Original Article

WM&R

Waste Management & Research
2018, Vol. 36(3) 236–246

DOI: 10.1177/0734242X17751848
journals.sagepub.com/home/wmr
SAGE

Evaluating oil palm fresh fruit bunch processing in Nigeria

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Abstract

Three routes of oil palm fresh fruit bunch (FFB) processing in Nigeria namely, industrial, small-scale and traditional were compared by means of determining fruit losses associated with each route. The fruits that are not recovered after each process were hand-picked and quantified in terms of crude palm oil (CPO), palm kernel (PK), mesocarp fibre (MF) and palm kernel shell (PKS). The energy value of empty fruit bunch (EFB), MF and PKS were used to determine the value of energy lost for each route. Additionally, the environmental implications of disposal of EFB were estimated, and socio-economics of the industrial and small-scale routes were related. The analysis showed that 29, 18, 75 and 27 kg of CPO, PK, MF and PKS were lost for every 1000 kg of FFB processed with the industrial route, whereas 5.6, 3.2, 1.4 and 5.1 g were lost with the small-scale route, respectively. Approximately 89 kWh and 31 kWh more energy were lost from MF and PKS with the industrial route than the other two routes, respectively. An equivalent of 6670 tonnes carbon dioxide equivalent of methane and nitrogen oxide was released due to the disposal of 29,000 tonnes of EFB from one palm oil mill. The monetary value of lost CPO per 1000 kg of FFB processed in the industrial route is more than the labour cost of processing 1000 kg of FFB in the small-scale route. The advantages of the industrial route are high throughput in terms of FFB processed per hour and high quality of CPO; however, high fruit loss is associated with it and therefore, the poorly threshed EFB is recommended to be fed into the small-scale route.

Keywords

Fresh fruit bunch, oil palm processing, empty fruit bunch, mesocarp fibre, palm kernel shell, crude palm oil

Received 17th July 2017, accepted 6th December 2017 by Editor in Chief P Agamuthu.

Introduction

Oil palm (*Elaeis guineensis*) is generally believed to originate from West Africa. Oil palm produces fruits in bunches known as fresh fruit bunch (FFB). An oil palm tree produces more than 8–12 bunches per year, each weighing up to 13 kg (Evbuomwan et al., 2013; Jagustyn et al., 2013). A bunch contains about 800–1000 fruits (Jagustyn et al., 2013). Nigerian farmers grow the Dura (thick shell), Tenera (thin shell), and Pisifera (shell-less or very thin shell) varieties (Izah et al., 2016a). Oil palm produces more oil per hectare of land than any other known oil crop (Evbuomwan et al., 2013; Ohimain et al., 2013).

Nigeria played a leading role in palm oil production and export contributing 43% of global palm oil production (Thomas et al., 2011) but at present produces 1.5% of the world's consumption (Izah et al., 2016a), though it still produces more than half of Africa's total palm oil production (Gourichon, 2013). Indonesia and Malaysia are the largest producers of palm oil from the oil palm tree in the world (Zainal et al., 2017), and Nigeria is the fifth largest producer after Thailand and Colombia (FAOSTAT, 2017). Global palm oil production in 2014 has been estimated to be 57 million tonnes according to FAOSTAT (2017).

The main products of the oil palm industry are crude palm oil (CPO) and palm kernel (PK), which yields another type of oil known as palm kernel oil (PKO), and residue known as palm kernel cake (PKC). The wastes generated from processing FFB are known as FFB wastes. The solid wastes include empty fruit bunch (EFB), mesocarp fibre (MF) and palm kernel shell (PKS), which represent important biomass in the oil palm industry (Kabir et al., 2017). Another important waste of the industry is palm oil mill effluent (POME), which comprises all the liquid wastes generated in the palm oil mills. As the demand for palm oil increases, FFB wastes generation will also follow a similar trend.

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Figure 1. (a) sterilized FFB from industrial route; (b) part of the facilities of industrial route; (c) quartered FFB from small-scale route; (d) part of the facility of the small-scale route; (e) bunch stalk, empty fruit spikelet and fruits from traditional route; and (f) wooden mortar from traditional route use in fruit digestion.

For every 1 kg of palm oil produced, 1.3 kg of FFB solid wastes were produced (Sulaiman et al., 2011); therefore, the total FFB solid wastes produced in 2014 was 75 million tonnes. This is equivalent to 7.9 million tonnes of CPO, 4.7 million tonnes of PK, 20.9 million tonnes of MF, 7.5 million tonnes of PKS and 22.8 million tonnes of EFB produced globally in 2014, respectively. Izah et al. (2016b) reported that Nigeria produced about 0.93 million tonnes of palm oil in 2013, which is equivalent to 1.3, 1.1 and 0.5 million tonnes of EFB, MF and PKS, respectively.

Most palm oil producing nations in Africa are known for their traditional techniques in FFB processing compared to the world's leading producers – Indonesia and Malaysia. Izah et al. (2016b) reported three scales of FFB processing in Nigeria: smallholder; semi-mechanized; and mechanized mills. However, Ohimain and Izah (2014) and Zu et al. (2012) classified FFB processing into small-scale and large-scale (industrial) mills, and added that the large-scale mill is between 20 and 23% while the small-scale mill is between 77 and 80% of FFB production in Nigeria. The Ohimain and Izah (2014) and Zu et al. (2012) reports suggested that the smallholder and semi-mechanized from the Izah et al. (2016a) report can be described as small-scale due to the low level of production while the mechanized mill according to Izah et al. (2016b) is the large-scale mill. However, in terms of how the fruits are separated (threshed) from the bunch, FFB processing routes (technology) in Nigeria are better classified into industrial (large-scale or mechanized mill), small-scale (semi-mechanized mill) and traditional (subsistence or smallholder) routes. The industrial route is characterized by the use of large-scale facilities, high throughput (FFB processed per hour), and high-quality palm oil in terms of low free fatty acids (FFA). The FFB is sterilized using steam with fruits still attached to it while threshing of the fruits is carried out afterwards (Ohimain and Izah, 2014). The small-scale route utilizes lower technology than the industrial route (Ohimain and Izah, 2014) but more than the traditional route (Izah et al., 2016b). It is tedious, time consuming and the FFB is usually first quartered to allow for quicker fermentation (Zu et al., 2012). Fermentation makes the removal of the fruit easier, which is one of the functions of sterilization of the fruits in the industrial scale. The traditional route is employed by families using manual labour and rudimentary equipment (Izah et al., 2016b) to

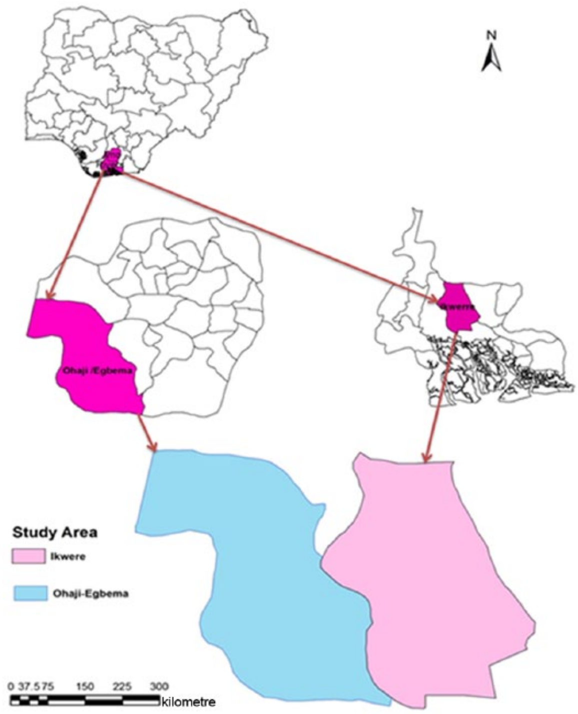

Figure 2. Map of Nigeria's regions showing the area of interest in the two states of Imo (Ohaji/Egbema) and Rivers (Ikwerre).

process FFB for the palm oil consumed by the individual families; the excess palm oil is usually sold and therefore of very low throughput. An FFB comprises a stalk known as bunch stalk (BS) and fresh fruit spikelet (FFS), which holds the fruits. The FFB in the traditional route is usually first separated into BS and FFS (Nafu et al., 2015) to allow for quick fermentation. Ohimain and Izah (2014) reported that the industrial route uses the wet milling method, while the small-scale and traditional routes uses the dry milling method resulting to dry EFB (quartered EFB or bunch stalk/spikelet). Wet milling involves the use of hot water in oil extraction while in dry milling the oil is extracted under pressure (mechanical press). Figure 1(a) and (b), (c) and (d), and (e) and (f) are from the industrial, small-scale, and traditional routes, respectively.

The industrial route is known to have increased productivity as well as improved quality of palm oil giving the ability of processors to process fruits the same day they are harvested, hence the high production capacity of Indonesia and Malaysia. However, there are challenges associated with the industrial route regarding utilization of the EFB, which include low bulk density, and the high moisture content (60–70%): according to Aziz et al. (2017) that will require an enormous amount of energy to dry and reduce its size to fit into most existing boilers.

Nyakuma et al. (2014) reported that the calorific value of MF and PKS could be improved by reducing the moisture contents, which also applies to EFB. Aziz et al. (2017) demonstrated an increase in efficiency of power generation through EFB gasification from 11.2 to 24.6% as the gasification temperature increased from 800 to 1000^{o}C. Kabir et al. (2017) reported 48% bio-oil yield and 23 MJkg^{-1} higher heating value during MF pyrolysis. On his own, Lee et al. (2017) demonstrated an increase in higher heating values of EFB and PKS biochar to 26.2 MJkg^{-1} and 27.5 MJkg^{-1} from the corresponding values of the raw fuel of 19.7 MJkg^{-1} and 19.7 MJkg^{-1}, respectively. Shahbaz et al. (2017) investigated the gasification of PKS and found a maximum syngas production of 61.9% at a temperature of 692^{o}C and particle size of approximately 0.8 mm. However, there is limited evidence on how the processing of FFB affects the quality of EFB as fuel, and the study of the three processing routes in terms of CPO, PK, MF and PKS yield.

Therefore, the objectives of this study are to: (a) determine how FFB processing routes affect fruit losses; (b) determine environmental and socio-economic implications of the different processing routes on EFB utilization as fuel; and (c) make recommendations on reducing fruit and EFB losses from FFB processing.

Materials and methods

Data collection

Two palm oil mills (industrial routes), each 60 tonnes/hr^{-1} and 30 tonnes/hr^{-1} mills, respectively, and one small-scale mill (Ohaji, Imo State) of about 0.6 tonnes/hr^{-1} (small-scale route), which are in the South-Eastern region of Nigeria (Figure 2) were visited in 2015 and 2016. The two mills (Ikwere, Rivers State and Ohaji, Imo State) on the industrial routes are the largest and only mills of 30 tonnes/hr^{-1} and above within 100 square kilometres of any of the two locations. The traditional route is used more widely in other parts of Imo State. Currently, the 60 tonnes/hr^{-1} mill gets its supply of FFB from the surrounding areas in addition to harvest

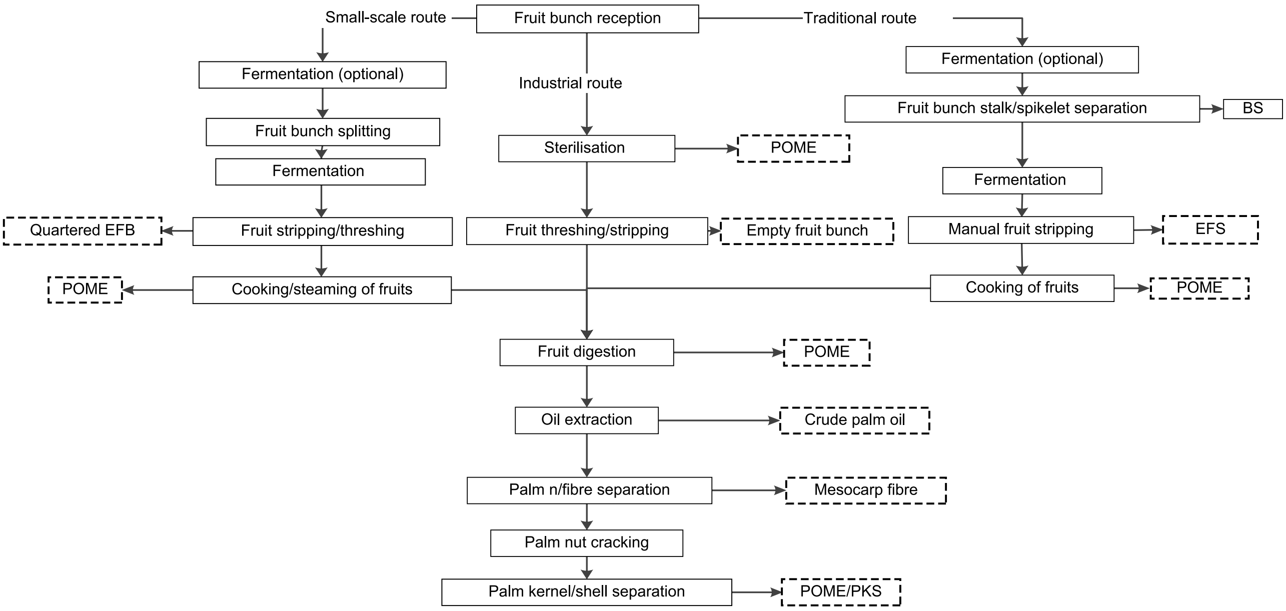

Figure 3. Flow chart of industrial, small-scale and traditional routes of fresh fruit bunch processing showing points of generation of waste.
Notes: solid box = process; dashed box = waste/output; EFB = empty fruit bunch; POME = palm oil mill effluent; BS = bunch stalk; EFS = empty fruit spikelet; and PKS = palm kernel shell.

from their plantations and was used in the analysis for fruit losses. Therefore, the palm oil and wastes from the area are a mixture of the three varieties of oil palm (Dura, Pisifera and Tenera), which are available within the study area. The assumption is that any sample from the area of study is a representative sample. The basic processes for all the routes include: sterilization; stripping; fruit digestion; oil extraction; and oil clarification (Figure 3).

These three processing routes of FFB were investigated at each of the mills to determine fruits losses associated with the three routes. On each day of data collection for the industrial route, FFB were randomly weighed before and after sterilization. Sterilized FFB threshed in the industrial thresher were randomly weighed and each of them manually threshed to recover the fruits left after the mechanical threshing. The lost fruits (not recovered by the processors) were weighed and recorded.

In the small-scale route, the FFB were weighed after reception in the mill and later quartered. After four days when the fruits have become detachable from the FFS, the quartered FFB were threshed using hammer. The fruits (lost) left with the threshed quartered FFB were picked manually. The lost fruits and empty quartered bunch were weighed and recorded. In the traditional route, the FFB were weighed before the separation of EFB into BS and FFS. After four days, the fruits were manually removed from the FFS. Fruits (lost) left with the FFS were carefully picked and weighed. The measurement was carried out using Camry Emperors weighing balance. The unstripped fruits left by the processors with the fruit bunch/spikelet are considered lost because there is no system to recover them without losing CPO, MF, PKS and PK derivable from the fruits, which are important products. Comparisons were made to determine the significance of the lost fruits for each processing route using analysis of variance carried out using Statistica 12 software (Dell, USA).

Air-dried samples of EFB, MF and PKS sourced from the small-scale mill visited in South- Eastern Nigeria were taken to Cranfield University, United Kingdom, and were stored at room temperature in sealed containers for 6 months. The oil palm trees are 9–29 years old. The EFB, MF and PKS were later taken to Marchwood Scientific Services (external laboratory), Southampton, United Kingdom, for the determination of the heating values according to British Standards Institute (2011) using the Parr Adiabatic bomb calorimeter model 6100. Similar analysis was carried out a year after for the determination of higher heating values of EFB, MF and PKS from the three routes at Cranfield University using Bomb Calorimeter (Parr 6400). The bulk densities of EFB, MF and PKS, were measured as received from the 60 tonnes/hr^{-1} small-scale mill using a 0.018 m^3 cylindrical container (0.261 m diameter and 0.332 m height) for PKS and MF, and a 0.146 m^3 cylindrical container (0.499 m diameter and 0.741 m height) for EFB. The bulk densities of quartered EFB, MF and PKS, BS and empty fruit spikelet from small-scale and traditional routes were also determined.

Losses of different processing routes

The fruits left with EFB/spikelet after FFB processing for each of the processing routes were weighed and quantified as lost products (CPO, PK, MF and PKS). The values were multiplied accordingly with the percentage of processed FFB for each of CPO (10.9%), MF (28.1%), PK (6.3%) and PKS (10%) as reported by Ohimain et al. (2013), which is the only report in the area of study detailing material-mass balance of FFB. The

Table 1. Total weight of fresh fruit bunch (FFB) and total weight of fruits (TWF) from industrial (I), small-scale (S) and traditional (T) routes of FFB processing.

Day number	Number of FFB weighed			Total weight of FFB (kg)			TWF (kg)		
	I	S	T	I	S	T	I	S	T
1	11	27	6	129.1100	236.2500	52.7500	25.6000	0.0096	0.0001
2	12	35	11	189.1500	318.9200	93.5000	42.8000	0.0056	0.0018
3	11	21	6	137.4000	168.0800	50.4300	34.9000	0.0101	0.0011
4	11	18	15	113.5000	180.7200	121.6800	26.8000	0.0144	0.0072
5	14	40	6	190.0300	240.5800	54.0300	56.3000	0.0064	0.0009
6	17	20	10	199.3300	180.3400	90.0800	58.2000	0.0160	0.0014
7	14	28	8	164.4800	263.2300	60.7300	41.5000	0.0134	0.0026
8	13	42	10	137.2000	294.5600	85.8000	47.4000	0.0134	0.0032
9	12	33	15	117.0500	297.7800	119.3500	26.9000	0.0158	0.0048
10	15	20	4	170.5000	178.8500	40.7300	55.2000	0.0086	0.0023
Total	130	284	91	1547.7400	2359.3100	769.0600	415.6000	0.1133	0.0254

average values of CPO, MF, PK and PKS in kg not recovered (lost) were calculated for every 1000 kg of FFB processed for each of the processing routes. This was done by dividing the product of 1000 and the quantity of CPO, PK, MF and PKS lost with the total weight of FFB in each case.

Energy losses associated with each processing route

The kWh generated per unit of fuel (EFB, MF and PKS) was calculated by dividing the fuel heat content (1.055 kJ/physical unit) with the heat rate (kJkWh^{-1}) (Energy Information Administration, 2012) where 1.055 is the conversion factor from Btu to kJ. The value of 15825 kJkWh^{-1} was used as representative heat rate for biomass (Mayhead, 2010) and with the lower heating values (LHV) of EFB, MF and PKS, the values of EFB, MF and PKS for 1 kg of fuel were estimated in kilowatt-hour (kWh). The energy values lost were estimated by multiplying the lost value of EFB, MF and PKS with the kWh value, respectively.

Economic analysis

The economic analysis was carried out for the small-scale route with emphasis on the labour cost and value of CPO. The different tasks in the processing of FFB in the small-scale route are divided into: (a) quartering of the FFB; (b) dusting and loading of fruits, which have fallen off during the quartering operation into the cooking drum; (c) threshing of the quartered FFB, dusting and loading of the fruits into the cooking drum; (d) water supply and cooking operation; (e) fruit digestion/oil extraction (pressing); and (f) mesocarp fibre/palm nut separation. Dusting is the process of removing the chaff, which is attached to the base of the fruit. The total costs as calculated were only the costs of labour for each of the tasks by people whose job it is to carry out these activities for the mill owners in the area of study. The labour cost of processing FFB in the small-scale route is measured by filling the barrel with fruits. The barrel is the name of the drum used in cooking the fruit. A barrel on average is filled by 125 FFB.

Results and discussion

FFB losses

The total weight of fruits (TWF) from industrial, small-scale and traditional routes of FFB processing are presented in Table 1, while the average values of CPO, MF, PK and PKS in kg lost for every 1000 kg of FFB processed are presented in Table 2. The detail calculations are presented in supplementary Table A-1–Table A-3 . The CPO, PK, MF and PKS lost in the industrial route are significantly higher ($p < 0.05$) than in the small-scale and traditional routes (Table 3). Results showed on the average that 28.9 kg of CPO, 16.7 kg of PK, 74.6 kg of MF and 26.5 kg of PKS were lost for every 1000 kg of FFB processed in the industrial route while 0.0056 kg, 0.0032 kg, 0.0140 kg and 0.0051 kg were lost in small-scale routes, respectively. The smallest losses of 0.0034 kg of CPO, 0.0020 kg of PK, 0.0087 kg of MF and 0.0031 kg of PKS were obtained in the traditional route. These represent almost 100% more CPO, PK, MF and PKS are lost in the industrial route than the small-scale and traditional routes for every 1000 kg FFB processed, respectively. The losses with the small-scale and traditional routes for every 1000kg of FFB processed were very small and insignificant making them quite efficient in ensuring the fruits are recovered from the FFB.

Under the industrial route, the FFB are sterilized the same day they are harvested while for the small-scale and traditional routes, the FFB can stay for a few days that subsequently enables the fruits to loosen from the spikelet. Nevertheless, the longer the fruits are allowed to stay before sterilization, the more the activity of lipase in the mesocarp of the fruit, which leads to increase in FFA content in the palm oil (Vincent et al., 2014). The FFA level is an important quality indicator of palm oil (Saad et al., 2007). It is used to measure both quality of palm oil for food consumption and non-food uses (Hayyan et al., 2013). Overall,

Table 2. Crude palm oil (CPO), palm kernel (PK), palm kernel shell (PKS) and mesocarp fibre (MF) lost for every 1000 kg of fresh fruit bunch processed for the industrial (I), small-scale (S) and traditional (T) routes.

Day number	CPO (kg)			PK (kg)			PKS (kg)			MF (kg)		
	I	S	T	I	S	T	I	S	T	I	S	T
1	21.6100	0.0041	0.0002	12.4900	0.0026	0.0001	19.8300	0.0041	0.0002	55.7200	0.0110	0.0005
2	24.6600	0.0019	0.0021	14.2600	0.0011	0.0012	22.6300	0.0018	0.0019	63.5800	0.0049	0.0054
3	27.6900	0.0066	0.0024	16.0000	0.0038	0.0014	25.4000	0.0060	0.0022	71.3700	0.0170	0.0061
4	25.7400	0.0087	0.0064	14.8800	0.0050	0.0037	23.6100	0.0080	0.0059	66.3500	0.0220	0.0170
5	32.2900	0.0029	0.0018	18.6700	0.0017	0.0010	29.6300	0.0027	0.0017	83.2500	0.0075	0.0047
6	31.8300	0.0097	0.0017	18.4000	0.0056	0.0010	29.2000	0.0089	0.0016	82.0500	0.0250	0.0044
7	27.5000	0.0006	0.0047	15.9000	0.0032	0.0027	25.2300	0.0050	0.0043	70.9000	0.0140	0.0120
8	37.6600	0.0050	0.0041	21.7700	0.0029	0.0023	34.5500	0.0045	0.0037	97.0800	0.0130	0.0100
9	25.0500	0.0058	0.0044	14.4800	0.0033	0.0025	22.9800	0.0053	0.0040	64.5800	0.0150	0.0110
10	35.2900	0.0052	0.0062	20.4000	0.0030	0.0036	32.3800	0.0048	0.0056	90.9700	0.0140	0.0160
Average	28.9300	0.0006	0.0034	16.7300	0.0032	0.0020	26.5400	0.0051	0.0031	74.5900	0.0140	0.0087

Table 3. Mean (± standard error) of the crude palm oil (CPO), palm kernel, palm kernel shell and mesocarp fibre lost for every 1000 kg of fresh fruit bunch processed in the industrial, small-scale and traditional routes for 10 days of measurement. In each column, values with same letters are not significantly different at 5% Duncan multiple range test.

Route	CPO (kg)	Palm kernel (kg)	Palm kernel shell (kg)	Mesocarp fibre (kg)
Industrial	28.9300±1.6200a	16.7300±0.9400a	26.5400±1.4900a	74.5900±4.1800a
Small-scale	0.0056±0.0008b	0.0032±0.0004b	0.0051±0.0007b	0.0140±0.0019b
Traditional	0.0034±0.0007b	0.0020±0.0004b	0.0031±0.0006b	0.0087±0.0017b

low grade CPO has FFA more than 5% (Hayyan et al., 2013). Fresh ripe fruit without any bruises has FFA of less than 0.3% (Vincent et al., 2014). The factors responsible for increased FFA in oil palm fruits include: bruises; time lapse after bruising; and activity of lipase enzyme in the mesocarp, which increases with time (Vincent et al., 2014). Cooking of palm fruits as carried out by the small-scale and traditional routes, and sterilization by the industrial route, respectively provide the needed heat to inactivate the lipase enzymes, soften the fruits, and break the oil-bearing cells to release oil. The heat also makes it easier for the fruits to be detached from the spikelet (industrial route), loosen the attachment between the palm nut and the mesocarp, and between the shell and the palm kernel. Therefore, immediate sterilization after harvesting of the FFB in the industrial processing route offers the best quality oil in processing FFB. As a standard, CPO from large-scale mills (industrial route) have FFA less than 5% (Vincent et al., 2014; Zu et al., 2012). However, sterilization of the entire FFB is responsible for the high moisture content of EFB.

In addition, another interesting operation is splitting the FFB into quarters, and into FFS and BS for small-scale and traditional routes, respectively. The size reduction makes it easier for BS and spikelet from the traditional route (Figure 4(a)), and the quartered bunches from small-scale route (Figure 4(b)) to dry faster under an ambient temperature condition and these can easily be used as fuel. Sterilized EFB (Figure 4(c)) from the industrial route with considerable quantity of oil takes a longer time to dry unless an enormous amount of energy is invested. Additionally, the fruit attached to EFB, which is more in the industrial route, limits its utilization. The volume generated at any time in the industrial route, and availability of PKS and MF limits the use of EFB as fuel. However, the use of EFB for fuel generation remains an energy option for increased power generation, and it is being encouraged in Malaysia (Nasrin et al., 2010).

Energy losses

The LHV of the EFB, MF and PKS were determined as 14499, 17846 and 17336 kJkg^{-1} at the external laboratory, respectively. The heating values of EFB, MF and PKS determined at Cranfield University for the three routes are presented in Table 4. The higher heating values of EFB was the lowest, followed by that of PKS for the industrial route. A similar pattern repeated itself for the small-scale and traditional routes. The FFB varieties processed in the study area are similar, which explains the similarity in the heating values. Expectedly, the bulk density of EFB was lower than that of MF, and PKS for the three routes (Table 4). However, the bulk densities of BS, and fruit spikelet and the combination of the two were higher than the corresponding value for MF. This is attributed to the relatively good packing with the BS and fruit spikelet compared to MF, which supports the importance of size reduction. The values of MF and PKS lost for each processing route was estimated in kWh using 1.19 kWh and 1.16 kWh as energy value for every 1 kg each of MF and PKS, respectively. Therefore, 89 kWh of energy value was lost from MF and 31 kWh of energy was lost from PKS with the industrial route. An insignificant 0.02 and 0.01 kWh energy values from MF, approximately 0.01 kWh, and less than 0.01 kWh

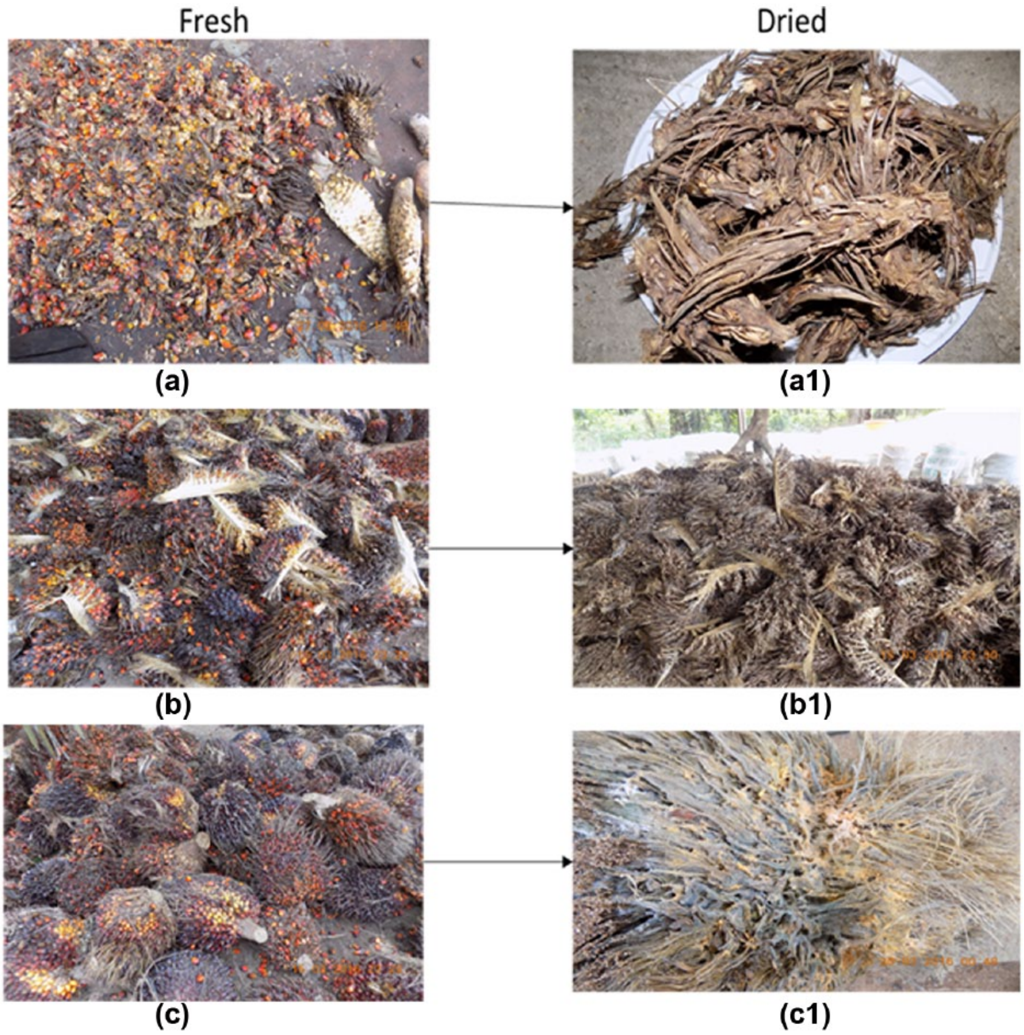

Figure 4. (a) Fresh fruit spikelets and bunch stalk of fresh fruit bunch separated in the traditional route, (a-1) natural drying empty fruit spikelets; (b) fresh quartered empty fruit bunch from a small-scale route in Nigeria, (b-1) natural drying empty quartered fresh fruit bunch; and (c) fresh fruit bunch, (c-1) natural drying empty fruit bunch processed from an industrial route in Nigeria.

Table 4. Bulk density and high heating value (as received) of empty fruit bunch, mesocarp fibre and palm kernel shell from industrial, small-scale and traditional routes.

Parameter	Bulk density (kgm^{-3})	High heating value (kJkg^{-1})
	Industrial route	
Palm kernel shell	715	18316
Mesocarp fibre	225	19331
Empty fruit bunch	144	15742
	Small-scale route	
Palm kernel shell	705	18645
Mesocarp fibre	219	19846
Quartered empty fruit bunch	132	15302
	Traditional route	
Palm kernel shell	701	18381
Mesocarp fibre	213	19606
Bunch stalk	268	
Fruit spikelet	282	
Bunch stalk/fruit spikelet	224	15911

Table 5. Data on production for 2014 of one of the palm oil mills in South Eastern Nigeria (approximate values). This mill has a capacity to process 60 tonnes of fresh fruit bunch per hour.

Parameter	Estimated quantity produced, kt	Estimated quantity lost, kt	Estimated Value produced in GWh	Estimated value lost in GWh
EFB	29.0	29.0	28.2	28.2
*¥CPO	10.3	0.3	-	-
*PK	6.0	0.1	-	-
MF	26.7	2.0	31.7	0.3
PKS	9.5	0.3	11.0	2.4
Total	81.5	31.7	70.9	30.9

Notes: empty fruit bunch (EFB); crude palm oil (CPO); palm kernel (PK); mesocarp (MF); and palm kernel shell (PKS).

energy values from PKS were lost for the small-scale and traditional routes, respectively. The details calculations of energy values for MF and PKS are presented in supplementary Table A-4 and Table A-5, respectively, and the procedure explained further in Table A-6.

From the calculations shown in Table 5, the energy loss with the industrial route is huge. Data from one of the palm oil mills (industrial route – 60 tonnes/hr^{-1} mill) visited in 2015 showed that about 95 kt of FFB was processed in 2014. From Table 5, the value of EFB produced was estimated at 29 kt. The total energy resources produced in 2014 in the mill was estimated at 70.9 GWh of which 30.9 GWh was lost through the poor processing of FFB. The World Bank report on electrical power consumption in Nigeria in 2014 was 142 kWh per capita compared to the corresponding figures of the United States of America (12088 kWh), and the United Kingdom (5407 kWh). From Table 5 the total lost biomass from a single industrial mill in Nigeria in 2014 per capita, considering a population of 167 million people (Ohimain, 2014) was 0.185 kWh in its energy value. The lost energy value is huge and would have been enough to power 3 million homes (10,000 MWh per million homes). Electricity consumption and steam demand for the production of 1 kg of palm oil according to Sulaiman et al. (2011), which are approximately 0.1 kWh and 2.5 kg, respectively can be met by burning 0.3–0.4 kg oil palm wastes. Therefore, over 29 kt of EFB deposited in the plantation could be used to produce approximately 73 kt of palm oil.

Environmental impact

The industrial route leads to the generation of more POME, which constitutes an environmental hazard, and requires high-energy and cost to process and dispose of POME from the small-scale and traditional routes are minimal and manageable. The bulk of the POME is from the water used in the sterilization of FFB in the industrial route, the hot water used in oil extraction, and most importantly due to the amount of FFB processed per hour. Chan et al. (2010) reported that 5–7.5 tonnes of water is required for a tonne of CPO production and over 50% of the water will result in POME in the large-scale mill (industrial route). On the other hand, Ohimain et al. (2013) demonstrated that the processing of FFB in the small-scale route led to the production of 3.4–12.1% of water (POME), while Ohimain and Izah (2014) reported 60–70% POME from processing a tonne of FFB in the industrial route. Sterilization of FFB is responsible for the the high moisture content of EFB, increased POME generation, and consequently poor utilization of EFB for energy purposes.

The disposal of POME poses a serious environmental threat with release of greenhouse gas (methane) and nutrients into surface and underground water (Verla et al., 2014; Wu et al., 2010). According to Elbersen et al. (2013), poor decomposition of EFB leads to the release of methane and nitrogen oxide up to 0.23 tonne carbon-dioxide equivalent per tonne of FFB processed. This is equivalent to the release of 6670 tonnes carbon-dioxide equivalent of methane and nitrogen oxide from the 29 kt of EFB disposed of in one of the industrial mills as shown in Table 5. This value equals 0.2% of the United States of America's greenhouse gas emission from wastes composting in 2014 and 2015 (United States Environmental Protection Agency, 2017).

Positive changes towards improving the quality of EFB from the industrial route will involve the use of less water, and therefore a low amount of POME will be generated. Tan et al. (2009) investigated the drying of fruits in place of sterilization and demonstrated that the lack of water from sterilization inhibits the action of lipase enzyme responsible for high FFA. Sukaribin and Khalid (2009) reported on the effectiveness of sterilization of oil palm FFB using microwave technology aimed at reducing oil loss and stripping efficiency. Similarly, Cheng et al. (2011) observed that using microwave for FFB processing improved the quality of CPO.

In some countries, incineration of EFB is forbidden because of smoke pollution (Nieves et al., 2011), which is largely due to the high moisture content of EFB from the industrial route. Though, EFB dumped in the plantations over time decays and adds nutrient to the soil, it is usually applied in excess at the same location (Claoston et al., 2014), especially in combination with the ash from the boilers, which follows the same disposal route. In Nigeria with low power production, using EFB for energy purposes is a promising option. Igwe et al. (2010) reported that the treatment of EFB would involve mechanically dewatering and de-oiling, and possible size reduction.

Table 6. Cost estimation of labour for the small-scale route. All units in N except where stated otherwise.

Operation	Cost per barrel (N)
Quartering of FFB	1250 (N10 per FFB)
Dusting and loading of fruits threshed during quartering	900
Threshing of FFB, dusting and loading	2000
Providing water for cooking and the cooking operation	500
Fruit digestion and oil extraction (pressing)	1200
Mesocarp fibre and palm nut separation	1000
Total cost of processing a barrel	5950
Cost per FFB	47.60
Average weight of a FFB	8.90 kg
Average weight of 125 FFB	1112.50 kg
Cost of processing 1000 kg of FFB	5348
Average weight of lost CPO from processing 1000 kg of FFB in the industrial route	28.90 kg
Cost of 20 kg of CPO	5320
Cost of 28.93 kg of CPO (same as quantity lost by processing 1000 kg of FFB in the industrial route)	7695.40

Notes: crude palm oil (CPO); and fresh fruit bunch (FFB).

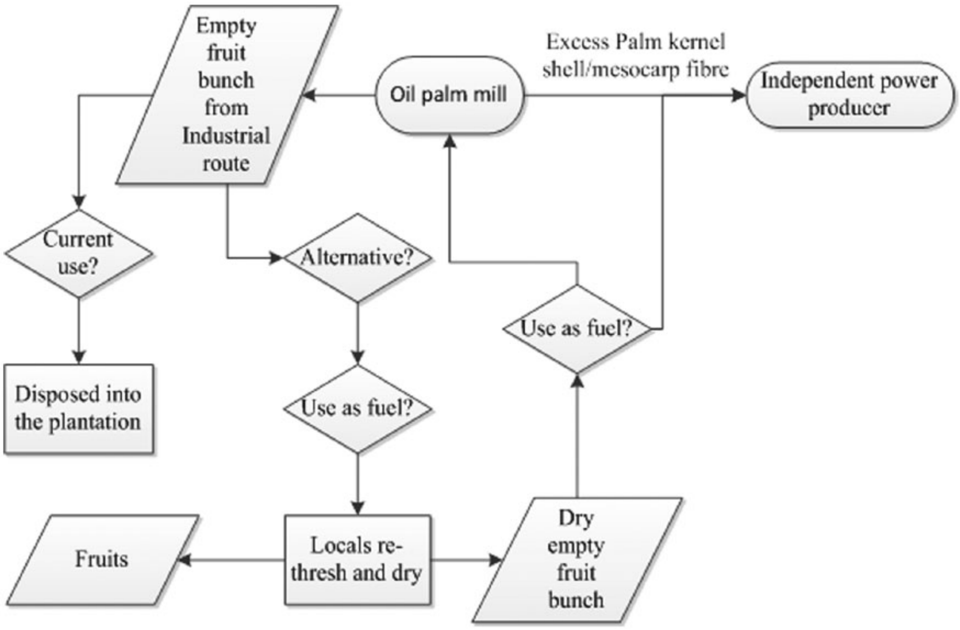

Figure 5. Process model for increased utilization of empty fruit bunch and a catalyst for economic activity and power generation in Southern Nigeria.

Socio-economic impact

The cost of processing FFB in the small-scale route was compared with the value of lost CPO in the industrial route in order to estimate the possibility of reducing the losses associated with the industrial route. Table 6 summarizes the cost estimate of processing FFB in the small-scale route. Labour cost for processing 125 FFB is N5950 Nigeria Naira, which is equivalent to \$21 (\$1 = N282 (Central Bank of Nigeria, 2016). At an average weight of 8.9 kg of a FFB, the labour cost of processing 1000 kg is N5348 (\$19). In terms of benefit, the value of 20 kg of oil is N5320 (\$19). Therefore, 28.93 kg of oil lost per 1000 kg of FFB processed from the industrial route is N7695 (\$27). The value (\$27) of lost CPO per 1000 kg of FFB in the industrial route can offset the cost (\$19) of processing 1000 kg of FFB in the small-scale route. This represents a significant amount of money in terms of employment and economic value at the local communities where FFB are processed. The small-scale and traditional routes of processing FFB discourage high productivity and quality CPO as it were. Obviously, the industrial route offers more opportunities in employment and wealth generation because of the amount of FFB that can be processed per hour of operation. A balance between the benefits associated with the current industrial route and the losses is very important in the context of the increasing demand for utilization of biomass in energy production.

The small-scale and traditional routes are less wasteful but the palm oil from the industrial route is of higher standard because the fruits are processed faster and in a shorter time frame between harvest and sterilization. It can take a few hours to process the fruits in the industrial route but a minimum of 4 days to process the fruits in the small-scale and traditional routes. The lower grade EFB from the industrial route makes available a waste that can only be disposed of in the oil palm plantation because of its poor quality as energy resource, and therefore this limits its value. In the small-scale level, EFB produced is used as fuel, which represents an economic benefit at that level.

Although, sterilization and stripping of fruits are important steps in FFB processing but contribute more to POME generation and the losses as the above study has shown, new approaches on sterilization and stripping of fruits are needed. This is important not only to process the fruits at a faster rate with high quality CPO as the industrial route can do, but also to increase the chances of threshing all the fruits from the FFB like the small-scale and traditional routes. Additionally, this will make it easier to use EFB as fuel in terms of low moisture content and high bulk density material, which could increase the transportation and utilization of EFB cost-efficiently beyond the point of generation.

Figure 5 is a process model for increased utilization of EFB and a catalyst for increased economic activity and power generation in Southern Nigeria where the FFB is processed. This will ensure recovery of all the fruits and drying of EFB for use as fuel by the locals who also supply FFB to industrial processors, thus creating a closed loop system. The abundance of fuel due to availability of EFB will create an opportunity for independent power producers, which can also be spinoffs for the palm oil mills.

Conclusions

The results of the analysis of losses due to FFB processing routes showed that more CPO, PK, MF, and PKS are lost for every 1000 kg of FFB processed with the industrial route than small-scale and traditional routes. The industrial route of FFB processing leads to higher energy losses, and methane and nitrogen oxide emission than the small-scale and traditional routes due to poorly processed EFB. In terms of the amount of FFB processed per hour, the industrial route is recommended; however, there is need to reduce the size of FFB prior to sterilization to ensure complete recovery of the fruits during the threshing operation. Additionally, the use of microwave instead of steam is highly recommended to reduce the moisture content of EFB. It is also recommended that threshed EFB from the industrial route be supplied to the local labourers for re-threshing and drying. The dried EFB will be sent back to the palm oil mills, and to independent power producers. Considering the lost energy value, the EFB is enough to power 3 million homes (10,000 MWh per million homes), neighbouring communities can be powered in this model. Finally, the utilization of EFB and POME together in compositing (co-composting) will reduce the effects of poor decomposition of EFB. The enactment of laws against disposal of EFB particularly will encourage efforts towards better ways of processing oil palm FFB.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship and/or publication of this article: The Tertiary Education Trust Fund (TETFUND), Nigeria and the Imo State Polytechnic Umuagwo, Ohaji Imo State, Nigeria.

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