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Tanzania Palm Oil Industry: Auditing and Characterization of Oil Palm Wastes Potential Bio-resource for Valorization

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Abstract: Valorization, the combination of conversion processes of biomass into valuable biobased products, is a basis of bioeconomy, which is emerging globally. Tanzania has a huge potential in biomass production potential for valorization currently hardly or inefficiently used resulting into environmental pollution problems and bioresource wastage. A waste audit case study was conducted for palm oil extraction wastes generated by smallholder farmers in Kigoma Tanzania to evaluate their potential for valorization by integrating quantitative with qualitative methods and laboratory analysis. Results showed that annual generation of fresh oil palmpost-harvest wastes was estimated at 100,250 tones and palm oil processing wastes was estimated at 132,709 tons of solid waste and 1.54 x $10^8 m^3$ of wastewater. The wastewater was high strength with a total chemical oxygen demand of 50,000 mg/l and biological oxygen demand of 40,000 mg/l. The chemical composition profile (mg/l) of the wastewater included 5.93 phosphorous, 6.9 phosphate, 4.3 ammonia, 13.59 nitrate, 18.4 organic nitrogen, a pH of 3.78 and a conductivity of 1.6 Mv. Percent nitrogen contents of the solid waste fractions including palm fronts, palm press fibers, palm kernels, empty fruit bunches and palm kernel cake ranged between 0.5-0.8 and their phosphorus content ranged between 0.12-0.34 mg/100g. In conclusion, on the basis of the established characteristics, palm oil wastes represent amongst renewable biological resource,which can be transformed into food, feed, bio-based products and bio-energy via innovative and efficient bioconversion technologies in an integrated and sustainable manner. An innovative approach for the utilization of the waste for integrated production of edible mushrooms and biogas was proposed.

Keywords: post harvest waste, processing wastes, characterization, utilization, management

INTRODUCTION

Valorization i.e. the conversion via chemical, thermal, biological or electrochemical treatments of waste and biomass to food, feed, bio-energy as well as valuable chemicals, is emerging as a strong trend for sustainable development in terms of safely reusing biomass in the era of biobased economy (bio-economy)[1,2]. Oil palm is a tropical palm, which is cultivated for the production of palm oil[3]. In Tanzania, oil palm crop is only popular in the western part, particularly in Kigoma District, where local farmers have cultivated this palm for the production of edible oil since the early 1920s. Experience show that oil palm loses its productivity and the yield becomes low with age and so new plants are to be re-planted after 30 to 50 years of economic life for local (dura and pisifera) and hybrid varieties (tenera), respectively. However in the case of Kigoma, replating was not done and as a result harvests are low. Nevertheless, in Kigoma, the local cooperative collects about 150,000 liters of palm oil annually and sells this to local refineries and soap producers in Dar es Salaam[4]. Palm oil production is relatively high waste process constituting about 10% of the total palm biomass produced in the plantation and the remaining (90%) biomass being various fractions of liquid and solid wastes.

Processing wastes are composed of solid wastes such as wet empty fruit bunches (EFB), wet press palm mesocarp fibre, wet endocarp, palm kernel shell and palm kernel press cake[5]. The liquid waste (wastewater) generated from the extraction of palm oil is known as the palm oil mill effluent (POME) [6]. The industry also produces post harvest wastes including, palm fronds and palm trunks pruned when harvesting fruit bunches and felled oil palms during the replantation[7]. In 2004, the national production of palm oil was reported at 65,000 tons obtained from 4,500 ha of oil palm[8].

Based on palm cultivated area for year 2004, an equivalent to 52,650 tons of pruned palm fronds per year was generated. On the other hand, based on the palm oil produced in 2004 an equivalent of 1,141,000 tons of palm oil extraction wastes fractions (POEW) was generated. Some of the solid wastes are mainly used for making household brooms, firewood and as building material. Part of the waste is also used as fuel feedstock in oil palm plant operations and over 90% are discarded without recuperating diverse value added bioproducts through various conversions. The huge palm oil extraction wastes generated in Tanzania annually must be reused until all useful qualities have been recycled or made into new bioproducts. However, scarcity of innovative sustainable technologies for valorization of POEW generated by palm oil industry in Tanzania contributes to environmental pollution, emission of greenhouse gases, underutilization and biological resource wastage. Nevertheless, palm oil wastes make the palm oil industry truly attractive as a future source of renewable bioresources, which if exploited prudently, have the potential to contribute to the sustainability of palm oil industry [9, 10]. Sheil *et al.*[11] reported that biomass wastes from palm oil can be converted by pre-treatment (enzymatic, concentrated or diluted acid hydyrolysis or alkali and hydrothermal) as fermentation feedstock to produce ethanol, bio-gas (methane) and even hydrogen or other components (acetone, butane) that can be used as 'green chemicals' and bioplastics (e.g. polylactic acid, polyhydroxyalkanoids, etc).

Furthermore Rupani *et al.*[12] reported that various fractions of palm oil wastes generated by palm oil industry are potential feedstocks for biological conversion for the production of biogas. However, no thorough quantification and characterization of these wastes has been done for Tanzania to guide their utilization through various conversions into value added bioproducts. Besides, the quantity and compositions of palm oil wastes as reported in the literature is only indicative and never universal since it varies considerably depending among other factors on the variety, means of processing, soils, water availability and degree of palm fruit maturity[13]. These wastes are renewable bioresources, which could fit well in the production of diverse value added bioproducts by employing bioconversions process[11]. The aim of this case study therefore, was to establish the quantity and quality of wastes generated by the palm oil industry in Kigoma, Tanzania.

MATERIAL AND METHODS

Waste quantification: Quantification of waste involved a field survey to smallholder farmers in Kigoma rural areas. The survey was carried in collaboration with a non-governmental organization "Farming for Energy and Better Livelihoods in Southern Africa" (FELISA) involved with promotion of the palm oil industry in Tanzania. Information was gathered on size of the farm, age of the plants, species of the plant found, rates of generation of the waste and its current management methods through guided interviews with the smallholder farmers and FELISA management staff. The post harvest wastes included empty fruit bunches, palm fronds, palm trunks pruned when harvesting fruit bunches and felled oil palms. Ten bunches of palm were collected randomly from one hectare farm. They were each weighed before the fruits were removed from the bunch by using an axe and categorized by weight to small, medium and large **(Table 1).** Five kilograms of empty fruit bunches and palm fronts (chopped into 4-5 cm pieces) were taken for laboratory analysis.

Table-1: Weights of different size categories of fruit bunches, palm fronts and empty fruit bunches

Category	Palm fronts (kg)	Empty fruit bunch (kg)	Fruit bunch weight (kg)
Small	0.4 – 0.6	1.8 – 9	3–15
Medium	0.7–0.9	10 –18	16–30
Large	1–1.4	18–24	31–40

PALM OIL EXTRATION

Red oil extraction: Palm oil is obtained from the fleshy mesocarp. The fruits removed from the bunches weighed, About 112 kg was weighed and put into 200 liters drum then 15 liters of water was added. The entire mixture was boiled at temperature of 100◦C for two hours. The boiled fruits are then pressed in a locally made expeller well known as "Burundi" expeller where it originated to extract the red oil. Water was added during the process, which at the end remains as wastewater known as palm oil mill effluent (POME) whereby its volume was measured. The solid left after oil extraction referred to as palm oil press fiber and palm kernels their weight was determined using a Golden Lark hanging scale (Model:ZY-006, China)

White oil extraction: Palm kernel oil/white oil is obtained from the seed. The kernel shells were removed manually from the kernels, which were both weighed separately to determine their weights, which were established to be 98 kg and 57 kg, respectively. Then the kernels were put into the pressing machine fabricated by Small Scale Industrial Organization (SIDO) in Kigoma to extract the white oil. The press cake remained after the oil extraction was then weighed and the amount of oil produced was determined**.** The resulted wastes were taken for laboratory analysis at the Department of Molecular Biology and Biotechnology, University of Dar es Salaam.

Analytical methods: The samples were analyzed in triplicates for physico-chemical parameters where determination of total solid (TS), total volatile solids (VS), and ash content was done by the oven-drying and ignition method, respectively according to standard methods APHA[14]. Total carbon (TC) was estimated by the dry combustion method previously described by Allen [15]. Whereas total Kjeldahl nitrogen (TKN) was determined by the Kjeldahl method (APHA[14]). Chemical oxygen demand (COD) and biological oxygen demand (BOD_5) were done according to standard methods APHA[14]. Crude fiber (CF) was determined by the oven ignition method according to Munguti *et al.*[16] and organic matter content was determined by the dry combustion method described by Lyimo *et al.*[17].

RESULTS AND DISCUSSION

Quantification of oil palm post harvest and palm oil processing wastes: Harvesting fruit bunches differs even on the same plot due to many factors including type of soil and available soil nutrients, dry and rainy season, temperature, humidity and other climatic factors. Based on palm-cultivated area of 4,500 ha for year 2004[8]. The estimated annual production of oil palm post harvest wastes was105, 250 tons. Currently, these wastes are used as fuel in the palm oil extraction process and some are disposed off in the environment.

The palm oil extraction in Kigoma rural areas which was done traditionally resulting into production of large quantities of waste in terms of waste water, POME and palm press fiber. In this study it was estimated that production of 1 ton palm oil resulted in generation of 2.041 tons of press fiber and kernels and 2,383 m^3 of POME. The production of palm oil annually in Kigoma rural district of 150,000 liters[4] resulted in generation of 306 tons of press fiber and kernels and 357,450 m^3 of POME. Hence the national production of 65,000 tons[8] resulted in generation of 132,709 tons of press fiber and kernels and 1.54 x $10^8 m^3$ of POME. To the best our knowledge, quantities and characteristics of palm oil wastes generated, which could guide their valorization in Tanzania are being reported for the first time.

Composition of oil palm post-harvest and palm oil processing wastes fractions: Suitability of any biomass as feedstock for utilizing to bioproducts usually depends on its chemical characteristics. The chemical compositions of the oil palm post harvest and palm oil processing wastes are shown in **(Tables 2).** Generally, the solid fractions were rich in biodegradable substances in terms of volatile solids (VS) in the range of 79-93%. The palm press cake had the highest VS (93.51%) content and palm kernel shell had the least (79.87%) and about 55% in terms of total organic carbon. The wastewater had a VS content of 86%. These values are similar to those obtained previously for fibers, shells, empty fruit bunches and POME [12, 18, 19].

The high values of organics contained in the palm oil waste fractions is indicative of their potential for valorization and as feedstock's for a biorefinery that could produce food (mushroom), feed, biofuels (biogas, bioethanol) and other bioproducts. Furthermore, the solid fractions were characterized by crude fiber content in the range of 1.7-16% and total organic matter content in the range 50-98%.The wastewater was found to be acidic (pH of 3.78) and high strength with a COD and BOD of 50,000 and 40,000 mg/l, respectively. Furthermore, the liquid fraction was observed to have a rich nutrient profile as shown in **(Table 2).** To obtain chemically balanced suitable substrates' for the proposed bioproducts, particularly in terms of C: N ration, blending of the various nitrogen and carbon rich fractions is necessary. Previous investigations proposed blending of POME with mesocarp fiber [20]. The former fraction has low carbon to nitrogen ratio 0.168:1, while the mesocarp fiber has different characteristics. Hence blending POME with mesocarp fibers or palm press cake or both which are nitrogen and carbon rich offers optimum substrate composition for anaerobic digestion. Salihu and

Alam[21] previously demonstrated such benefits.

Table-2: Chemical characteristics of palm oil waste fractions (Mean ± SD, n=3)

Parameter	POME	Empty Fruit Bunches	Fruit Palm fronts	Shell	Press fiber	Press cake
Total solids (TS %)	5.38± 0.75	64.42 ± 1.57	24.02±0.2	82.52 ± 1.38	38.96 ± 1.37	81.09 ± 0.56
Volatile Solids (% TS)	86.24± 2.59	88.92 ± 0.49	82.59±030	79.87 ± 0.95	91.44 ± 0.96	93.51 ± 0.13
Moisture content (%TS)	94.62± 0.75	35.58 ± 1.57	75.97±0.2	17.48 ± 1.38	61.04 ± 1.37	18.91 ± 0.56
Ash content (%TS)	13.76± 2.59	11.08 ± 0.49	17.40±0.30	20.13 ± 0.95	8.55 ± 0.96	6.48 ± 0.13
Total carbon (%TS)	3.10 ± 0.01	51.11 ± 0.56	52.59 ± 0.84	54.72 ± 0.28	51.11 ± 0.56	16.94 ± 0.83
Total organic matter (%TS)	50±6.29	87.586±0.121	83.567±1.14	97.68±0.019	91.94±0.76	97.05±2.5
Crude fibers (%TS)	7.37±3.38	9.55±0.58	16.22±2.70	1.73±0.59	13.66±3.41	2.33±1.16
Total Nitrogen (%)	18.43±0.57	0.532±0.2	0.727 ±0.25	0.795±0.15	0.586±0.20	0.539
C:N	0.168:1	96:1	72:1	68:1	87:1	31:1
Total Phosphorus	5.93±0.1mg/l	0.12±0.02mg/100g	0.34±0.04mg/100g	0.24±0.1mg/100g	0.28±0.1mg/100g	0.18±0.02mg/100g
NH^+_4 (mg/l)	4.129±0.20	ND	ND	ND	ND	ND
PO_4 (mg/l)	6.93±0.30	ND	ND	ND	ND	ND
NO_3 (mg/l)	13.59±0.20	ND	ND	ND	ND	ND
COD(mg O_2/l)	50,000±120	ND	ND	ND	ND	ND
BOD_5(mg/l)	40,000±130	ND	ND	ND	ND	ND
pH	3.78±0.30	8.3±0.80	9.95±0.40	7.85±0.40	7.56±0.80	7.68±0.50
Conductivity (Mv)	1.6±0.6	0.05±0.01	1.57±0.83	0.48±0.12	0.68±0.13	0.54

ND=Not Determined

Proposed integrated utilization of palm oil waste: Palm oil production be it by manual traditional small-scale processing methods, which are simple, but tedious and inefficient or advanced large-scale techniques using machinery, generate huge quantities of organic wastes. The oil make up only about 10% of the total biomass produced in the plantation and the remaining 90% consists of liquid and solid wastes[5].Waste management is therefore very important from the point of view of reducing impact to the environment and sustainable utilization of the waste for production of value added products. Depending on the nature of their compositions some of the wastes are already utilized singly for generation of energy in the form of fuel pellets, briquettes and biogas. Other current uses include soil mulching and production of paper pulp, paper products and composite fiberboards. Furthermore, processed palm fronds and kernel meal are used as animal feed and for mushroom cultivation [9, 10]. On the basis of the results of this study, two innovative approaches are proposed **(Figure 1).** The first option involves blending all the six palm oil wastes namely; palm press fiber, palm kernel press cake, palm kernel shell, empty fruit bunches, palm fronts and POME as substrates for mushroom cultivation. Followed by utilization of spent mushroom substrate (i.e solids remains after mushrooms harvested) as feedstock for biogas production when co-digested with cow dung during anaerobic digestion. Alternatively the six palm oil wastes mixture can be leached using percolation technology in which solid wet palm oil wastes serves as a fixed bed and the liquid (=percolate, hydrolysate) percolates that fixed bed [22]. Then the percolate, hydrolysate liquid (leachate) co-digested with cow dung manure anaerobically for biogas production. The remaining solids after leachate extracted mainly lignocellulosic, which when dried is yet a potential renewable bioresource suitable for mushroom production. The biogas digester effluent known as biogas manure (a byproduct obtained from biogas digester) after anaerobic digestion of organic matter for production of biogas rich methane) is valuable biofertilizer. Such an integrated innovative approach processing multiple waste streams into value added byproducts offers sustainable economical and environmental benefits[23]. In the second option, the wastes may be utilized for the production of different products eg. empty fruit bunches can be processed into pulp and returned to the plantation as mulch to enhance moisture retention, soil nutrient content and soil organic matter. Kernel press cakes can be used as livestock feed and POME may be converted into a number of valuable products example carotenoid which can be further utilized for production of vitamin A and vitamins E (tocopherols), citric acid, biofertilizer, biodiesel and hydrolytic enzymes. Valorization is yet another option of utilizing the wastes that is proposed for improved energy efficiency and alternative uses for the wastes and additional income generation while reducing the GHG (greenhouse gas) emissions. Contrary to the current practices of utilizing waste generated by the palm oil industry, the proposed approaches and other already proposed approaches by other researchers[24] gives additional options for more products giving the flexibility in choices for utilizing the palm oil wastes, which is an additional competitive advantage.

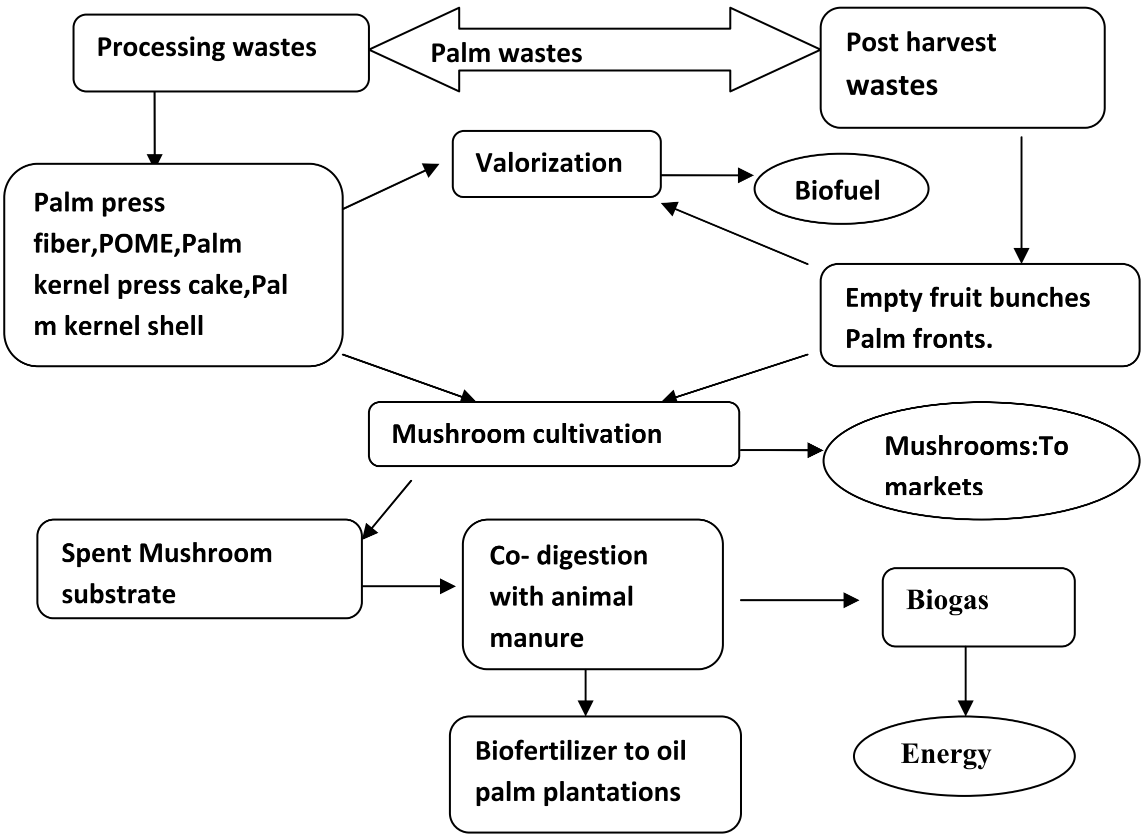

Figure 1: Proposed integrated utilization of oil palm post-harvest and prossecing wastes integration across applications/mutiple end products value added cycles

CONCLUSION

Palm oil production in Tanzania produces large quantities of wastes. When not disposed off into the environment untreated, their use is still limited to fuel and animal feed. However, basing on their characteristics, they are a potential bioresource for use in several conversion processes for producing valuable products. The waste generated by palm oil extraction in Kigoma is currently available for free and in abundance awaiting exploitation by valorization into food, feed, bio-energy as well as green valuable chemicals.

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