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Quantitative assessment of palm oil wastes generated by mills in Southern Benin

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While waste management is given more care for protecting the environment and human health, agro industrial wastes are still a concern, in developing countries. This study quantitatively assesses the palm oil wastes generated by mills and describes their management in Southern Benin. Twenty four out of 335 regional palm oil mills were randomly selected and assessed for waste quantities generated during the oil production season. From 1 ton (t) of full fruit bunches (FFB), each palm oil mill produces an average of 712.1 kg of fruits, 254.7 kg of empty fruit bunches (EFB), and 399.8 kg of palm kernel cake, 114.9 kg of fibre, 240.4 L of palm oil mills effluents (POME) and 152.3 L of crude palm oil. Numeric classification analyses resulted in four groups of palm oil mills following production factors and wastes quantities generated: small, medium, large and very large mills. These groups produced yearly on average respectively 12.4, 31.3, 132.7, and 800.7 t of EFB; 5.6, 13.6, 135.2, and 637 t of fibre and 15.1, 40.9, 233.4, and 572.6 t of POME. They differed in nature, plantations size, and capacity to employ people. About 80% are small producers. The use of all POME generated depend on waste quantity produced.

Key words: Palm oil mills, wastes, system production.

INTRODUCTION

The palm oil tree (*Elaeis guineensis* Jacq) is a native of the humid tropics of West Africa. It is one of the major oil crops in the world, producing more oil than all other plants oil (Adeoluwa and Adeoye, 2008). Palm oil is used mainly for cooking (cooking oil, margarine, shortening, etc.) (Baharuddin et al., 2009). It is an important source for edible oils, as raw material for cosmetics and detergents and more recently for biodiesel production (Wicke et al., 2008; Lim, 2010; Hirsinger, 1995; Stalmans, 1995). In Benin Republic, palm cultivation was developed under the Guezo's Kingdom (1818 - 1858). Western African countries were the main outlet of palm oil in order to feed their soap mills. In 1848, palm oil gradually replaced slave trade. The production system

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was entirely traditional until half of the twentieth century. Thereafter, it was industrialized from 1950 to 1975 with 44000 t of palm oil being exported yearly. But this industrialization failed due to the Asian markets competition and decline of plantation productivity (Fournier et al., 2001). However, the National Living Forces Conference in 1990 resulted to the adoption of a liberal economic system of the development of palm trees and small private nuts productive units for women under supports from government, donors, and NGOs. In this context, plantation self-developers and palm oil self-producers might reverse threatening the profitability and hence, enable some small scales producers to survive in the coming years (Carrere, 2010). After the large-scale supply of improved seeds in the early 1990s, the industry was fairly supported; nonetheless, every attempt to recover was unsuccessful. However, the oil palm production developed with the involvement of associations such as the Regional Union of Palm Oil Producers (RUPOP) and the Communal Union of Palm Oil Producers (CUPOP) in 2004. Moreover, several private mills were also created and developed. These sources supplied mainly Nigeria' soap mills. This sector impacts several households in Benin. Indeed, palm oil and sodabi (that is, local palm wine) highly contribute to the income and social capital accumulation; this also discriminates operators and their households socially and economically. In Southern Benin, as oil palm acreage expanded, so did farmers' income (Adegbola et al., 2009). Nowadays, palm oil belongs to the main agricultural production chains which are planned to be nationally promoted. Palm oil production generates residues or wastes, such as empty fruit bunches (EFB), palm oil mill effluents (POME), palm kernel cake, palm kernel shell and fibre from the mesocarp. Every ton of crude palm oil produced causes the emission of 46 m^3 (that is, 32.9 kg) of methane, corresponding to 384 m^3 (that is, 756 kg) of CO_2 (Schuchardt et al., 2007). The POME waste induced methane is the major environmental pollutant (Schuchardt et al., 2006). The raw POME has biological oxygen demand (BOD) values averaging 25.000 mg/L, making it about 100 times more hazardous than domestic sewage (Maheswaran and Singam, 1977). Therefore, the palm oil industry is the single largest polluter in Malaysia contributing to 83% of total pollution, and this might be similar where ever palm oil is produced (Ojonoma and Nnennaya, 2007). Ensuring effective and sustainable management of palm oil mills wastes is important while enjoying the reverse from production (Ojonoma and Nnennaya, 2007). Also, the appropriate waste management might become the major contributor for reducing overall global greenhouse gas emissions (Sudirman et al., 2011). Hitherto, quantitative data are still lacking on waste generated through the local production systems. Here, a monograph of the palm oil mills waste production system was assessed throughout the processes description and quantitative analyses in Southern Benin.

METHODOLOGY

Study site

This study was carried out in Southern Benin Republic and covered the departments of Atlantic, Mono, Couffo, Oueme, and Plateau (Figure 1). The South of Benin Republic extends from the coast at 6° 25' to 7°30' N latitude. This part of Benin Republic belongs to the Guinea-Congolese zone. The climate of this part is sub-equatorial with two rainy seasons (March to June and September to mid-November) and two dry seasons (July to September and November to March). The annual rainfall varies between 1,100 and 1,400 mm. The average daily temperature ranges from 25 to 29°C and the average daily humidity from 69 up to 97%. The Guinean zone is the area of deep Lateritic soils of low fertility (700 000 ha), and that of 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 (Adjanohoun et al., 1989).

Sampling

This study considered palm oil mills which belong to RUPOP. In each department, the CUPOP was contacted and palm oil producing villages, comprising significant numbers of plantations and mills were selected. In each village, only mills which produced palm oil for commercial income were considered. Mills which buy nuts from CUPOP mills members and produced for commercial income were also surveyed. Three hundred and thirty five palm oil mills were surveyed (Table 1).

Survey

The survey was carried out from November 2011 to March 2012. A semi-structures questionnaire was used and complemented with personal observations. The questionnaire evaluated information concerning the biodata (name, sex, age, ethnic group, main activity), the production factors (palm oil production process, number of employees, production period, property of palm plantation, palm plantation area, external supply of nuts by buying, variety of nuts used, average monthly quantity of oil produced) and palm oil mills waste management (proportion of palm oil mills waste quantity used by the producer, proportion sold and proportion discarded were determined using the matrix notation method). The discussion with the producers was completed with direct observations on the surroundings of the mills.

Palm oil mills wastes (POMW) quantification

According to the type of machine used for palm oil production in a partial or total process, palm oil mills processes were classified into 4 categories (Figure 2):

i) Traditional palm oil process: Producers do not use any machinery. All the steps of production were made by feet and hands;
ii) Semi mechanized or improved palm oil process: Producers have only digester engine in their mills. Whereas all other steps were made by feet and hand, digestion step was made with machine;
iii) Motorized or modern palm oil process: Producers have a digester engine and almost all of them use the DECAM press;
iv) Semi industry palm oil process: Only threshing step was made by feet. Producers possess big cookers, presses, sterilizers, clarifiers and other big facilities for oil production.

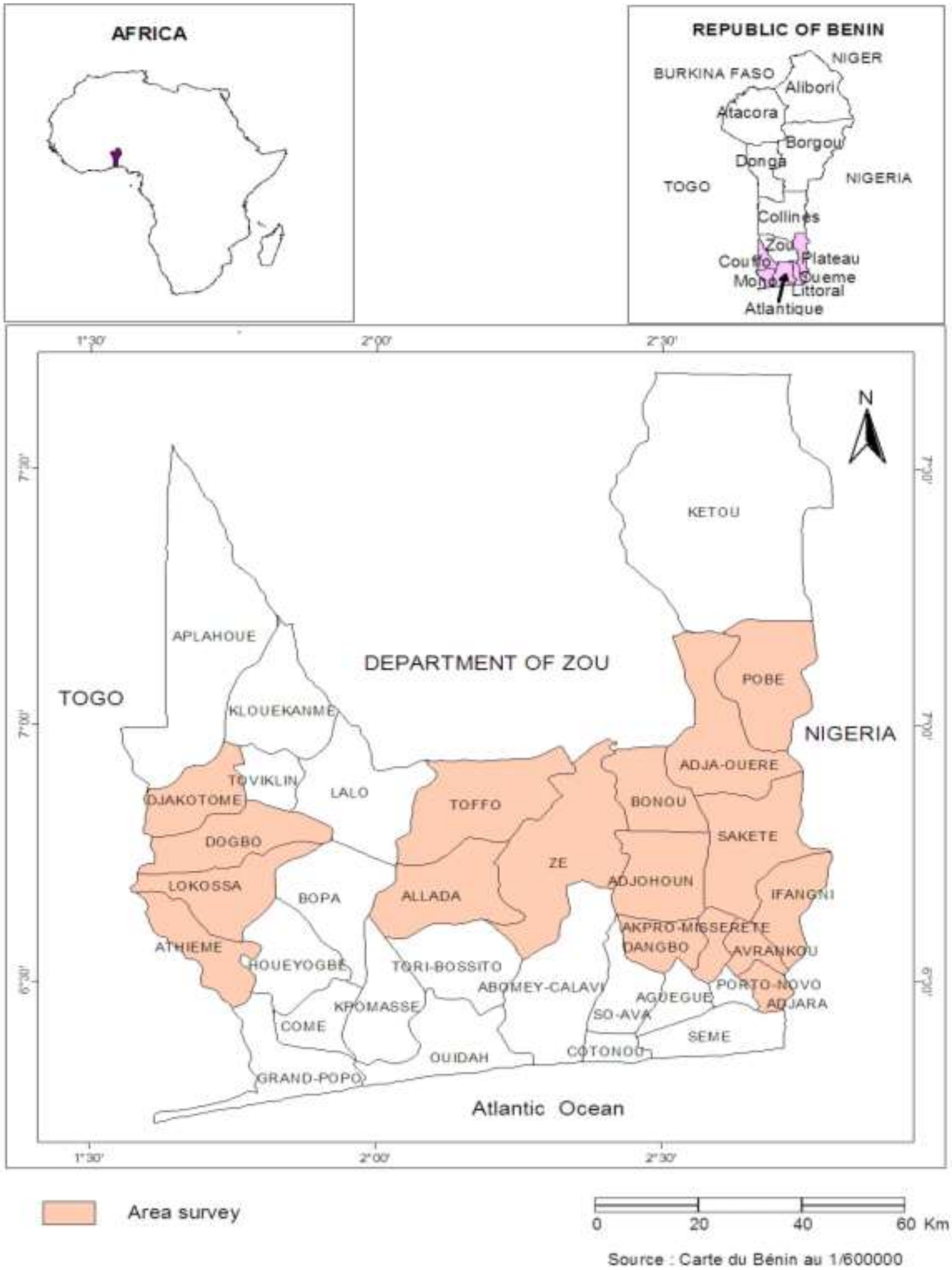

Figure 1. Location of experiment site.

All semi industrialized mills know their extraction rate and waste proportion. For the 3 other groups, 15 mills were randomly chosen in order to assess their palm oil mills waste quantities. Seven traditional mills, 4 modern mills and 4 improved mills were monitored three times during their transformation process. These numbers were chosen because the engine used among modern mills and improved mills were similar. At each producing step, waste weight was assessed. The waste quantities Q (t) of each mill

Table 1. Palm oil mills responders.

Department	Respondents	
	Number	Percentage
Atlantic	80	23.9
Couffo	56	16.7
Mono	63	18.8
Oueme	90	26,9
Plateau	46	13.7
Total	335	100

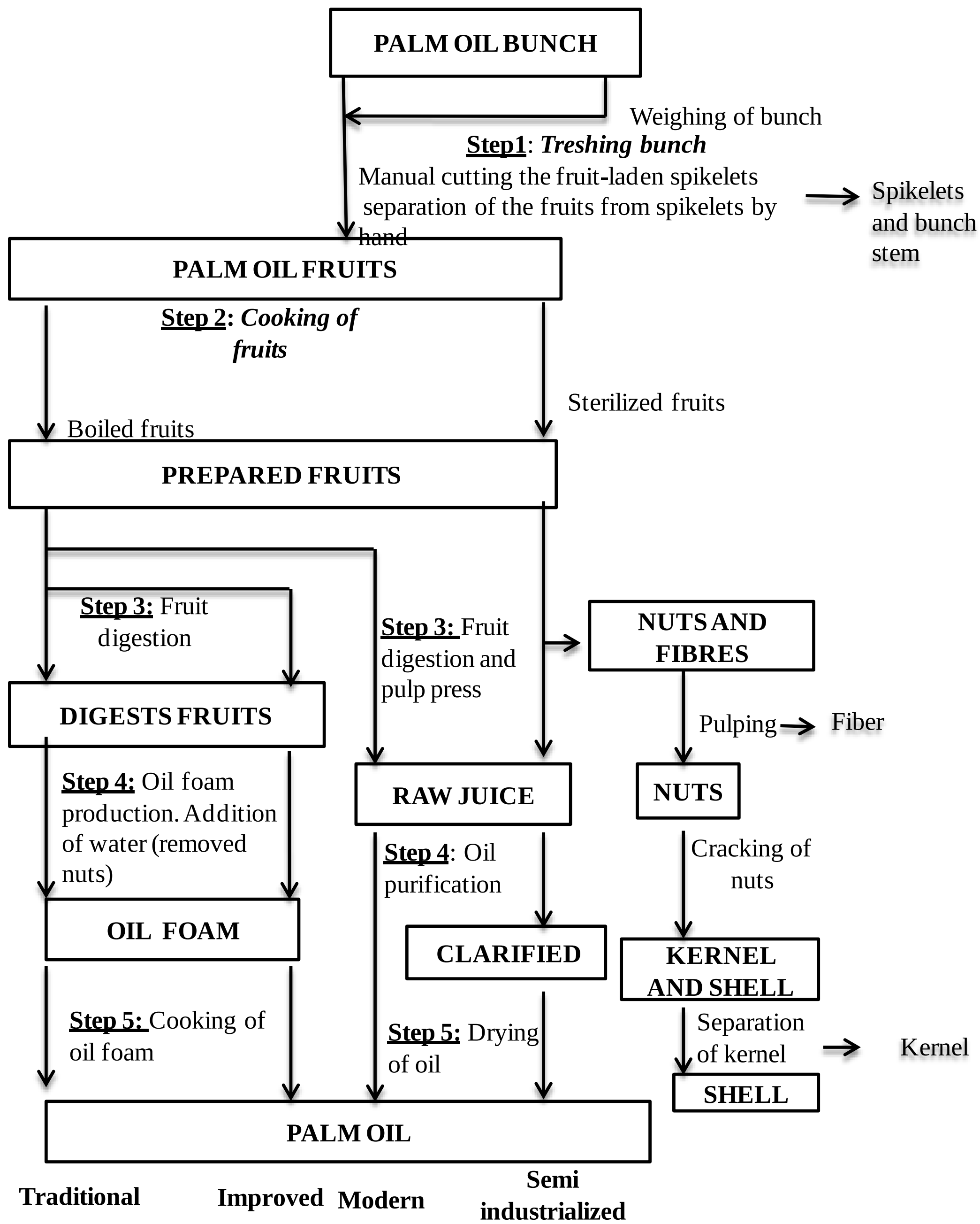

Figure 2. Palm oil processing types.

Table 2. Palm oil mills owners: Characterization and activities sector classification.

Sex		Age		Sectors activities					
				Agriculture		Buisiness		Industry	
Male	Female	23 < X ≤ 50	X > 50	Oil	Oil and tree	Oil	Oil and tree	Oil	Oil and tree
247 (75)	88 (25)	211 (63)	124 (37)	51 (15.2)	234 (69.9)	2 (0.6)	7 (2.1)	12 (3.6)	29 (8.7)

( ) in percentage.

were calculated as:

$$Q = \frac{q_{wi} * q_{prod}}{q_{ri}}$$

where q_{wi} stands for the quantity of waste produced by 1 t of full fruits bunches (FFB) according to the oil production category "i" that mill belongs to, 1 t of FFB according to the production category "i" that mill belongs to, q_{prod} is the annual palm oil quantity (t) produced by the mill or $q_{prod} = q_{ri} \times F_i$ and where F_i = the total quantity (t) of FFB according to the production category "i" that mill belongs to.

Statistical analyses

The cluster analysis was realized with Ward "minimum variance cluster procedure" to classify palm oil mills according to the waste production system. The palm oil mills production factors (employees number, property of palm plantation, palm plantation area, nuts buying, variety of nuts used, the average quantity of oil produced by month) and the waste quantities generated EFB quantity, the fibre quantity and POME quantity) were considered for this classification. A data matrix comprising the waste quantities produced and waste production systems was submitted to a Principal Component Analyses (PCA) to evaluate the linkage between waste quantities and their production system among palm oil mills. Analysis of variance was used to compare different averages of waste quantities, and homogeneous groups were determined using Tukey honest significant difference (HSD). These analyses were performed using SASv9 software. Chi-square analysis with one classification criterion (4 groups) was performed on the observed group frequencies with respect to the expected rate 1:1:1:1.

RESULTS

Socio demographic characterization of palm oil mills' owners

Table 2 presents palm oil producers according to their sex, age and activities sectors. Two-thirds of mills surveyed belonged to men and 63% of owners were less than 50 years old. Although almost all mills' owners are farmers, 15% of them are involved in business and industry sectors. Seventy one percent of them own palm plantations and produce palm oil.

Evaluation of palm oil mills waste quantities

In the mills, producers collect all the FFB that they have. These FFB originate from different palm oil plantations of different ages. From 1 t of FFB, each palm oil mill produced an average of 712.1 kg of fruits, 254.7 kg of EFB, 399.8 kg of palm kernel cake, 114.9 kg of fibre and 240.4 L of POME, 152.3 L of crude palm oil. Table 3 presents the average of palm oil mills waste quantity generated by each kind of mills. The semi industrialized process produced significantly more EFB, fibre and less palm kernel cake than the traditional process.

Characterization of palm oil mills wastes production systems

The cluster procedure for palm oil mills waste production systems identified 4 groups of palm oil mills wastes production systems according to the waste quantities generated and production factors. R^2 was 53% for this analysis and 61% for the PCA used to describe these groups with the first two axes. Table 4 shows the coefficients of correlation between the factors palm oil production and the first two PCA axes. This table shows that axis 1 is correlated positively with quantity of palm oil, palm oil mills waste quantity generated (EFB quantity, fibre quantity, POME quantity, palm kernel cake (PKC) quantity), the process oil production category, employees number and palm oil plantation area. Axis 2 explains palm oil plantation possession, the variety of nuts used and the buying of nuts. Figure 3 shows the projection of the different palm oil mills waste production systems in both axes 1 and 2.

Group 1 is composed of 64 mills owned by people in the business or industry sectors. These owners do not possess palm oil plantations (98%) and need to buy the nuts for feeding the palm oil plant (Table 5). Most of them (56.3%) use a local variety. These mills use modern processing (59.4%) or improved processes (28.1%) and employ 7 persons to produce 16.71 t of oil per mill and per year on the average during 6 months of production activity. To produce this palm oil quantity, each mill generated during the production period 31.34, 13.64, 40.87 and 81.17 t, respectively of EFB, Fibre, POME and PKC on average. Group 2 contains 264 mills whose owners belong equally to all activity sectors (37.5, 42.4, and 20.1%, respectively are farmers, palm oil producers, and other sectors). They all possess 5.98 ha palm oil plantations on average and most of them buy nuts (63.6%) in addition.

Table 3. Palm oil wastes and crude palm oil quantities generated from 1 t of full fruit bunch.

Type of palm oil mills	Traditional	Improved	Modern	Semi industrial
Palm oil fruits (kg)	786.9 ± 34.0[a]	777.1 ± 31.8[ab]	783.9 ± 14.9[ab]	656.6 ± 31.7[b]
EFB (kg)	213.1 ± 34.0[a]	222.9 ± 31.8[ab]	216.1 ± 15.0[ab]	343.3 ± 31.7[b]
Palm Kernel Cake (kg)	458.9 ± 57.9[a]	674.8 ± 118.1[a]	558.6 ± 140.8[a]	161.1 ± 18.2[b]
Fibre (kg)	87.4 ± 15.6[a]	91.6 ± 14.0[ab]	94.5 ± 20.3[ab]	155.6 ± 13.0[b]
POME (l)	282.1 ± 33.9[a]	285.4 ± 55.5[a]	281.9 ± 38.1[a]	169.4 ± 26.3[a]
Crude Palm Oil (l)	97.5 ± 15.6[a]	145.8 ± 14.7[a]	114.6 ± 20.5[a]	214.4 ± 12.4[b]

Table 4. Correlation between the characteristic parameters (palm oil mills waste production system and production factors) and the first 2PCA axes (in brackets is the proportion of variation explained by each axis, expressed in percentage).

Parameter	Axis 1 (45.88%)	Axis 2 (15.13%)
POME quantity	0.95566	- 0.08615
Palm oil quantity	0.91932	- 0.05404
Fiber quantity	0.90909	0.00630
Palm kernel cake quantity	0.87000	- 0.12840
EFB quantity	0.88058	- 0.07075
Palm plantation area	0.62837	0.30984
Employees number	0.56996	0.34230
Process category of palm oil production	0.45773	- 0.20286
Palm oil plantation possession	- 0.00785	- 0.80801
Nuts buying	0.00789	0.78425
Nuts variety used	- 0.02764	0.33152

They use more a mixture of selected and local (47.7%) or local (39.4%) nut varieties to be processed either into improved (43.6%) or modern (39.0%) production lines. Each mill in this group employs 12 persons to produce palm oil. In these mills, there are of 4 mini industry productions. These mills are rarely installed and do not run at optimum level. The mills in this group produce less palm oil mills waste quantities than group 1 (Table 5).

Group 3 contains 3 mills which encompass a big palm oil plantation area (209.1 ha on average) and buy nuts again to increase their production. They employ 83 persons on average and almost all of them use the two nut varieties as well as a more selected variety through a semi industrial process attaining 159.2 t palm oil per mill per year. This kind of production generates more waste than the first two groups. One of these mills uses an improved process with only 20 employees with more selected varieties whereas those which have 200 employees use only local varieties through a mini industrialized process.

Group 4 comprises 4 mills differing from the other groups by its number of employees (54). Each mill of this group uses only nuts provided by their selected palm plantation (85.3 ha), producing more oil (252.9 t) and waste than other groups (Table 5). Three of them are semi industrialized and use a mix of local and selected nuts. One of them uses a modern process with only selected nuts in order to produce palm oil.

In the study area, most of palm oil mills surveyed belong to Group 2 (Figure 4). More than 84, 85.18 and 73.05% of traditional, improved and modern palm oil mills belong to Group 2 and the rest in each category belong to Group 1. However, rarely improved mills belong to Group 4. Forty four percent of the semi industrialized mills are component of Group 3 while the rest belong to Group 4.

Relation between the group and use of all waste quantities

All waste materials generated were used for many purposes by mills' owners. In fact, EFB are used as fertilizer, cooking fuel or to produce snail (Table 6). The χ^2 analysis between waste production groups and use of all waste quantities show that the use of all EFB and FIBER quantities produced by mill does not depend on group. But for POME, most mills which belong to Group 2 use all the quantities of this waste produced. For palm kernel, almost all mills use all the quantities by producing palm kernel oil or selling to palm kernel oil producers.

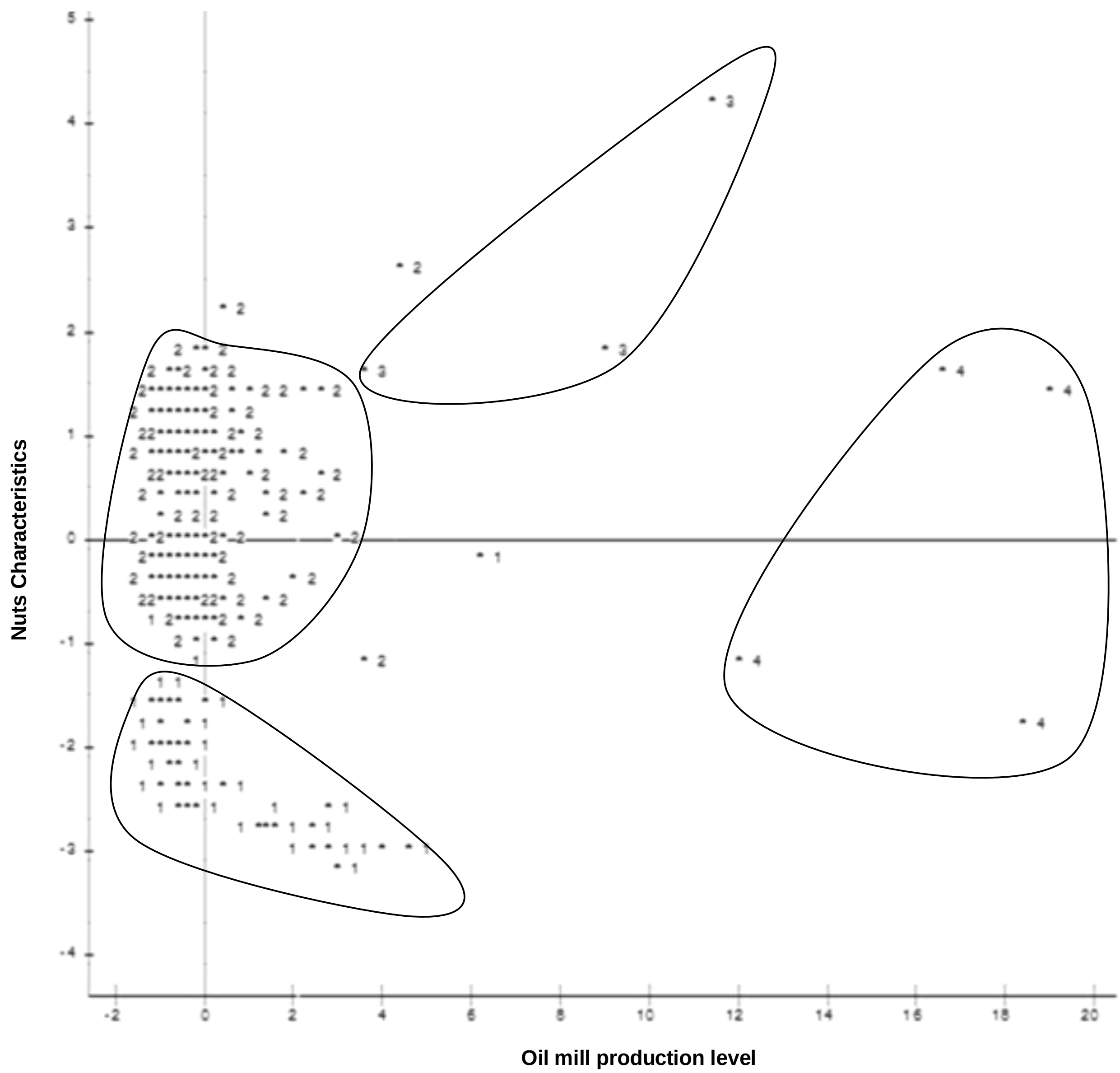

Figure 3. Projection of the different palm oil mills wastes production system in the system Axes 1 and 2.

Table 5. Wastes usages and the heterogeneity of group frequencies testing results.

Parameter	Different uses	Number of users				χ^2	P
		G_1	G_2	G_3	G_4		
EFB	Mulch, cooking fuel, soap, snail	36	154	2	1	1.9	0.5833
FIBER	Cooking fuel, mulch, fire starting cake, fertilization	49	205	2	1	6.289	0.0984
POME	Pig alimentation, fire starting cake, fertilization	26	184	1	1	22.496	<0.0001

DISCUSSION

Palm oil tree is cultivated by many farmers and retailed to secure a decent retirement. It is also an agricultural source of employment for many rural women. In some mills that employ more than 200 persons, per season each year, women are in majority. This is confirmed by Olagunju (2008) in Nigeria who reported that, palm oil

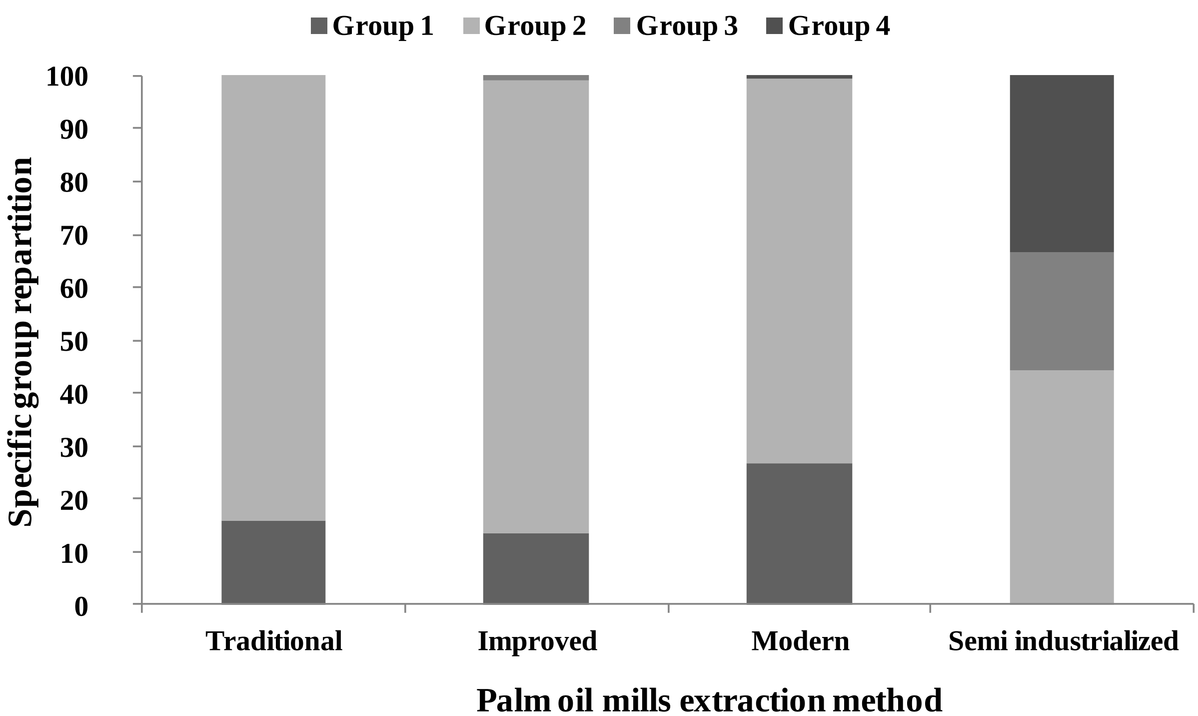

Figure 4. Palm oil mills investigated classification in each department.

mills employ 4 million Nigerians in about 20 palm oil growing states and indirectly to other numerous people involved in processing and marketing. Results show that, 1 t of FFB generates on average 712.1 kg of fruits, 254.7 kg of EFB, 399.8 kg of palm kernel cake and 114.9 kg of fibre. These values are similar to those observed in Malaysia and in Indonesia. In Malaysia, Maheswaran and Singam (1977) found that 1 t of FFB composed of 230 to 250 kg of EFB, 130 to 150 kg of fibre, 60 to 65 kg of shell, 55 to 60 kg of kernel, and 160 to 200 kg of crude oil. Hayashi (2007) found that in Indonesia, palm oil mills produce 22.5, 14.3, 6.7, 54.8, 5.4 and 21.8%, respectively for EFB, fibre, shell, POME, kernel and crude palm oil with 1 t of FFB. Palm kernel cake weight is higher in Benin than Malaysia. In fact, producers in Benin Republic use the local (Dura variety) and selected (Tenera x Dura variety) nuts. Palm kernel cakes obtained by mini industrialized mills are less and not different from those obtained in Malaysia, because these mills use selected nuts, Tenera. According to Twumasi et al. (2014), Tenera palm kernel is smaller than the Dura kernel, although the Tenera bunch is much larger than Dura. Jimoh and Olukunle (2013) reported that Dura' possesses more shell than the kernel while 'Tenera' possesses more kernel than the shell. The EFB, fibre and kernel shells generated by 1 t of FFB are approximately the same as those found by Sudirman et al. (2011). Among these palm oil mills solid wastes, palm kernel cake and EFB are more produced. These results differed from those reported by Rupani et al. (2010) and Najafpour et al. (2005), who found that POME and EFB are more produced in Malaysia mills. For transforming 1 t of FFB, small scale mills produce more POME than medium scale mills (mini industrialized). Medium scales mills produce more POME per season each year, because they produce more oil than small scale mills. The production of 240.4 L POME by transforming 1 t of FFB is less than 0.5 to 0.75 t estimated by Yacob et al. (2005). The Principal Component Analysis (PCA) reveals 4 waste production groups: small (Group 2), medium (Group 1), large (Group 3) and big (Group 4) mills waste producers, respectively. In the country, most of the mills are small waste producers. Medium, large and big mills produced the wastes quantities of 2, 11 and 66 small mills. The more important is the oil produced by mills, the more important are also the wastes produced by them. The palm oil productions depend not only on palm plantation, but the use of selected nuts and the money invested in the production. According to Twumasi et al. (2014), Tenera is a much better variety for industrial and economic purposes. Large mill (Group 3) employed more persons and had the big plantation area but produce less than very large mill (Group 4). This shows that large mills producers have some problems that do not permit them to reach their maximal capacity of production. EFB is more used as cooking fuel or incinerated for soap or as fertilizers by some mills. Fibre is used as cooking fuel and starting cake and also as fertilizers. Using all EFB and fibre quantities generated was not dependent on their quantities produced. In fact, small mills waste producers

Table 6. Production factors and waste quantities according to palm oil mills wastes production groups.

Parameter		Group 1	Group 2	Group 3	Group 4	P
Palm mills number		64	264	3	4	-
Employees number		7±7	12 ±12	83 ±102	54 ± 35	<0.0001
Total production months		6 ±1.6	6.5±1.8	7.3 ± 4	7.8 ± 2.2	-
Possession of plantation	Selected plantation	0	117	2	3	-
	Local plantation	0	46	0	0	-
	Selected and local possession	0	101	1	1	-
Source of nuts	Plantation	0	168	1	3	-
	Buying	64	0	0	0	-
	Plantation and buying	0	96	2	1	-
Characteristics of nuts	Local variety	36	104	1	1	-
	Selected variety	5	34	0	0	-
	Local and selected varieties	23	126	2	3	-
Average Plantation area (ha)	Selected plantation	0	4.1 ± 6.7	207.4 ± 39.4	83 ± 91.2	-
	Local plantation	0	3.5 ± 7.9	5	5	-
	Total areas	0	6 ± 9.2	209.1 ± 39.1	84.3 ± 89.7	<0.0001
Average Full fruits bunches (T)		144.9 ± 242.7	57 ± 94.5	942 ± 463	3723.6 ± 944.2	<0.0001
Average Palm oil quantity (T)		16.7 ± 28	7.2 ± 12.3	159.2 ± 98.5	252.9 ± 89.7	<0.0001
Average Wastes quantities produced per year (T)	EFB	31.3 ± 52.8	12.4 ± 22	132.7 ± 59.1	800.7 ± 418.1	<0.0001
	Fiber	13.6 ± 23.1	5.6 ± 10.3	135.2 ± 95.2	637 ± 312.6	<0.0001
	POME	40.9 ± 28	15.1 ± 23.7	233.4 ± 172.1	572.6 ± 90.3	<0.0001
	PKC	81.2 ± 136.4	30.3 ± 46.8	218.3 ± 80.8	937.5 ± 399	<0.0001

do not use all their wastes produced as the waste management is highly questionable in this area. How to manage waste is important as it is a source of pollution (Oyelola et al., 2009; Yacob et al., 2005). Contrary to other wastes, POME becomes a problem when so much was produced. Our study reveals that only small mills wastes producers in this location arrive to use all the waste produced by their systems. Otherwise, so much attention is needed where large and very large mills wastes are produced, this means that all semi industrialize mills and some modern and traditional mills that belong to medium wastes producers need to be improved in order to avoid environmental pollution, because this type of waste pollutes the environment 100 times more than domestic sewage (Schuchardt et al., 2007; Singh et al., 2010; Maheswaran and Singam, 1977).

Conclusion

Palm oil production globally contributes to the environment pollution. This production system monograph shows small, medium, large and big mill waste producers. Majority of mills in Benin Republic are small oil plants, with some big producers. The large quantities of EFB and fibre are not used while POME which is produced in a little quantity is easily valorised. But the pollutant nature of the latter requires proper management of critical priority. Further studies are needed for the relevant approach to manage the wastes generated and their effects.

Conflict of Interests

The authors have not declared any conflict of interests.

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