar.

Adulteration

Adulteration is defined in the "Dictionary of Food Science and Technology" as the "addition of substances to foods, or substitution of food ingredients with inferior substances, with the intent of lowering the quality and costs of producing the food and defrauding the purchaser". Producers and marketers of PO in Nigeria are suspected to be adding numerous unknown and unregulated additives to enhance sensory attributes, preserve the oil or mask adulteration (Sam and Nenman, 2019). Adulterants used in PO include Sudan III dye (Ndidi *et al*., 2020), Sudan IV dye (Andoh *et al*., 2019), lime, red dye, ripe plantain and banana peel extracts (Sam and Nenman, 2019). The banned carcinogenic Sudan III and Sudan IV dyes are the most reported adulterants used in PO not only in Nigeria but also in neighbouring countries as reported by Andoh *et al*. (2020) and MacArthur *et al*. (2020) in PO samples collected from Ghana. Sudan IV dye is carcinogenic and mutagenic and was banned by the International Agency for Research on Cancer (IARC) (Andoh *et al*., 2019)

Adulterants can affect the physical and chemical properties of oil but most detection techniques are based on the changes in physical properties (George et al., 2017; Tomaszewska-Gras, 2016)**.** Lim *et al*. (2018) reported changes in the appearance of short-chain fatty acids (C8:0 and C10:0) and trans fatty acids (trans C18:1), presence of other fatty acids (C11:0 and C20:5) not found in fresh PO, increase in MUFAs and OCFAs and decrease in PUFAs in adulterated PO. PO adulteration using red dye from the leaf sheath of *Sorghum bicolour* causes an increase in free fatty acid and significant changes in colour and aroma during short-time storage (Okogeri and Uchenna-Onu, 2016). Dikko *et al* (2015) reported a linear increase in activation energy in contaminated PO, this was suspected to cause by the Increased intermolecular attractive force in the contaminated PO.

Consumption of unsafe adulterated foods reported to cause complicated health conditions that can lead to death (Oti, 2021). Animal studies conducted by various researchers reported adverse effects on the vital organs of a rat. Nwachoko and Fortune (2019) reported changes in the kidney tissues and creatinine, urea, sodium ion, potassium ion and bicarbonate in the blood of albino rats fed with PO adulterated with Sudan III dye at 0.5g/20 ml PO. Sudan dyes induce an increase in the levels of alanine aminotransferase, aspartate aminotransferase and alkaline phosphatase activities in albino rat and adversely affects their liver function (Oparaocha *et al*., 2019). Sudan III dye used in PO increases liver enzyme activity and lead to liver severe inflammation and damage in albino rat (Ndidi *et al*., 2020). Sam and Nenman (2019) described PO adulterated with lime and red dye as a slow killer.

In contrast, PO was reported to be used in the adulteration of other oil in some Asian and European countries. The use of refined PO as an adulterant was reported in butter fat (Tomaszewska-Gras, 2016), sesame oil (Rohman and Man, 2011), olive oil (Rohman and Man, 2010) and coconut oil (Rohman and Man, 2009).

Processing Wastes Handling

Environmental Concerns

Oil palm plantation and the subsequent processing of the palm fruit into palm oil and other by-products are detrimental to the environment (Ezeomedo and Ogbogu, 2022). Effluent from PO processing contributed to inland waterways pollution in the oil palm belt region which expanded from Cross River to Lagos state (Ado *et al*., 2015). Wastes generated by PO processing include solid (palm press fibre, chaff, palm kernel shell and empty fruit bunch), liquid (palm oil mill effluent i.e. POME) and gaseous (pollutant gases). Only small portions of the solid wastes are used as fuel during cooking while the rest are discharged into the environment without or with very little treatment (Izah *et al*., 2016). In addition to ecological disruption, POME can also be genotoxic to the biotic component of the ecosystem. The results of a genotoxicity study conducted by Dada *et al*. (2018) revealed that POME can cause growth inhibitions and chromosomal aberrations in the root of *Allium cepa*

Effects on water

Wastewater treatment is not receiving due consideration in Nigeria. Untreated effluents are among the major causes of river pollution, food contamination, contamination and losses of aquatic life, critical diseases and disorders and shorter life expectancy (Ado *et al*., 2015). Sludge from PO processing is characterised by high acidity, inorganic chemical (Nwoko and Ukiwe, 2016), BOD, COD, suspended solids and dark colour (Ado *et al*., 2015).

Incessant discharge of POME is devastating to the environment and can elevate BOD and metal concentrations in soil and water bodies (Edward *et al*., 2017). POME is rich in pathogenic microorganisms and possesses higher concentrations of BOD and COD and is capable of polluting soil and freshwater (Imo and Ihejirika, 2021). Discharge of POME increases BOD and metal concentration in rivers and incessant discharge can contaminate streams and render them unfit for human use (Edward *et al*., 2017). POME obtained from local processors in Umuaka, Imo State possessed higher concentrations of Cu, Cr and Fe (Uroko, 2014). Discharge of untreated POME elevated the levels of turbidity, total bacterial count, Cr, Pb, Mn, and Mg in Ogele Stream, Ogbadibo, Benue State beyond WHO threshold limits (Yuguda *et al*., 2021). Edward *et al*. (2017) also reported pH, turbidity, temperature, alkalinity, TDS, TSS, TS, Metals and Nutrients values above WHO permissible limits in water samples collected from River Awemu in Ijero-Ekiti, Ekiti State which receive a large volume of POME from local processing of PO.

Effects on Soil

Discharging untreated POME is stocking soil with numerous contaminants that affects soil qualities and functionality by altering its biological and chemical composition (Nwoko and Ukiwe, 2016). Soil contaminated with POME can have elevated acidity and depreciated physicochemical qualities (Chikwendu and Ogbonna, 2019). The higher acidity in the POME can deprive the soil of phosphorus and significantly reduces soil lipase, catalase and dehydrogenase activities (Uroko, 2014).

Indiscriminate disposal of POME can alter soil physicochemical properties and soil microbiota and by extension can pose threat to the ecosystem (Nmaduka *et al*., 2018). POME can alter soil properties by increasing organic matter, pH, electrical conductivity, available phosphorus, exchangeable bases, cation exchange capacity (Ako and Anegbe, 2022) and heavy metals content (Nnaji *et al*., 2016; Nwoko and Ukiwe, 2016; Ubani *et al*., 2017). Nmaduka *et al*. (2018) reported an increase in BOD, COD, DO, oil and grease, pH, total suspended solids and calcium in POME dumpsite soil. In contrast, Ubani *et al*. (2017) reported a decrease in K^{+}, Ca^{2+}, Mg^{2+}, cation exchange capacity and phosphorus content in soil contaminated with POME.

Soil enzyme is among the quality indicators of soil. Ezirim *et al*. (2017) reported higher lipases and dehydrogenase activities in POME-contaminated soil. In contrast, (Nmaduka *et al*., 2018) reported a decrease in the catalase and dehydrogenase activities in the topsoil (0-15 cm) and elevated activity of dehydrogenase in the subsoil (15-30 cm) of the POME dumpsite. (Ubani *et al*., 2017) reported significance decrease in dehydrogenase and phosphatase in soil irrigated with POME. The age of the POME, sampling time and nature/composition of the effluent microflora may lead to these contradicting results.

POME Treatment

Treatment of POME before discharging can lower its environmental impact. Proper treatment of POME can lower its COD and BOD and reduce its environmental impact. Researchers recommended biodegradation using lipases-producing microbes that can be obtained from POME dumpsites. POME treatment methods recommended by researchers in recent findings include the work of Suseela and Muralidhar (2018) who reported that a mixed culture of fungal isolates (*Emericella nidulans* + *Aspergillus* niger + *Aspergillus* fumigatus) obtained from POME dumpsite can efficiently reduce COD and BOD in POME by 91.43 % and 94.34 % respectively. The presence of catabolic microorganisms such as *Proteus*, *Clostridium*, *Micrococcus* and *Pseudomonas* can also assist in crashing the abundant organic matter present in the POME (Imo and Ihejirika, 2021). Jagaba *et al*. (2020) reported the efficacy of synthetic and natural coagulants in removing total suspended solids (TSS), oil and grease, turbidity, colour, chemical oxygen demand (COD) and NH_3-N from palm oil mill sludge. The findings of Nwabanne *et al*. (2018) also revealed how Electrocoagulation can be used to significantly reduce the concentration of Total Suspended and Dissolved Solids (TSDP) in POME.

Agricultural applications of POME

Raw POME is capable of improving soil fertility and the growth performance of many crops (Nmaduka et al., 2018; Nwoko and Ukiwe, 2016) through the provision of nitrogen, phosphorus (Ogboi *et al*., 2010), iron, potassium (Osman *et al*., 2020), organic carbon, organic matter and exchangeable cations such as Mg^{2+}, Ca^{2+}, K^{+} and Na^{+} (Ogboi *et al*., 2010; Uroko, 2014). This can only be achieved through the application of proper treatments that will neutralise its acidity (Nwoko and Ukiwe, 2016). POME that is densely contaminated with metals and high BOD may not fit agricultural uses (Ezeomedo and Ogbogu, 2022).

The finding of Osman *et al*. (2020) revealed the potential of POME in facilitating the growth of elephant grass used in the phytoremediation of contaminated soil. Okolie *et al*. (2020) reported that the application of POME at 8000l/ha enrich soil with essential nutrient and prevent root-knot nematode in cowpea. In another finding, Okolie *et al*. (2019) also reported that POME significantly improves soil chemical properties and reduces weed contamination in cowpea fields. Maize grown in soil altered by POME show better germination rate, height, leaf area, tasselling rate and yield (Ogboi *et al*., 2010).

The Potentials of POME in Soil Amendment

POME can be used as a cheap source of exogenous hydrocarbon-degrading bacteria for the amendment of contaminated soil in crude oil-polluted areas (Nwankwegu *et al*., 2016). Egobueze *et al*. (2019) investigates the ability of PO processing solid wastes in the amendment of crude oil-contaminated soil, their findings revealed the potential of the waste in recovering soil qualities and enhancing maize yield. . In a similar finding, Amechi and Felix (2019) found that POME is capable of degrading 51% of CO in crude oil contaminated soils. Their finding further discovered the promising efficiency of POME in nutrient recovery after the amendment.

Various microorganisms isolated from POME and POME dumpsites show excellent oil degradation capabilities. The findings of Ani (2020) revealed the potential of mixed microbial culture isolates from POME in degrading crude petrol spillage. Ayinla *et al*. (2017) identified a fungus with higher extracellular lipase production from POME-contaminated soil, the discovered *Rhizopus oryzae* ZAC3 (NCBI accession No: KX035094) recommended for biotechnological and industrial applications including bioremediation of oil contaminated sites. *Pseudomonas aeruginosa* isolated from palm oil processing industries produces lipase with high lipolytic activities that can be used in the biodegradation of wastes rich in fat and oil (Ibiyemi *et al*., 2022). *Escherichia fergosonii*, *Klebsiella Variicola* and *Micrococcus luteus* isolated from POME show excellent hydrocarbon biodegrading ability in crude petrol-contaminated soil (Nwankwegu *et al*., 2016).

Biomolecule production

The finding of Hope and Gideon (2015) revealed how bio-surfactant can be produced from POME through microbial activities. The bio-surfactant is recommended to be used as a replacement for synthetic surfactants used by oil and gas industries. This is an important milestone that will save the environment from both POME and synthetic surfactants hugely used in oil mining. POME can also be used as a substrate for the production of biogas. Research conducted by Imoke and Muma (2018) demonstrates how biogas with high methane content can be obtained from POME using a catalyst derived from fresh cow dung. Another benefit that can be drived from PO processing waste is the production of single-cell protein to be used as an ingredient in both food and feed. Izah (2018) was able to produce biomass with 27 % protein content and total essential amino acids of 40g/100g using POME as a fermentation stock.

The use of PO processing wastes in water treatment was also reported. Muhammed *et al*. (2017) demonstrate how a mixture of palm oil fuel ash and granite residual soil can be used in the removal of Zn, Pb, Mg, Cr and Fe from water and wastewater.

RECOMMENDATIONS

i. Production is mostly done in rural areas with poor and dilapidated roads. Construction of roads that will connect rural areas with markets will not only easier the transportation of PO to the major markets but will also cut transportation cost
ii. Effects of endogenous and intentional contaminants on the storability and nutritional qualities of PO should be studied since some researchers associated quality degradation with chemical contamination
iii. To curtail the environmental dangers, caused by raw POME in the palm oil processing areas and its environs, local palm oil millers should be guided on how to neutralise POME before discharging it into the environment. Elsewise can preferably be converted to useful by-products through bioprocessing
iv. The potentials of POME microbial isolate in breaking down crude petrol into environment-friendly compounds need to be explored, this will provide a cheap source for liberating the soil in the oil-producing states from awful contamination.
v. The quality of PO can be improved by adopting good handling and processing techniques, selecting good-quality raw materials and prevention of post process contamination
vi. The traditional handling and processing techniques need to be improved to ensure the production of good quality PO that can compete in the international market
vii. Anthropogenic sources of soil and water contamination need to be curbed and appropriate amendment methods need to be device to ensure the production of good-quality palm fruit with the lowest possible contamination.
viii. The provision of a good road network will ease access to rural communities and reduce raw materials and finished products transportation fare
ix. Research on the hydrocarbon-degrading ability of POME microbial isolates should be intensified, this will assist in finding a local solution to the disturbing soil degradation affecting many oil-producing localities
x. Production of biogas from PO processing wastes needs to be explored
xi. Local regulatory agencies need to pay more attention to the PO supply chain to curtail the frequent and habitual adulteration using various harmful chemicals

CONCLUSION

Concern authorities on food and environmental safety need to pay attention to the happenings along the supply chain of locally produced crude PO. The actors in the supply chain need to be cautioned on the dangers of their activities to the environment, PO quality and safety and more importantly the public health issue. There is a need for the local environmental protection agencies to support the implementation of various research discoveries on the possible utilisation of POME and its derivatives in the amendment of oil-contaminated soil. The utilisation of POME in soil enrichment and biomolecule production also needs to be explored by the relevant stakeholders in the public and private sectors.

REFERENCES

Abdul-Qadir, M. I., Okoruwa, V. O., and Olajide, A. O. (2016). Productivity of Oil Palm Production Systems in Edo and Kogi States, Nigeria: A Total Factor Productivity Approach. *International Journal of Advanced Science and Technology*, *97*, 37–44. https://doi.org/10.14257/ijast.2016.97.04

AbdullRani, S. N. N. (2015). *Prediction of Free Fatty Acid in Crude Palm Oil using Near Infrared Spectroscopy*. Universiti Teknologi Malaysia.

Abiodun, O. A., Tolulope, M. O., Femi, F. A., and Samuel, A. A. (2019). Assessment of Palm Oil Sold in Mainland Markets, Lagos State, Nigeria. *EC Nutrition*, *14*(3), 208–214.

Ado, A., Tukur, A. I., Ladan, M., Gumel, S. M., Muhammad, A. A., Habibu, S., and Koki, I. B. (2015). A Review on Industrial Effluents as Major Sources of Water Pollution in Nigeria. *Chemistry Journal*, *1*(5), 159–164.

Ahmed, A., and Wagini, N. H. (2018). Bacteriological Quality of Palm Oil Sold at Some Selected Markets within Katsina

Metropolis. *Katsina Journal of Natural and Applied Sciences*, *7*(2), 15–22.

Ajai, A. I., Adedokun, T. A., Inobeme, A., and Jacob, J. O. (2016). Determination of Physicochemical Properties of Selected Vegetable Oils in Minna. *FUW Trends in Science and Technology Journal*, *1*(2), 475–478.

Akanni, K. A. (2018). Effect of Quality Assurance Deficit on Market Competitiveness for Export Commodities and Household Income in Nigeria. *Applied Studies in Agribusiness and Commerce*, *12*(4), 103–108. https://doi.org/10.19041/apstract/2018/3-4/12

Akinola, S. A., Omafuvbe, B. O., Adeyemo, R. O., Ntulume, I., and Ailero, A. A. (2019). Effect of storage on the quality of processed palm oil collected from local milling points within Ile-Ife, Osun State, Nigeria. *Journal of Food Science and Technology*, *57*(3), 858–865. https://doi.org/10.1007/s13197-019-04117-6

Ako, P., and Anegbe, B. (2022). Total and Available Copper and Zinc in Soils Affected by Palm Oil Mill Effluent in Oghareki, Oghara Kingdom, Delta State, Nigeria. *Journal of Applied Science and Environmental Management*, *26*(6), 1049–1055.

Amadi, E., and Wogborama, N. (2016). Role of Vocational Technical Education on Capacity needs for Palm oil and Kernel marketers in rural dwellers of Niger Delta in Nigeria. *Current Studies in Comparative Education, Science and Technology*, *3*(1), 135–143.

Amechi, A. K., and Felix, E. (2019). Effects of process parameter on crude oil biodegradation of palm oil mill effluent using response surface optimization. *Journal of Chemical Health Risks*, *9*(2), 117–132. https://doi.org/10.22034/jchr.2019.664497

Andoh, S. S., Nuutinen, T., Mingle, C., and Roussey, M. (2019). Qualitative analysis of Sudan IV in edible palm oil. *Journal of the European Optical Society*, *15*(1), 1–5. https://doi.org/10.1186/s41476-019-0117-0

Andoh, S. S., Nyave, K., Asamoah, B., Kanyathare, B., Nuutinen, T., Mingle, C., Peiponen, K. E., and Roussey, M. (2020). Optical screening for presence of banned Sudan III and Sudan IV dyes in edible palm oils. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment*, *37*(7), 1049–1060. https://doi.org/10.1080/19440049.2020.1726500

Ani, K. A. (2020). Kinetics of crude oil degradation by an indigenous mixed culture isolated from palm oil mill effluent. *Indian Journal of Science and Technology*, *13*(15), 1555–1562. https://doi.org/10.17485/ijst/v13i15.171

Aphiar, A. E., and Raphael, N. I. (2019). Quality Assessment Of Physicochemical Properties Of Palm Oil From Different Palm Oil Mills In Isoko , Delta State. *International Journal of Innovative Research and Advanced Studies*, *6*(6), 31–35.

Ayinla, Z. A., Ademakinwa, A. N., and Agboola, F. K. (2017). Studies on the Optimization of Lipase Production by Rhizopus sp. ZAC3 Isolated from the Contaminated Soil of a Palm Oil Processing Shed. *Journal of Applied Biology and Biotechnology*, *5*(2), 30–37. https://doi.org/10.7324/jabb.2017.50205

Bamidele, J. (2015). Occupational hazards and their effect on the health and socio-economic status of local palm oil processors in delta state, Nigeria. *Annals of Agricultural and Environmental Medicine*, *22*(3), 483–487. https://doi.org/10.5604/12321966.1167719

Bello, R., Essien, B., and Jauro, M. (2015). Economic Potentials of Oil Palm Production and Machinery Use in UDI, Enugu State, Nigeria. *Science Journal of Business and Management*, *3*(5), 16–20. https://doi.org/10.11648/j.sjbm.s.2015030501.14

Chigbogu, M. P., Jonathan, E. I., Onyenankeya, E. I., and Ikechukwu, O. S. (2015). Evaluation of the Quality and Level of Adulteration of Palm Oil Obtained from Different Locations in Enugu Metropolis , Nigeria. *International Journal of Multidisciplinary Sciences and Engineering*, *6*(6), 23–26.

Chikwendu, M. U., and Ogbonna, A. N. (2019). Impact of Palm Oil Mill Effluent on the Soil in Upkom- Bende Forest Reserve, Abia State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, *10*(3), 55–61. https://www.ajol.info/index.php/jrfwe/article/view/186260

Chinakwe, E. C., and Ogbuagu, D. H. (2019). Microbial and Physicochemical Qualities of Edible Palm Oil Sold in Major Markets of South-Eastern Nigeria. *Journal of Agricultural Science and Food Technology*, *5*(6), 117–125. https://www.researchgate.net/profile/Dike_Ogbuagu/publication/335727735_Microbial_and_Physicochemical_Qualities_of_Edible_Palm_Oil_Sold_in_Major_Markets_of_South-Eastern_Nigeria/links/5d77eb344585151ee4adea1f/Microbial-and-Physicochemical-Qualities-of-Edi

Chuku, E. C., and Chuku, O. S. (2016). Fungi Associated with the Rancidity of Palm Oil. *Nigerian Journal of Mycology*, *8*, 122–130.

Constant, L.-L.-N. B., Ntsomboh-Ntsefong, G., Ngando-Ebongue, G. F., Ngalle-Bille, H., Nyouma, A., and Bell, J. M. (2017). A review of main factors affecting palm oil acidity within the smallholder oil palm (Elaeis guineensis Jacq.) sector in Cameroon. *African Journal of Food Science*, *11*(9), 296–301. https://doi.org/10.5897/ajfs2017.1611

Dada, E., Akinola, M., and Haruna, R. (2018). Physico-Chemical and Genotoxicity Assessments of Palm Oil Mill Effluent Generated by a Corporate Refinery In Nigeria. *Pollution*, *4*(1), 83–92. https://doi.org/10.22059/poll.2017.237168.293

Dhiman, A., Thakur, D., and Suhag, R. (2021). Influence of encapsulating materials on spray-dried palm oil-based powder. *The Pharma Innovation Journal*, *10*(1), 120–125.

Dikko, A. B., Alkasim, A., and Ahmed, A. D. (2015). The Effect of Impurity Concentration on Activation Energy Change of Palm Oil and a its Application to Identify an Adulterated Palm Oil. *IOSR Journal of Applied Physics*, *7*(1), 22–25. https://doi.org/10.9790/4861-07132225

Ebere, E. C., Wirnkor, V. A., Chinedu, E. E., and Ngozi, V. E. (2018). A Review on the Quality of Palm Oil (*Elaeis guineensis*) Produced Locally in Imo State, Nigeria. *Sustainable Food Production*, *4*, 40–50. https://doi.org/10.18052/www.scipress.com/sfp.4.40

Edward, J. B., Agunbiade, R. O., and Ayodele, A. P. (2017). Impact of Palm Oil Mill Effluent on River Awemu in Ijero-Ekiti. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, *11*(7), 53–56. https://doi.org/10.9790/2402-1107025356

Egobueze, F. E., Ayotamuno, J. M., Iwegbue, C. M. A., Eze, C., and Okparanma, R. N. (2019). Effects of organic amendment on some soil physicochemical characteristics and vegetative properties of Zea mays in wetland soils of the Niger Delta impacted with crude oil. *International Journal of Recycling of*

Organic Waste in Agriculture, *8*(s1), 423–435. https://doi.org/10.1007/s40093-019-00315-6

Ekpo, G. I., Eteng, O. E., Ukeme, E., Ekwu, M., Bassey, S., and Uboh, F. (2022). Evaluation of Public-Health Risk of Heavy Metals Contaminants and Physicochemical Parameters in Adulteration Palm Oil Commonly Consumed in Calabar, Nigeria. *Journal of Applied Sciences and Environmental Management*, *26*(2), 307–314. https://doi.org/10.4314/jasem.v26i2.19

Enyoh, C. E., Ihionu, E. A., Verla, A. W., and Ebosie, P. N. (2017). Physicochemical Parameter of Palm Oil and Soil from Ihube Community, Okigwe, Imo State Nigeria. *International Letters of Natural Sciences*, *62*, 35–43. https://doi.org/10.18052/www.scipress.com/ilns.62.35

Enyoh, E. C., Enyoh, C. E., and Amaobi, C. E. (2017). Quality Assessment of Palm Oil from Different Palm Oil Local Factories in Imo State, Nigeria. *World Scientific News*, *88*(2), 152–167. www.worldscientificnews.com

Ezeomedo, I. C., and Ogbogu, N. V. (2022). Oil Palm Industries and Its Environmental Influence in Akpo, South-Eastern Nigeria. *International Journal of Research and Innovation in Social Science*, *VI*(IX), 819–825. https://doi.org/10.47772/IJRISS/819-825

Ezirim, C. Y., Chikezie, P. C., Iheanacho, K. M., and Nwachukwu, N. R. (2017). Comparative Activities of Soil Enzymes from Polluted Sites in Egbema, Imo State, Nigeria. *Journal of Pollution Effects and Control*, *5*(2), 1–7. https://doi.org/10.4172/2375-4397.1000185

Filusi, O. J., Ayinde, J. O., Oladimeji, F. V., and Olorunshola, E. O. (2022). Youth Involvement in Entrepreneurial Activities Along Oil Palm Fruit Processing Value Chain-a Call To Skill Development and Livelihood Sustenance in Nigeria. *Food and Agribusiness Management*, *3*(2), 55–58. https://doi.org/10.26480/fabm.02.2022.55.58

George, T., Rufus, E., and Alex, Z. C. (2017). Artificial neural network based ultrasonic sensor system for detection of adulteration in edible oil. *Journal of Engineering Science and Technology*, *12*(6), 1568–1579.

Gourichon, H. (2013). Analysis of incentives and disincentives for palm oi in Nigera. In *Food and Agriculture Organization: Monitoring African Food and Agricultural Policies*.

Hope, N., and Gideon, A. (2015). Biosurfactant production from Palm Oil Mill Effluent (POME) for applications as oil field chemical in Nigeria. *Society of Petroleum Engineers - SPE Nigeria Annual International Conference and Exhibition, NAICE 2015*, *2013*. https://doi.org/10.2118/178315-ms

Ibiyemi, M. F., Julius, O. O., Oluwatobi, F. B., and Arotupin, D. J. (2022). Optimization, Purification and Characterization of Lipase by Pseudomonas aeruginosa Isolated from Palm Oil Processing Cottage Industries in Ekiti State, Nigeria. *Asian Journal of Biotechnology and Bioresource Technology*, *8*(1), 12–25. https://doi.org/10.9734/ajb2t/2022/v8i130116

Idoko, O., Emmanuel, S. A., Obigwa, P. A., and Fadeyi, A. E. (2018). Physicochemical and Antioxidant Properties of Palm Oil Samples obtained from Kwali Area Council, Abuja, Nigeria. *Journal of Chemical Society of Nigeria*, *43*(4), 779–782.

Imo, E. O., and Ihejirika, C. E. (2021). Microbial load and biodegradation of palm oil mill effluent (POME) by microorganisms at different stages of discharge. *EQA-International Journal of Environmental Quality*, *44*, 9–17. https://doi.org/10.6092/issn.2281-4485/11667

Imoke, E. D., and Muma, C. B. (2018). Estimation of Biogas Production from Anaerobic Digestion of Palm Oil Mill Effluent (Pome) in Real Oil Mills Palm Plantation, Odukpani L.G.A., Nigeria. *African Journal of Environment and Natural Science Research*, *1*(1), 24–32. https://doi.org/10.1088/1751-8113/44/8/085201

Izah, S. C. (2018). Feed potentials of Saccharomyces cerevisiae biomass cultivated in palm oil and cassava mill effluents. *Journal of Bacteriology and Mycology: Open Access*, *6*(5), 287–293. https://doi.org/10.15406/jbmoa.2018.06.00220

Izah, S. C., Angaye, T. C., and Ohimain, E. I. (2016). Environmental Impacts of Oil Palm Processing in Nigeria. *Biotechnological Research*, *2*(3), 132–141. http://www.ecotrendsalliance.org/assets/files/Environmental-impacts-oil-palm-kalangala.pdf

Izah, S. C., and Ohimain, E. I. (2016a). Review Microbiological quality of palm oil used in Nigeria : Health impacts perspective. *Point Journal of Botany and Microbiology Research*, *2*(1), 37–45.

Izah, S. C., and Ohimain, E. I. (2016b). The opportunities and weakness of Nigerian oil palm industry. *Biotechnological Research*, *2*(1), 33–43.

Jagaba, A. H., Kutty, S. R. M., Hayder, G., Latiff, A. A. A., Aziz, N. A. A., Umaru, I., Ghaleb, A. A. S., Abubakar, S., Lawal, I. M., and Nasara, M. A. (2020). Sustainable use of natural and chemical coagulants for contaminants removal from palm oil mill effluent: A comparative analysis. *Ain Shams Engineering Journal*, *11*(4), 951–960. https://doi.org/10.1016/j.asej.2020.01.018

Jolayemi, O. S., Ajatta, M. A., and Adegeye, A. A. (2018). Geographical discrimination of palm oils (Elaeis guineensis) using quality characteristics and UV-visible spectroscopy. *Food Science and Nutrition*, *6*(4), 773–782. https://doi.org/10.1002/fsn3.614

Kenechi, N., Felix, A., Linus, C., and Kayode, A. (2017). Analysis on the Physicochemical Properties of Palm Oil Within Isialangwa Local Government Area of Abia State , Nigeria. *International Journal of Bioorganic Chemistry*, *2*(3), 159–162. https://doi.org/10.11648/j.ijbc.20170203.22

Lim, K., Pan, K., Yu, Z., and Xiao, R. H. (2020). Pattern recognition based on machine learning identifies oil adulteration and edible oil mixtures. *Nature Communications*, *11*(1). https://doi.org/10.1038/s41467-020-19137-6

Lim, S. Y., Mutalib, M. S. A., Khaza'ai, H., and Chang, S. K. (2018). Detection of fresh palm oil adulteration with recycled cooking oil using fatty acid composition and ftir spectral analysis. *International Journal of Food Properties*, *21*(1), 2428–2451. https://doi.org/10.1080/10942912.2018.1522332

MacArthur, R. L., Teye, E., and Darkwa, S. (2020). Predicting adulteration of Palm oil with Sudan IV dye using shortwave handheld spectroscopy and comparative analysis of models. *Vibrational Spectroscopy*, *110*(103129), 1–6. https://doi.org/10.1016/j.vibspec.2020.103129

Muhammed, A. S., Kundiri, A. M., Daud, N. N. N., and Muhammad, I. S. (2017). Sorption Characteristics of Contaminants in Compacted Granite Residual Soil - Palm Oil Fuel Ash Mixture. *Nigerian Journal of Engineering Science and Technology Research*, *3*(1), 70–75.

NAFDAC. (2020). *Fats and Oils Regulations*.

Ndidi, N., Tamuno-boma, O., Udiomine Brantley, A., and Tamunomiebam Emmanuel, I. (2020). Toxicological Effects of Sudan III Azo Dye in Palm Oil on Liver Enzyme and Non Enzyme Markers of Albino Rat. *International Journal of Nutrition and Food Sciences*, *9*(4), 104–111. https://doi.org/10.11648/j.ijnfs.20200904.12

Ngangjoh, A. S., Tatanja, N. A., and Ejoh, A. R. (2020). Spoilage and microbial quality of crude palm oil from the North-west Region of Cameroon. *African Journal of Food Science*, *14*(9), 304–312. https://doi.org/10.5897/ajfs2020.1993

Nmaduka, N. J., Obioma, N. U., Victor, A. C., Chukwudi, O. C., and Juliet, O. C. (2018). Impact of Palm Oil Mill Effluent (POME) Contamination on Soil Enzyme Activities and Physicochemical Properties. *Research Journal of Environmental Toxicology*, *12*(1), 34–41. https://doi.org/10.3923/rjet.2018.34.41

Nnaji, J., Okoye, J., and Omotugba, S. (2016). Soil quality in the vicinity of palm oil mills in Umuahia, Nigeria. *International Research Journal of Chemistry and Chemical Sciences*, *3*(1), 29–32.

Nwabanne, J. T., Oguegbu, O. O., and Agu, C. M. (2018). Removal of Solids from Palm Oil Mill Effluent and Paint Wastewater Using Electrocoagulation Technique. *International Journal of Electrochemistry*, *2018*, 1–9. https://doi.org/10.1155/2018/4349639

Nwachoko, N., and Fortune, R. (2019). Toxicological effect of Sudan III Azo Dye in Palm Oil on Kidney Parameters of Albino Rats. *Worl Jounal of Pharmaceutical and Medical Research*, *5*(5), 5–11.

Nwachukwu, I. N., Amadi, E. S., Ogwo, U. C., Umeh, S. I., Opurum, C. C., Chinakwe, E. C., Nwaogwugu, N. U., Ochiagha, I. E., Ogbuagu, H. D., and Ujowundu, F. N. (2019). Molecular Screening of Fungal Isolates of Palm Oil from South Eastern Nigeria for Aflatoxin and Ochratoxin Biosynthetic Genes Using Multiplex Polymerase Chain Reaction (mPCR). *Microbiology Research Journal International*, *28*(5), 1–9. https://doi.org/10.9734/mrji/2019/v28i530142

Nwankwegu, A. S., Ikpe, E. M., Chukwura, E. I., Irondi, R. C., and Obika, E. I. (2016). Ex Situ Biodegradation of Crude Oil Using Bacterial Isolates From Palm Oil Mill Effluent. *American Journal of Life Sciences*, *4*(3), 71–73. https://doi.org/10.11648/j.ajls.20160403.11

Nwoko, C. I. A., and Ukiwe, L. N. (2016). Physicochemical characteristics of soils treated with palm oil mill effluent in three localities in Imo State, Nigeria. *Pure and Applied Chemical Sciences*, *4*(1), 1–8. https://doi.org/10.12988/pacs.2016.5127

Obire, O., and Hakam, I. O. (2015). Evaluation of the Microbiological Quality of Palm Fruits in the Various Stages of Palm Oil Production. *Current Studies in Comparative Education, Science and Technology*, *2*, 313–323.

Odoh, C. K., Amapu, T. Y., Orjiakor, I. P., Martins, P. E., Seibai, B. T., Akpi, U. K., Ugwu, C. S., Lerum, N. I., and Nwankwegu, A. S. (2017). Assessment of mold contamination and physicochemical properties of crude palm oil sold in Jos, Nigeria. *Food Science and Nutrition*, *5*(2), 310–316. https://doi.org/10.1002/fsn3.393

Ogboi, E., Kperegbeyi, J. I., Nmor, E. I., and Odeh, H. O. (2010). The performance of maize (Zea mays) in soil contaminated with palm oil mill effluent (POME) in South, South Central Nigeria. *African Journal of General Agriculture*, *6*(1), 19–24.

Ogundare, F. O., Adekola, F. M., and Oladosu, I. A. (2019). Compositions and photon mass attenuation coefficients of diesel, kerosene, palm and groundnut oils. *Fuel*, *255*, 115697. https://doi.org/10.1016/j.fuel.2019.115697

Ohimain, E. I., and Izah, S. C. (2015). Physicochemical Characteristics and Microbial Population of Palm Oil Sold in Major Markets in Yenagoa Metropolis , Bayelsa States , Nigeria. *Journal of Environmental Treatment Techniques*, *3*(3), 143–147.

Okogeri, O., and Uchenna-Onu, U. (2016). Changes occurring in quality indices during storage of adulterated red palm oil. *International Journal of Food Science and Nutrition*, *1*(3), 1–5. http://www.foodsciencejournal.com

Okolie, H., Ekwuribe, C., Obidiebube, E., and Obasi, C. (2020). Impact of palm oil mill effluent (POME) on the populations of rhizobium and meloidogyne species in Awka, Nigeria. *Global Journal of Agricultural Sciences*, *19*(1), 27–32. https://doi.org/10.4314/gjass.v19i1.4

Okolie, H., Ekwuribe, E., Obasi, C., Obidiebube, E., and Obasi, S. (2019). Evaluation of Palm Oil Mill Effluent (POME) Impact on Soil Chemical Properties and Weed Cover in Awka–Rain Forest Zone of Nigeria. *Canadian Journal of Agriculture and Crops*, *4*(2), 93–100. https://doi.org/10.20448/803.4.2.93.100

Olafisoye, O. B., Fatoki, O. S., Oguntibeju, O. O., and Osibote, O. A. (2020). Accumulation and risk assessment of metals in palm oil cultivated on contaminated oil palm plantation soils. *Toxicology Reports*, *7*, 324–334. https://doi.org/10.1016/j.toxrep.2020.01.016

Olafisoye, O. B., Oguntibeju, O. O., and Osibote, O. A. (2017). Trace elements and radionuclides in palm oil, soil, water, and leaves from oil palm plantations: A review. *Critical Reviews in Food Science and Nutrition*, *57*(7), 1295–1315. https://doi.org/10.1080/10408398.2014.886032

Oluwatusin, F. M. (2017). Performance Analysis of Technical Palm Oil Marketing in Ondo and Ekiti States Nigeria. *Researcher*, *9*(2), 9–16. https://doi.org/10.7537/marsrsj090217.03.Key

Omotoso, A. E., Igbinaduwa, P., and Barifa, A. M. (2018). Quality assessment of crude palm oil available in Benin-city, Nigeria. *European Journal of Advanced Research in Biological and Life Sciences*, *6*(1), 39–47.

Omozemoje, A. A., Ovuru, K. F., and Izah, S. C. (2017). Evaluation of Selected Heavy Metals in Palm Oil Sold in Some Markets in Yenagoa Metropolis. *EC Nutrition*, *11*(6), 244–252.

Onu, S. E., Ekwe, K. C., Aguaguiyi, F. N., and Ufomba, V. U. (2022). Comparative Analysis of Use of Traditional and Modern Methods of Palm Oil Processing Among Rural Farmers in Abia State, Nigeria. *Journal of Community and Communication Research*, *7*(1), 96–103.

Oparaocha, E. T., Akawi, J. A., Eteike, P., and Joakim, N. (2019). Effects of Palm Oil Colorant on the Hepatic Functions of Albino Rats. *ACTA Scientific Nutritional Health*, *3*(4), 41–44.

Osman, N. A., Ujang, F. A., Roslan, A. M., Ibrahim, M. F., and Hassan, M. A. (2020). The effect of Palm Oil Mill Effluent Final Discharge on the Characteristics of Pennisetum purpureum. *Scientific Reports*, *10*(1), 1–10. https://doi.org/10.1038/s41598-020-62815-0

Oti, J. A. (2021). Awareness and Use of Food Adulterants among Food Vendors and Market Women in the Northern Part of Ghana. *European Journal of Nutrition and Food Safety*, *13*(2), 79–94. https://doi.org/10.9734/ejnfs/2021/v13i230378

Rafiu, O. R., Azibaola, K. I., Jackson, G., and Kola, K. A. (2022). Assessment of proximate and physicochemical properties of crude palm oil from south-west and South-south Nigeria. *African Journal of Pure and Applied Chemistry*, *16*(2), 40–56. https://doi.org/10.5897/ajpac2022.0890

Raphael, O., John, O. O., and Sandra, U. I. (2017). Trace Metal Contamination of Some Edible Oils Consumed in Benue and Taraba States of Nigeria. *American Journal of Food, Nutrition and Health*, *2*(4), 20–25.

Rohman, A., and Man, Y. B. C. (2009). Monitoring ofvirgin coconut oil (VCO) adulteration with palm oil using Fourier transform infrared spectroscopy. *Journal of Food Lipids*, *16*(4), 618–628. https://doi.org/10.1111/j.1745-4522.2009.01170.x

Rohman, A., and Man, Y. B. C. (2010). Fourier transform infrared (FTIR) spectroscopy for analysis of extra virgin olive oil adulterated with palm oil. *Food Research International*, *43*, 886–892. https://doi.org/10.1016/j.foodres.2009.12.006

Rohman, A., and Man, Y. B. C. (2011). Palm oil analysis in adulterated sesame oil using chromatography and FTIR spectroscopy. *European Journal of Lipid Science and Technology*, *113*(4), 522–527. https://doi.org/10.1002/ejlt.201000369

Sam, C. E., and Nenman, D. V. (2019). The Effects of Four Local Additives on Some Physico- Chemical Properties of Palm Oil Obtained from Jos Metropolis, Plateau State, Nigeria. *Proceedings of the 5th Postgraduate Colloquium for Environmental Research*, 48–49.

Samuel, E., Salisu, S., Abdulraheed, A., Babai, M., and Sule, H. R. (2020). Variations on the Physiochemical , Microbiological and Selected Heavy Metals of Different Palm Oil Samples Sourced from Galadima , Tarauni , Sabon-Gari , Yan-Kura of Kano State and Samples from Kogi and Edo States of Nigeria. *Chemistry Research Journal*, *5*(6), 189–194.

Samuel, E., Salisu, S., Yahaya, U. B., Danlandi, I. Y., and Sule, H. R. (2018). Comparative studies on the quality of palm oil samples collected from different markets (Galadima, Sabon Gari and Singa) of Kano State, Nigeria West Africa. *International Journal of Chemistry and Chemical Processes*, *4*(2), 2545 – 5265.

Shehu, S., Salleh, M. A., and Syahadat, E. F. (2021). the Challenges Facing Palm Oil Industry in Nigeria. *Asian People Journal (APJ)*, *4*(1), 26–33. https://doi.org/10.37231/apj.2021.4.1.201

Suseela, L., and Muralidhar, P. (2018). Reduction of organic load from palm oil mill effluent (POME) using selected fungal strains isolated from POME dump sites. *African Journal of Biotechnology*, *17*(36), 1138–1145. https://doi.org/10.5897/ajb2016.15821

Tomaszewska-Gras, J. (2016). Rapid quantitative determination of butter adulteration with palm oil using the DSC technique. *Food Control*, *60*, 629–635. https://doi.org/10.1016/j.foodcont.2015.09.001

Ubani, C. S., Onwuneme, C., Okpashi, V. E., Osuji, A. C., and Nwadike, U. G. E. M. (2017). Palm Oil Mill Effluent Effect on Soil Fertility: a Longitudinal Assessment of Zea Mays Plant. *EQA – Environmental Quality*, *23*, 43–53. https://doi.org/10.6092/issn.2281-4485/7135

Urhibo, F. A. (2022). Factors Influencing Linkages in Oil Palm Innovation System in Delta and Edo States, Nigeria. *African Journal of Sustainable Agricultural Development*, *3*(1), 63–72.

Uroko, R. I. (2014). *Impact of Fresh and Fermented Palm Oil Mill Effluents on Soil Physico-Chemical Parameters and Enzyme Activities in Umuaka, Njaba, Imo State of Nigeria*. University of Nigeria, Nsukka.

Yuguda, A. U., Jalam, A. M., Ibrahim, H. G., Sadiq, L. S., Garba, M., and Natu, B. S. (2021). Assessment of Water Quality in Relation to Palm Oil Mill Effluent Discharge, Ogele Stream, Ogbadibo, Benue State, Nigeria. *African Journal of Environment and Natural Science Research*, *4*(1), 45–52.