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Palm Oil Mill Solid Waste Generation and Uses in Rural Area in Benin Republic: Retrospection and Future Outlook

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Abstract

Palm oil is one of the major oil crops in the world, producing important vegetable oils in the world oil and fats market. Its production generates solid wastes whose sustainable management is crucial for the oil chain development in oil palm producing countries. Benin Republic is a small oil palm producing country where oil palm plays social, cultural, and economic roles for farmers. This chapter analyzes the linkage between improvement of palm oil process extraction and palm oil mill solid waste (POMSW) management for sustainable palm oil production. Composed mainly of fibers, the two kinds of POMSW are empty fruit bunches (EFBs) and press mesocarp fibers (PMFs), which are rich in units' fertilizers and are renewable energy. POMSW in Benin Republic is used in agriculture, in cosmetic, or as energy. The upgrade of traditional mills generates POMSW use as a boiler fuel to reducing wood necessity and increasing farm profit. As this use is not sustainable, research must be made to generate electricity with POMSW and its use for crop fertilization, to ensure environment protection, enhance contribution to food security, restore degraded soils, and increase earnings of producers of rural areas.

Keywords: POMSW, improvement of palm oil process extraction, electricity, fertilization, rural area

1. Introduction

Within these last decades, with the population growth and food security, both developed and developing countries face many environmental challenges as waste management [1, 2]. Nowadays, the sustainable management of waste is a global issue, because of their permanent

increase and their harmful effects on the environment. According to Sotamenou and Kamgnia [3], wastes are produced during household, agricultural, industrial, and commercial activities. In Benin Republic, a new national waste strategy adopted in 2008, concerns mainly solid household wastes and market wastes [4]. Despite population bury and burn household wastes, the solid waste disposal rate is very low in cities and villages. The systems of collection, evacuation, and treatment being little operational and garbage are evacuated in the side streets and empty plots. The situation is worse in rural areas. The survey demographic and health, conducted in Benin in 2001, evaluated the garbage evacuation rate at 39% in urban and 3% in rural areas [5]. There is no specific national strategy to manage agricultural and industrial wastes in Benin. For agricultural wastes, farmers had to burnt them or return them to the field. Almost all research studies on waste management concern household wastes in urban areas [4, 6–8]. Industrial wastes are mostly come from food processing. Small-scale food industries are important in the rural areas because they generate employment; reduce rural-urban migration, and associated social problems. They are vital to reducing postharvest food losses and increasing food availability [9]. Food processing has traditionally been the domain of women. They had to produce little quantities and manage all wastes quantities. Nowadays, food processing had been improving by introduction of new technologies and engines. This is the case of palm oil production in Benin Republic. Oil palm is an oleaginous crop. It provides 39% of vegetable oil world production with 7% of oleaginous plantation areas compared with soybean (61%), colza (18%), and sunflower (14%) [10]. Benin Republic is a small oil palm producing country, where oil palm plays social, cultural, and economic roles for farmers. In 1848, palm oil gradually replaced slave trade. Oil palm through its products, the palm oil and “sodabi” (local palm wine), highly contributes to the income and social capital accumulation; this also discriminates operators and their households socially and economically. In Southern Benin, the more the oil palm acreage is wide, the more farmers are wealthy [11]. Oil palm is cultivated by many farmers and retailed to secure a decent retirement. They used this crop to affirm and secure their land. In addition, incomes from palm kernel sales help households to pay their children school fees. The local wine is used in festivities and ceremonies (weeding, mourning, receptions, etc.). This made the oil palm a serious component in populations’ culture where it is grown [12]. Moreover, during revitalization of this sector by the government and NGO, oil palm become as a cash crop that means “money symbol” and palm oil become a great interest for people in this production chain, who began to produce palm oil by themselves. These people improved the extraction method by introducing engines [13, 14]. According to the type of machine used for palm oil production in a partial or total process, they are categorized into four palm oil mill processes: traditional palm oil process (no machine use), small mechanized or improved palm oil process (integration of digester engine in the process), motorized or modern palm oil process (integration of digester and press engines in the process), and semi-industrial or mechanized palm oil processing (integration of large cookers, presses, digesters, sterilizers, clarifiers, and other facilities in the process) [15] (**Figure 1**). Despite of that, only 40% of national needs in vegetable oils were covered [16]. These improvements consequently increase palm oil mill wastes to an extent that some mills struggle to recycle all quantities produced. These wastes cause environmental nuisances. According to Ojonoma and Nnennaya [17], the sustainability of the palm oil

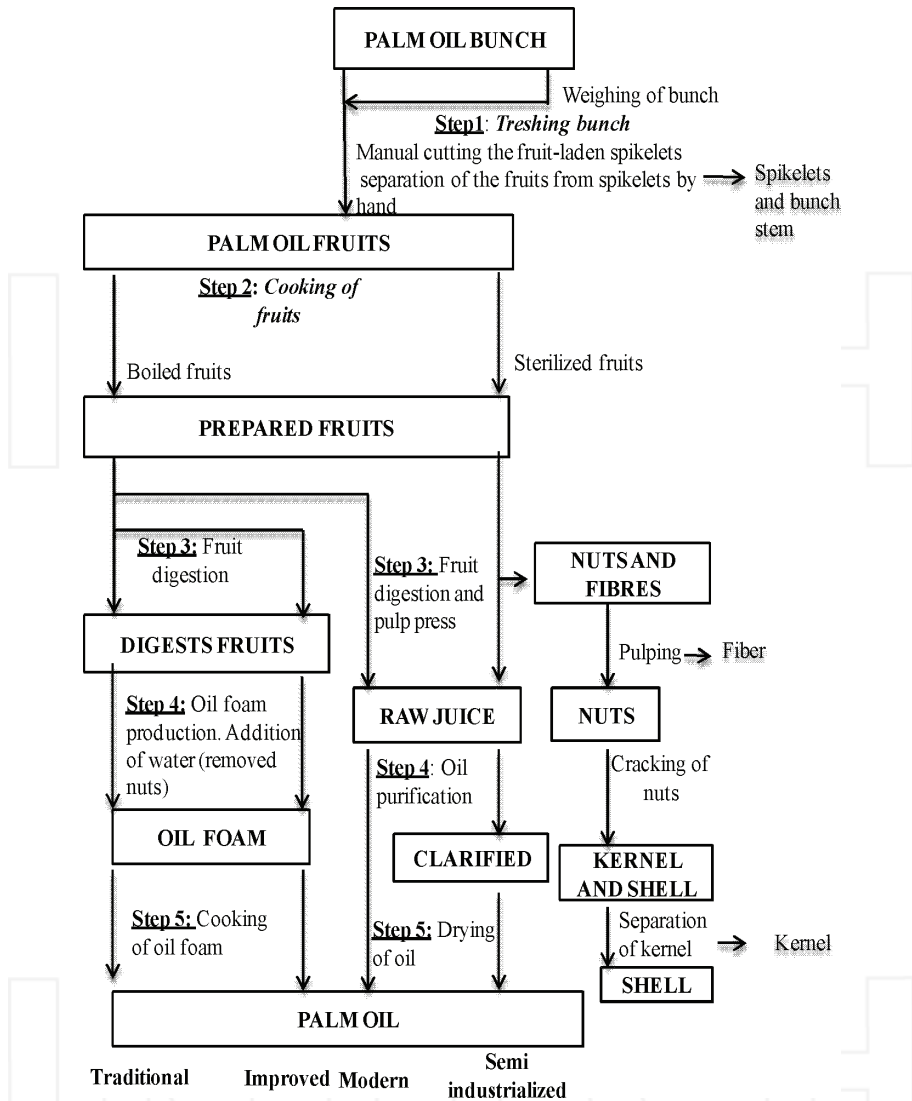


Figure 1. Types of palm oil processing [18].

sector is questioned in the majority of oil palm producing countries because of environmental harm due to the mismanagement of palm oil mill wastes. In Benin Republic, traditional palm oil mills had to use these wastes for many purposes. The present study analyzes the linkage between the improvement of palm oil process extraction and palm oil mill solid waste (POMSW) management for sustainable palm oil production in Benin Republic.

2. Methodology

The data were collected from (i) literature review on the characterization and uses of palm oil mill solid wastes in the world and (ii) research project fieldwork. An approach used for the research project fieldwork was based on the survey in the six departments of the Southern part of the Republic of Benin (**Figure 2**). This part of Benin Republic extends from the coast at 6°25' to 7°30' N latitude. It belongs to the Guinea-Congolese zone and submits to subequatorial with two rainy seasons (March–June and September–mid-November) and two dry seasons (July–September and November–March). The annual rainfall of this area, which varies between 1100 and 1400 mm, makes this part of the country adequate for oil palm production. The average daily temperature ranges from 25 to 29°C. The soils are in 66% (700,000 ha) deep lateritic soils of low fertility, and the rest are more fertile alluvial soils and heavy clay soils (360,000 ha) located in the river valleys of Mono, Couffo, Oueme, and in the Lama depression [19]. The survey was carried out from November 2011 to March 2012 and 335 palm oil mills were randomly surveyed using a semi-structure questionnaire. The collected data concerned the method of palm oil production, management of wastes produced, and management practices of waste quantities use (Did he use it? Did he sell it? Did he dump it? How did he use it?). The percentage usage (P_u) or proportion of interviewees who used palm oil mill wastes, the commercial value (CV) or proportion of mills who sell the wastes and rejection rate (RR) or proportion of mills who discard the wastes were calculated as follows:

$$P_u = \frac{N_{users}}{N} \quad (1)$$

where N_{users} is the number of informants who use a waste;

$$Cv = \frac{N_w}{N} \quad (2)$$

where N_w is the number of informants who sell wastes;

$$RR = \frac{N_r}{N} \quad (3)$$

where N_r is the number of informants who discard wastes; and N is the total number of informants.

All these parameters vary between 0 and 1.

Concerning POMSW nutrient composition analyses, samples were collected in one semi-industrial palm oil mill. The palm oil extraction process was followed three times and at each time, sample of 1 kg of each kind of wastes was randomly selected. All the samples were mixed and a sample of 500 g was taken. The analyses were performed with ion chromatography system Dionex ICS 1000. Nitrogen was determined by the Kjeldahl method.

Double principal component analysis (PCA) was performed using SAS software to explain the relation between palm oil mill categories and POMSW uses.

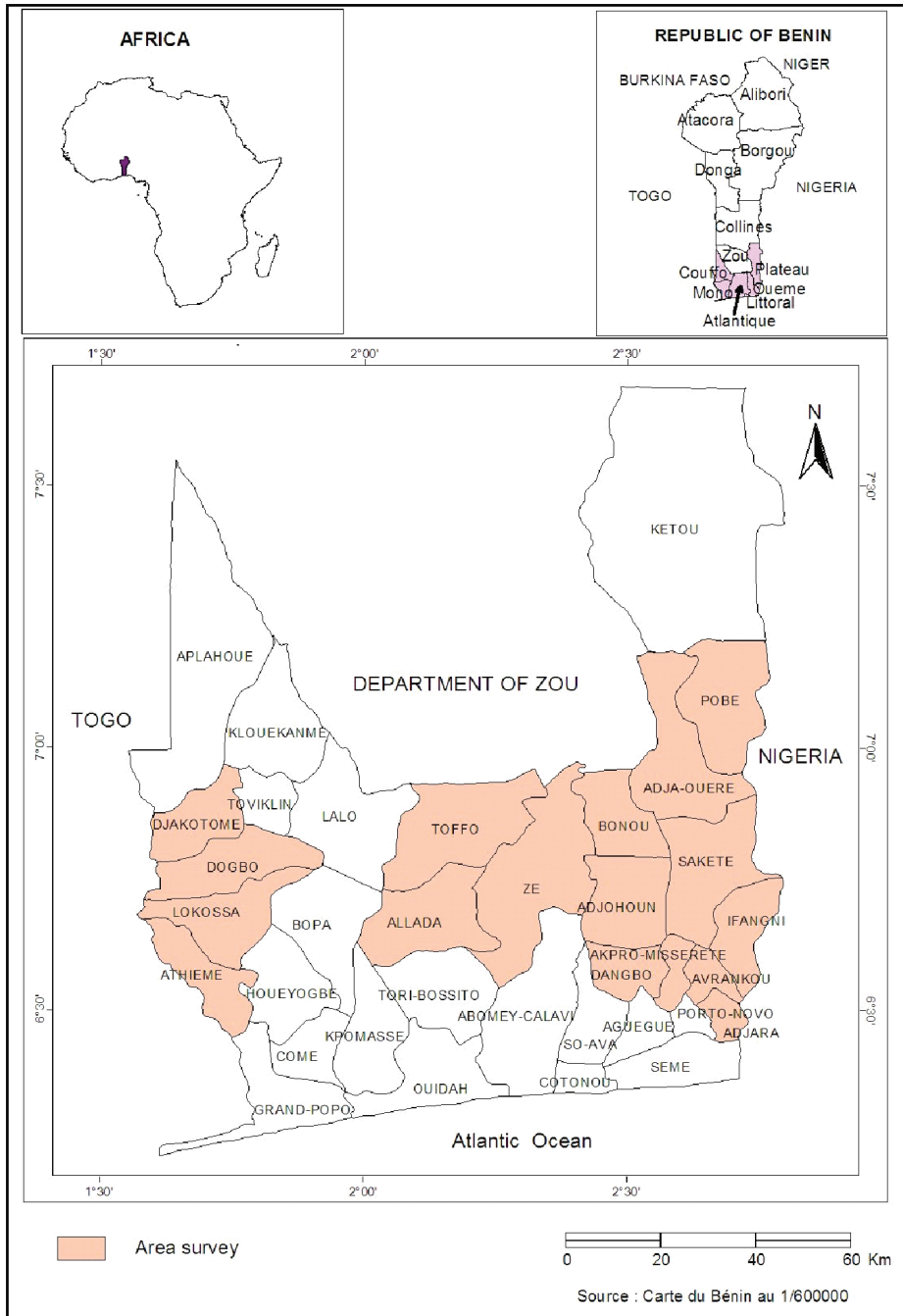


Figure 2. Study area.

3. Results and discussion

3.1. Types, chemical and mineral composition of POMSW

Palm oil mills generate two kind of solid wastes during palm oil fruits transformation: empty fruit bunches (EFBs) and palm mesocarp fiber (PMF) (**Figure 3**). EFB is obtained after the removal of oil seeds from fruit bunches. It is the supporting structures of the oil-bearing fruits in a bunch and comprises spikelet (68–80% dry matter) and stalks (20–32% dry matter) [20, 21]. PMF is the fibrous residues separated from the mesocarp and kernel during palm oil extraction [22]. POMSW is mainly composed of fibers. Spikelet contains more fibers than stalk. Fibers of spikelet are stronger than those of stalk. PMFs are richer in cellulose and lignin than EFB (**Table 1**).

The chemical and mechanical proprieties of these fibers vary with the type of waste. Fibers are the wastes that contain the most ammonium and nitrates. Stalks and spikelet contain low amount of phosphorus. All these wastes contained large amount of calcium (0.6–1.6%) and sulfur (0.2–0.7 mg/g). Fibers and stalks contain large amount of chloride (21.4 and 20.7 mg/g, respectively). The high amount of potassium and chloride can be explained by the fertilizer of oil palm in plantation with KCl.

3.2. Solid biomass from Benin oil palm processing mills in rural area

In Benin Republic, from 1 ton of fresh fruit bunch (FFB), any mill obtains 152.3 l of crude palm oil and generates an average 254.7 kg of EFB and 114.9 kg of PMF [15, 18]. Compare to the other oil palm producer countries (**Table 2**), there are no great differences on EFB obtained. However, mills from Benin produce more EFB than those from Indonesia and less PMF than those from Nigeria,

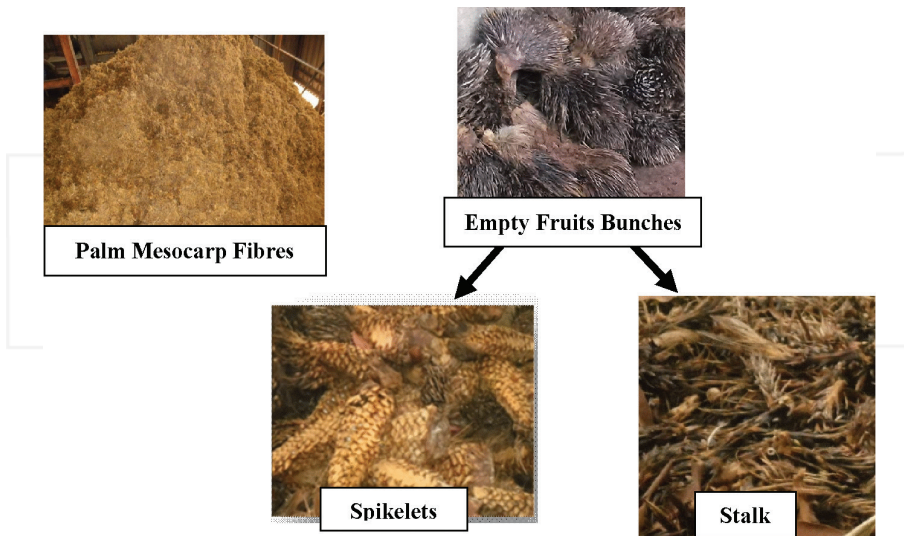


Figure 3. Palm oil mill solid wastes (POMSW). **Source:** Koura pictures.

Main fraction/ Parameters	EFB (literature) [20, 23–30]	Spikelet (study)	Spikelet (literature) [20, 32]	Stalk (study)	Stalk (literature) [31, 32]	PMF (study)	PMF (literature) [33]
C (%)	44.1–54.5	na	50.23–51.67	na	43.62–48.6		45.61
N (%)	0.44–1	0.95	0.5–0.96	1.2	0.7–071	1.4	1.36
C/N	58.9, 77.7	na	–	na	–	50.3	33.54
Lignin (%)	10.5–36.6	na	23.5–29.10	na	–	na	11–20.5
Cellulose (%)	33.7–63	na	20.6–20.7	na	26.9–28.8	na	14–39.9
Hemicellulose (%)	20.1–35.3	na	23.9–28.9	na	24–28.8	na	20.8–28.9
P (%)	0.03–0.7	0.001	0.05–0.19	0.001	0.07–0.3	0.17	–
K (%)	1.4–2.8	16.9	1.75–1.78	16.2	3.31–4.03	4.6	–
Ca (%)	0.16–0.9	0.9	2–2.41	0.6	0.09–0.31	1.5	–
Mg (%)	0.008–0.8	0.003	0.12–0.17	Traces	0.13–0.15	0.9	–
Na (%)	–	0.6	0.001–0.03	0.5	0.004–0.05	1.4	–
Cl ⁻ (mg/g)	–	4.7	–	21.4	–	20.68	–
SO ₄ ²⁻ (mg/g)	0.1–1.4	0.7	–	0.19	–	0.27	–

Table 1. Mineral and chemical composition of POMSW.

Malaysia, and Thailand. These differences can be explained by the variety of fruits used to produce oil. “Dura” variety possesses more shell than the kernel, while “Tenera” possesses more kernel than the shell [34] and the quantities of PMF produce by Dura are less than those from Tenera [35]. In Benin Republic, POMSW quantities vary with the oil extraction process (**Figure 4**).

The semi-industrialized process produced significantly more EFB and PFM than the traditional process. In fact, mills that extracted palm oil by semi-industrialized process used only Tenera fruit variety. Mills that use traditional method transform more Dura variety [18]. The other mills use the two seed varieties. POMSW quantity trends were similar to palm oil produced (**Figure 5**). From 1961 to 1968, 1980 to 1985 and 1991 to 1999, POMSW was relatively stable. After 1968 and 1985, POMSW drop in 1971 and 1997. A pic evolution of POMSW was obtained in 176 (78,600.8 tons of EFB and 35458,3 of PMF. After 1999, POMSW increased quickly from

Country	Benin	Indonesia	Indonesia	Mwalaysia	Nigeria	Thailand	Thailand
References	[15]	[36]	[37]	[38]	[35]	[39]	[40]
Varieties	–	Tenera	Tenera	Tenera	Dura	Tenera	Tenera
EFB (kg)	254.7	225	210	230–250	237–324	257–282	240
PMF (kg)	114.9	143	144	130–150	232–281	191–203	140
Palm oil (l)	152.3	218	235	160–200	94–128	260–282	–

Table 2. Palm oil wastes and crude palm oil quantities generated from 1 t of full fruit bunch in different country.

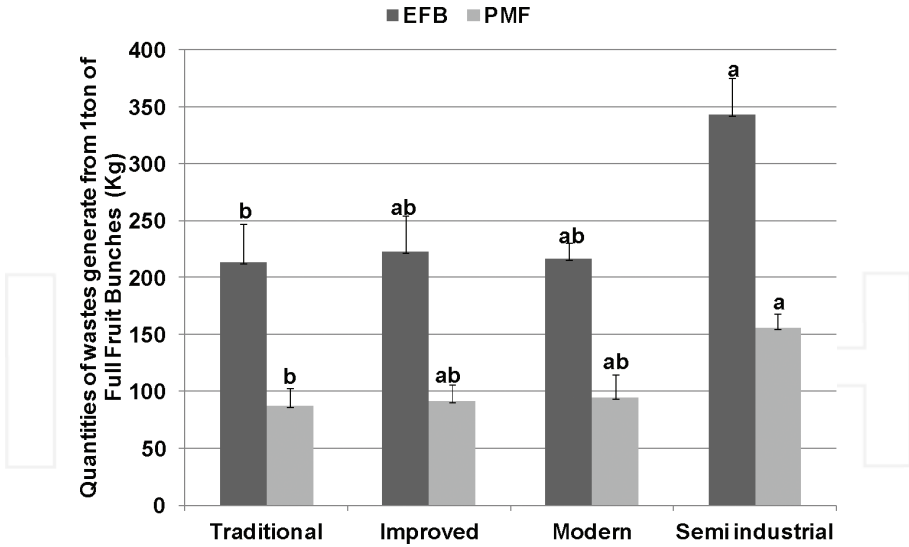


Figure 4. Quantities of POMSW generate by each category of mills. a; b and c: figures followed by different letters are significantly different (Tukey HSD test, $p < 0.05$) (adapted from Ref. [15]).

60,204.86 and 27,159.6 tons in 2000 to 93,652 and 42,248 tons in 2013 for EFB and PMF, respectively. This period corresponds to the entrance of men in palm oil chain value. These men possess large areas of exploitable selected oil palm plantation and have a high financial capacity to buy modern engine or build big palm oil extraction engine and to employ a large number of laborers [13, 14, 18]. In 2022, POMSW quantities generated by mills are projected to reach

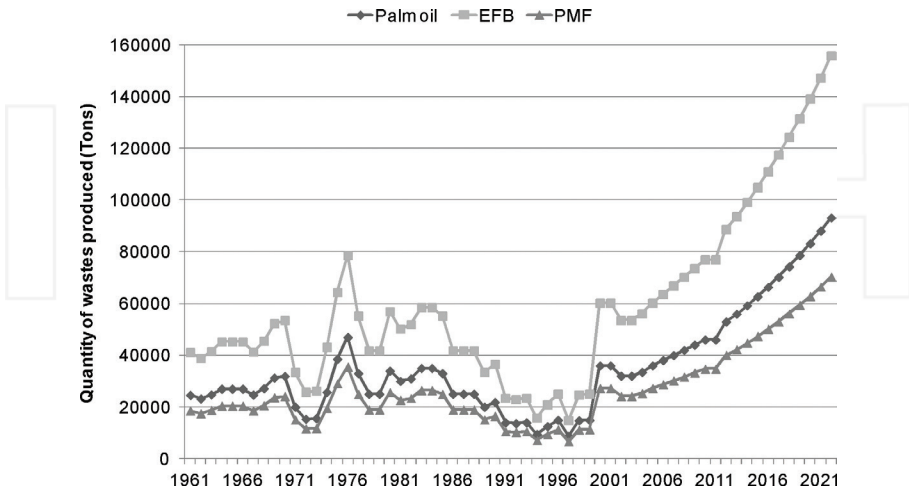


Figure 5. Evolution of POMSW biomass generated in Benin Republic [41].

155,821.3 tons of EFB and 70,294 tons of PMF. Koura et al. [18] identified four classes of oil mills based on the quantity of waste produced: small, medium, large, and very large producers of waste. The analysis of POMSW quantities generated by mills of regional union of oil palm producers (RUOPPs) union régionale des producteurs de palmier à huile (URPPH) during the last years reveals that EFB and PMF increased only in mills that used the modern and semi-industrialized process (Figure 6).

3.3. Palm oil mill solid waste management in sustainability context

In Benin Republic, some mills do not use all of their generated POMSW. Consequently, they sell and/or discard the excess (Table 3). The PMFs are more used and sold than EFB. When traditional mill owners decide to upgrade their mills by using the improved extraction method, most of them used these wastes. However, fewer mill owners who practice the modern extraction method use POMSW. Compared to other mill categories, most semi-industrialized mills sell and reject PMF. The problem of fiber and empty fruit bunches management is not related to the amount of waste generated. In fact, palm oil mills are facing problems of management of fiber and empty fruit bunches even if they are produced in small quantities.

3.3.1. Uses of POMSW according to mill categories in the south of Benin Republic

POMSW was used as energy, in agriculture and cosmetic (Figures 7 and 8). EFB was burned and the ash was used as potassium in preparation of local soap called “Koto”. According to FAO [43], this ash is also used as a fertilizer by some mills. Analyses of the physicochemical parameters of this ash by Udoetok [44] in Nigeria reveal that it contains appreciable amount of plant nutrients such as calcium (146.15 mg/kg), potassium (139.35 mg/kg), nitrate (97.6 mg/kg), phosphate (47.5 mg/kg), sodium (0.63 mg/kg), magnesium (1.68 mg/kg),

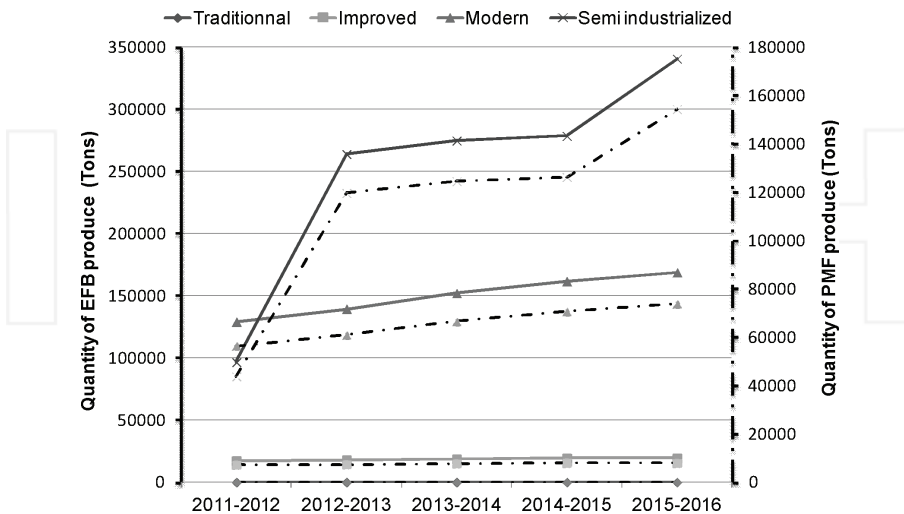


Figure 6. Evolution of POMSW biomass according to extraction palm oil process [42].

Mills categories	% users (Up)		Commercial value (CV)		Rejection rate (RR)	
	EFB	PMF	EFB	PMF	EFB	PMF
Traditional (50)	72	98ab	0.02b	0.1b	0.4	0.1b
Improved (134)	83.6	100a	0b	0.3a	0.5	0.1ab
Modern (142)	87.3	94.4b	0.03b	0.1b	0.4	0.01c
Semi-industrialized (9)	88.9	88.9ab	0.1a	0.6 a	0.4	0.6a
P (0.05)	0.09	0.02	<2.2e ⁻¹⁶	3.2 e ⁻⁶	0.37	3.9e ⁻¹⁰

Notes: Values in bracket are the number of mills surveyed in each category. The p -values displayed indicate a significant difference among the mill categories according to each parameter ($p < 0.05$). a, b, and c: figures followed by different letters are significantly different.

Table 3. Management of palm oil mill waste quantity generated according to each mill category.

and zinc (0.38 mg/kg) and that it justifies its use as an organic manure. POMSW was used directly or indirectly in agriculture as the fertilizer. Fresh POMSW was applied in palm plantation (33.1% of informants) by using two methods. The most common method is local application and the second is mulching [15]. Schuchardt et al. [45] stated that EFBs need to be applied in fresh state to reduced erosion, decreased nitrogen losses, controlled weed growth, improved soils nutrients, and avoided the danger of *Ganoderma boninense* and *Oryctes rhinoceros* (rhinoceros beetle) build up, important oil palm pathogen and pest. Bakar et al.'s study [46] shows that the application of 300 kg of POMSW per year in heaps in the middle of every four palms during 10 years improved the soil physicochemical characteristics of the top of soil (0–60 cm) and increased the fresh fruit bunch (FFB) yield more than 150 kg EFB and NPK. Nwoko and Ogunyemi [47], Embrandiri et al. [48], and Kolade et al. [49] stated that these wastes are very rich in nutrients and improve soil fertility and crop growth and yield. However, composting of POMSW is considered as the sustainable method of POMSW use [49–55]. In Benin Republic, composting was less practiced (13.6% of informants) using the heaping method (87.5% of informants) or pig breeds on POMSW (8.3% of informants) or holing POMSW (4.2% of informants) [18]. The compost made from palm oil mill wastes obtained by producers is used in plantations or vegetable production. Koura et al. recommended the use of POMSW and cattle manure compost applied at 10 t/ha for best tomato yield and the use of POMSW and poultry manure composted altogether in covered system and applied at least at 20 t/ha for best amaranth growth and yield production [56, 57]. Sabrina et al. [58] reveal in their study that fresh, composted, and field composted EFB produced phenol compounds, whereas no phenolic compounds were detected in vermicomposted EFB. EFB was also used for mushroom production. POMSW was used in energy production directly as a boiler fuel and PMF was used indirectly as energy after mixed it with palm oil mill effluent for fire starting cake production.

However, POMSW use as a boiler fuel was prohibited in some countries [59] to preserve human and ecological health [60–62]. The double PCA shows that two axes explain 82% of different POMSW uses according to mill categories. Table 4 shows the coefficients of correlation between the POMSW uses and mill categories and the first two PCA axes.



Figure 7. Uses of POMSW as energy and in cosmetic in Benin Republic. **Source:** Koura pictures. (a) Woman in mixing PMF and POME to make fire starting cake; (b) fire starting cake produce in industrial palm oil mill; (c) fire starting cake produce in traditional palm oil mill; (d) use of EFB as boiler fuel; (e) use of PMF as boiler fuel; (f) local soap making with POMSW called “Koto”.

This table shows that axis 1 explains modern (modern) and semi-mechanized (minimech) mills and uses of PMF for fertilization (ffert) and fire starting cake production (ffire). The axis 2 explains traditional (traditio) and improved (improved) mills and EFB uses as a boiler fuel (eboil) or mushroom production (emush) and PMF uses as a boiler fuel (fboil). **Figure 9** shows the projection of the POMSW uses by palm oil mill category in the system axes 1 and 2.



Figure 8. Uses of POMSW in agriculture in Benin Republic. **Source:** Koura pictures (2012). (a) Local application of EFB in plantation; (b) mulching system of EFB and PMF application in plantation; (c) heaping POMSW near mills for decomposition; (d) pig breeding on POMSW; (e) old compost obtained from pig breeding system.

The results show that modern mills use more PMF for fire starting production and EFB as a boiler fuel. Mini industrial mills use fibers for fertilization and boiler fuel and EFB for soap production. Traditional mills use EFB for fertilization, mushroom production, and PMF for

Parameters	Axis 1	Axis 2
Traditional	-0.021	0.159
Improved	0.04	-0.06
Modern	-0.059	-0.005
Semi-industries	0.509	-0.102
EFB uses for soap	0.017	-0.015
EFB uses as boiler fuel	0.008	-0.046
EFB uses for fertilization	-0.073	0.174
EFB uses for mushroom production	0.034	0.297
Fiber uses for fertilization	1.084	0.367
Fiber uses as boiler fuel	0.021	-0.034
Fiber uses for fire starting cake production	-0.134	0.06

Table 4. Correlation between the POMSW uses and mill categories and the first two PCA axes (in brackets is the proportion of variation explained by each axis, expressed in percentage).

fertilization and fire starting production. Improved mills use more POMSW as the boiler fuel and sometime EFB for soap production. These wastes can be used for other purposes. According to Abdullah and Sulaiman [63], EFB and PMF are clean, noncarcinogenic, free from pesticides, and soft parenchyma cells. Consequently, they can be used in erosion control, mattress cushion production, soil stabilization, horticulture and landscaping, ceramic and brick manufacturing, paper production, and acoustics control [63]. In great oil palm countries, such as Malaysia, Indonesia, and Thailand, others potentialities of oil palm wastes had been studied [64]. These results demonstrate the possibility of employing hydro thermal for producing solid fuel as well as nutrient recovery from EFB. POMSW can also use as a source of renewable energy [64, 65]. In fact, they can produce steam for processing activities and for generating electricity [64].

3.3.2. Factors that influence palm oil mill waste management in rural area

The wastes management choice must be influencing by many factors. In Garissa municipality, a study shows that understaffing, lack of education, poor supervision, lack of appropriate facilities, and lack of resident's support are among reasons leading to poor solid waste management [66]. In Benin Republic, the use of POMSW by a mill does not depend on waste quantities [18] but on the knowledge of producers on this waste uses, the importance and economical input of these wastes. In fact, it had been shown by Koura et al. [67] that the use values of these wastes depend on their importance for mill owners and by Koura et al. [15] that the uses of POMSW for new purposes as composting depends on farmers' knowledge on what is compost, composting method and possibilities to compost POMSW. Contrary to traditional mills, all others mills use POMSW as the boiler fuel. These mills reduce the quantities of wood use to cook palm fruits with POMSW.

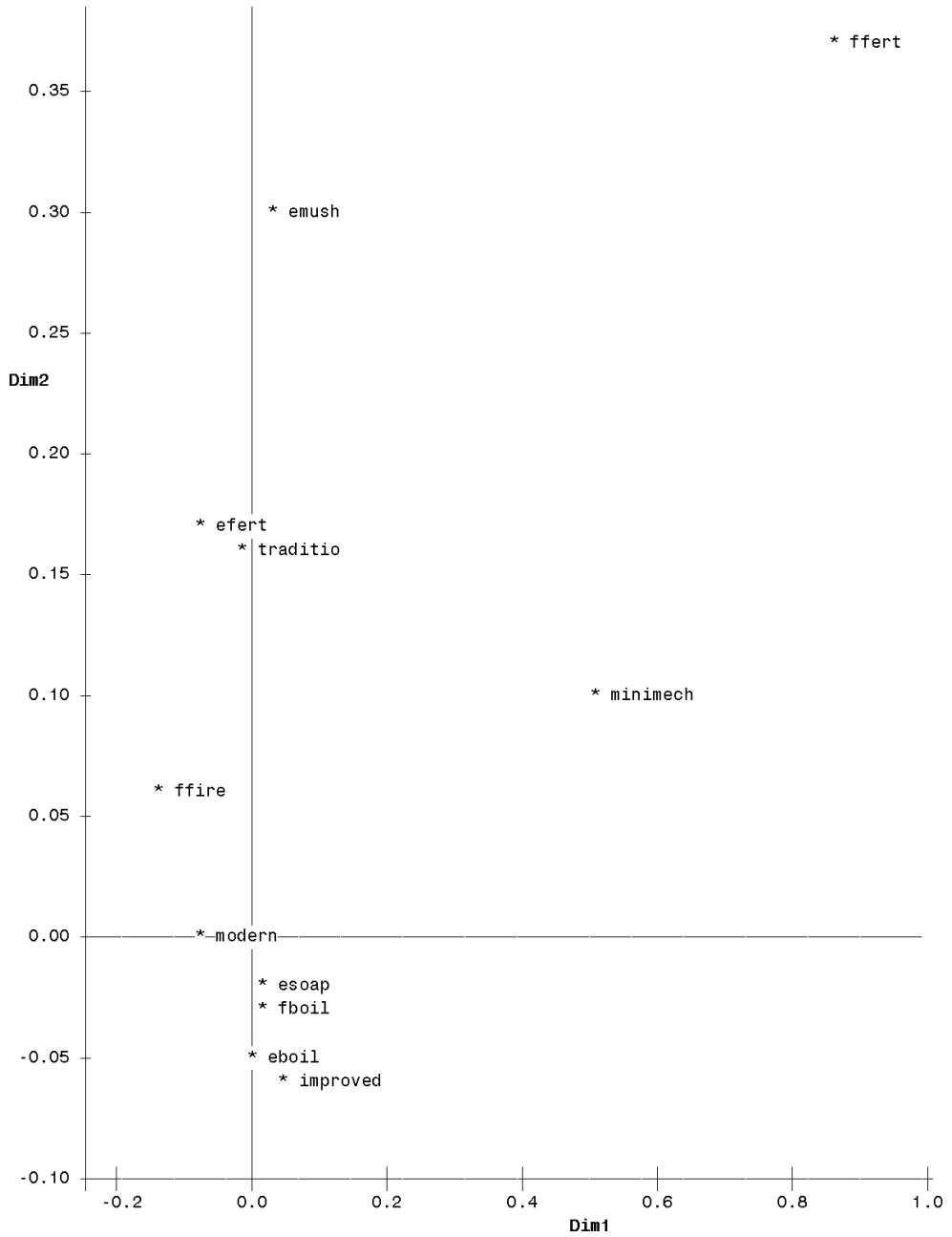


Figure 9. Projection of POMSW uses by mill categories in the system axes 1 and 2.

3.4. Future outlook for sustainable POMSW management in rural area

POMSW is useful for farmers in Benin Republic. However, because of the large quantity of wastes produced, some palm oil mills face waste management problem. The choice of one use of these wastes depends on its importance and economic input. By improving oil extraction process, mills are confronted to wood necessity as fuel for stoves and boilers. Consequently, these wastes are priority use as the boiler fuel. This use must be prohibited for environment protection. POMSW is mainly composed of fibers that can be used as renewable energy and solve electricity problems in rural areas. **Table 5** presents the estimation of energy content on POMSW in different oil palm countries. Energy content of these wastes is very lower in Benin Republic than the others palm oil producer's countries. However, this is an opportunity for palm oil mill owners' country, where there is a predominance of wood energy (fuel wood and charcoal) in the national energy balance. Fuel wood represents 59.4% in the final energy total consumption in 2005, while petroleum products accounted for 38.4%. Electricity represents only 2.2% of these intakes [14].

On the other hand, POMSW is agricultural waste, rich in unit fertilizers in particular nitrogen and potassium. The best manner to valorize agricultural wastes is their use as fertilizers to improve soil fertility and increase crop yields, hence enhance food security since waste generation had increased with population expansion and industrialization [72]. The present study reveals that the use of POMSW as fertilizer was practiced in traditional mills and was abandon with the upgrade of traditional mill to improve and modern palm oil mills. This use was practiced in semi-industrial mills that produce big quantities of POMSW. Further research must conduct on the possibilities of using biogas derive from composting to produce electricity for the mill and compost for soils fertilization. It is important to integrate raw materials rich in phosphorus such as poultry manure for POMSW composting because they are poor in this nutrient. These two kinds of POMSW uses will ensure environmental protection, contribute to food security, restore degraded soils, and increase earning money of producers of rural areas.

POMSW	Benin Republic [68]	Nigeria (Rivers state) [69]	Nigeria (Imo state) [70]	Malaysia [71]
EFB (MJ/kg)	4.4	17.75	–	18.84
PMF (MJ/kg)	9.6	18.75	19.67	19.07

Table 5. Energy content of POMSW.

4. Conclusion

Mainly formed of fibers, EFBs composed of spikelet and stalk, and PMFs are the solid wastes generated during palm oil fruit transformation. These wastes contained large amount of nitrogen, calcium, potassium, sulfur, and chloride and less phosphorus. In Benin Republic, POMSW had increased only in mills that used modern and semi-industrialized process during the 5 last years. Some mills sold and/or discarded these wastes.

The present study reveals that as mini industrial mill that produces big POMSW quantities, traditional mills are confronted to waste management. POMSW was used as energy, in agriculture and cosmetic. The upgrade of traditional mill to improve or modern mills creates the need of wood to feed boiler and stoves. However, this use must be avoided preserving environment. Since the use of POMSW depends on its importance and economic input, further studies must be made on its use for electricity generation and cropping soil fertilization through composting.

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