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An Assessment of Cleaner Production Opportunities in Cassava Processing for Gari Production

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Abstract The processing of cassava for *gari*production is one of the largest food processing industries in the rural economy of Nigeria. However, using a basis of 100kg of raw cassava tubers the traditional method of cassava processing for gari production has resulted in heavy water pollution as it generates large amount of solid waste (39.66kg) and wastewater with high organic content. This study explores the applicability of cleaner production technology options to improve the environmental performance of cassava processing mills in Nigeria. A major cassava processing mill in Jesse community in Ethiope- West Local Government Area of Delta State, Nigeria was selected for an exclusive analysis of the dynamics of clean technology development and adoption. Upon detailed diagnosis of the industrial process and waste flows generated, the opportunities for environmental improvement were identified and CP measures were recommended. Proposed options mainly involve: water reduction, reuse and recycling of water, technology modification in the production process, use of sharp knife to peel the roots and remove the skin, use of a grater made of stainless steel and of small mesh size, use of clean woven polythene sacksof smaller mesh size to hold the cassava mash after grating, the use of extra -fine siever of 0.25 mm to 0.5 mm aperture sieve and the practice of good housekeeping measures.

Keywords Cassava; *gari*; material balance; cleaner production; waste prevention; wastewater.

1. Introduction

Industrial emissions are a major cause of environmental problems, both globally and locally [1]. It has a strong influence on both the local environmental situation and quality of life. Over the past decades, the industrialized nations have responded to pollution and environmental degradation; by not recognizing or ignoring the problem of environmental pollution; by diluting or dispersing pollution; by seeking to control pollution and wastes through the end-of-pipe; by controlling material and energy balance and by facilitating the practice of reuse and recycling [2]. It has been observed that the aforementioned strategies proved less effectivein solving environmental problems. For example, end-of-pipe technology simply shifted waste or pollutants from one environmental medium to another [2].

All in all, pollution control approaches of the 1970sand 1980s were no longer sufficient, and a new more flexible approach, had to be put in place that allowed creative solutions to be developed jointly by industry, government and environmentalists.In United Nations Conference on Environment and Development (Earth Summit) in 1992 in Rio de Janeiro, Brazil, the concept of Cleaner Production (CP) was suggested [3]. Cleaner Production is the continuous application of an integrated preventative environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment [4].Cleaner production is a preventive designed to minimize waste and emissions and maximize product output. The scope of cleaner production includes, good housekeeping; replacement of hazardous materials by less hazardous materials; modification of the working procedures, lower rates of waste and emission generation;and replacement of the technology.

Traditional method of cassava processing into its various products in developing countries has been regarded as polluting and a burden on natural resources [5]. For example, in Cong Hoa village, Vietnam, the total volume of water required to process 300 tonnes of roots for the area is about 2,400 m^3 [6]. Fermentation of the residues can cause the formation of CO_2 and organic acetic and lactic acids which contribute to its reduction and production of strong odours [7-9]. Water bodies receiving untreated cassava water have been reported to be highly acidic, sometimes with pH as low as 2.6 [10]. In the course of cassava processing (fermentation, pressing and washing) cyanide (a toxic component) is released into the environment in the form of hydrocyanic acid [11]. Product loss resulting from cassava processing into gari as a product have also been reported [12]. Within the scope of cleaner production, this study was designed to achieve the following objectives (i) examine the current traditional method of processing cassava for *gari*, (ii) quantify the losses that occur at the various stages of the production chain and (iii) propose a cleaner production option for the production of *gari* from cassava.

2. Materials and Methods

2.1 Study Area

The study area is Jesse, a rural community of Ethiope West Local Government Area of Delta State, Nigeria. The people are mainly farmers with cassava and yam being the main crops grown. The community lies within latitude 5^o43^1N and 5^o30^1N and longitude 6^o20^1E and 6^o12^1E. The area is within the humid tropical zone with defined dry (November – March) and rainy (April – October) seasons [13]. The relative humidity of the area is high with values ranging from 70% in January to 80% in July. Previous study [13] of the area reveals the average atmospheric temperature to be 25.5^{o}C in the rainy season and 30^{o}C in the dry season months (19.8 - 50.1mm).

2.2 Methodology

The methodology adopted for the study was based on UNEP's Audit and Reduction Manual for Industrial Emissions and Wastes (1991) and other relevant literature [14-18]. The methodology is used as a tool for assessing industrial activity aiming at detecting potential opportunities for prevention and reduction of pollution at source. It also provides sufficient data to the industry helping to direct its policy towards cleaner practices through technically and economically viable practices and technologies.

In this study, the adopted approach comprised of three phases; a pre-assessment phase for assessment preparation; assessment phase (data collection phase to derive material balance); and a synthesis phase where the findings from the material balance are translated into a waste reduction plan as outline in Table 1.

Table 1: The outline of cleaner production steps adopted in this study

S/N	Phases	Steps
1	Pre-assessment	• Visit and meeting with gari producers in the study area. • Listing of unit operations in the traditional method of gari production from cassava • Construction of the process flow diagram
2.	Assessment	• Working visit • Determining inputs • Measuring the levels of wastes and other losses • Quantifying outputs • Analysing inputs and outputs for unit operation • Development of the material balance
3	Synthesis	• Cleaner production option: A waste reduction plan.

3 Results and Discussions

3.1 Assessment of Traditional Method of Cassava Processing For Gari Production

Cassava root consists of 60 to 70% water and has a shelf life of 2 to 3 days [19]. Once harvested, it has to be either consumed immediately or processed into more stable product forms. Processing it into dry form reduces the moisture content and converts it into a more durable and stable product with less volume, which makes it easier for transportation. Processing is also necessary to eliminate or reduce the level of hydrocyannic acid

(HCN) or cyanide in the crop and to improve the palatability of the food products.The traditional method of cassava processing for *gari* production as illustrated in Figure 1 is made up of the following steps: peeling of the tubers, washing of peeled tubers, grating the washed tubers into mash, dewatering the mash, pulverization of dewatered mash and sieving, roasting of dewatered mash and cooling and final sieving.

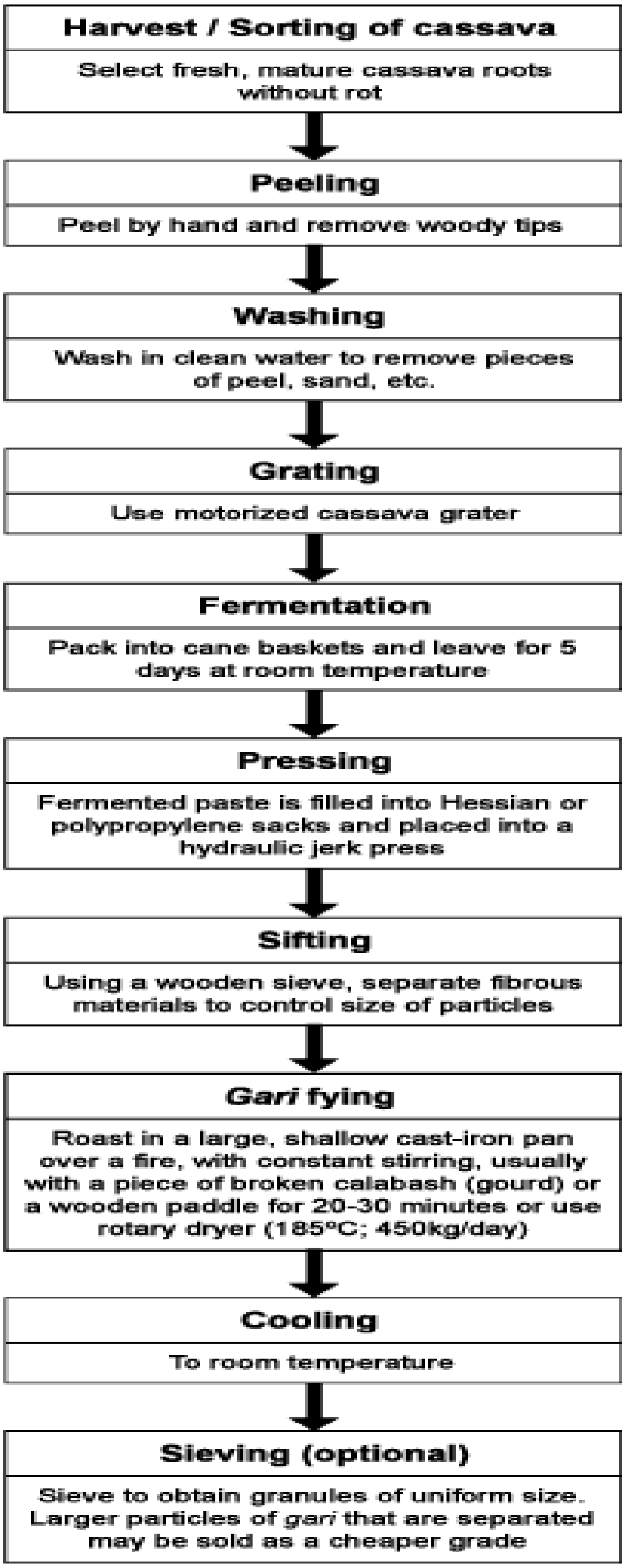

Figure 1: Flow Process for Traditional method of Gari production from cassava

Peeling: Peeling involves the manual removal of cassava peel with a knife or cutlass.The cassava is held in one hand and sliced thinly with the knife in the other. The whole cortex is removed, and it is generally understood that the peel is the most toxic part of the root [20]. The peeling operation is slow and time consuming and the rate of peeling depends on the variety and size of the cassava root [12]. The process of peeling may be described as unwrapping of the cassava skin. In Ghana, it has been estimated that, the rate of peeling varieswidely and averages at 25-50kg of peeled cassava per person per hour with a peeling loss of about 20-30 percent of the edible portion of the cassava [21]. In Nigeria, the rate of peeling is about 37kg cassava per hour per person [22]. There is the danger of the human peelers injuring their finger with the peeling knife in the process.

Washing: Washing is done manually and is aimed at removing dirt (sand, etc.) from the peeled tubers to avoid contamination of the final product. The tubers are collected in large containers and are washed with frequent changes of clean water.

Grating: Grating is an important step in the production of *gari*. After washing the peeled tubers, they are grated. Grating alters the texture of the raw material, cassava [23]. Grating can be carried out by hand (usually smaller quanity (20-30 kg), using a galvanised metal sheet with nail-punched holes attached to the bench on which the operator sits. This stage is labour-intensive. No more than 20 kg can be grated per hour per person and the process becomes even slower when the cassava roots are old and lignifications has set in. Moreover, because of danger to the fingers it is not possible to grate a whole cassava completely and about 3-5% of the root may be left un-grated. This type of grater is cheap and easy to construct.However, it is difficult to clean after use and residue of grated cassava lodged in the holes becomes a substrate for microbial growth and subsequent food contamination [12].

Almost all *gari* producers in the study area now use powered mechanical graters which is either diesel or petrol engine.

Fermentation and Dewatering: Fermentation consists of two distinct methods; aerobic and anaerobic fermentation. *Gari* production utilises anaerobic fermentation. In anaerobic fermentation, grated cassava is placed in sacks and pressed for 1-5 days. The optimum temperature for the fermentation of *gari* is 35 degree Celsius, increasing up to 45 degree Celsius depending on the ambient temperature [24]. Expressing all water from the mass will stop fermentation, the end of which is indicated by the appearance of froth on the outside of the sack. In this case, the fermentation time affects the colour, taste and texture of the gari [24]. After grating, the resulting mass is packed into perforated plastic sacks or polypropylene bags and dewatered. Dewatering involves the removal of internal liquid from the mash by pressing. Dewatering can take from 20 minutes to 4 days depending on the method used to squeeze out the water [24]. Traditionally, dewatering takes place simultaneously with fermentation. Pressure is applied to the mash-filled sacks either by placing stones or heavy objects on top of the sack or by twisting the necks by a tourniquet arrangement, or by pressuring the sacks between two parallel wooden boards and tightened by ropes. Sometimes the grated material is left to ferment in the open air for 1-4 days before pressure is applied to squeeze out the water [12]. It has been found that fermentation is a period or process of detoxification, which occurs in two stages. The bacterium, *Corynbacterium manihoti*, starts the fermentation process by attacking the starch present with the production of lactic and formic acids. This results in the lowering of the pH, which produces favourable conditions for theendogenous enzyme *linamarase* to hydrolyse *linamarin* and *lactomastralin* into gaseous hydrogen cyanide resulting in detoxification. The lowered pH also produces favourable conditions for the growth of the fungus *Geotrichu mcandida* that produces a variety of aldehydes and which contributes to the characteristic flavour and aroma of *gari* [25].

In upgraded mechanical processes, dewatering takes place after fermentation so that much of the fermentation liquor has already disappeared. Various press designs exist ranging from the simple, easily constructed parallel pressboards, press frame or wedge press to more sophisticated screw and hydraulic press [26]. Six threaded rods pass through the bottom frame to fit holes in the top. Tightening exerts pressure on the sacks by pressing the frame close together. The actual pressing time is not reduced but rather the time and labour necessary either to gather stones or sticks around the sacks are reduced. Only wood, bolts and threaded rods are needed [26].

Sieving: The pressed mash appears as a solid cake, which has to be broken up into separate individual particles. Sieving is important to obtain a high-quality product, free of fibrous contaminants and having similarsized granules. The primary aim of sieving is to remove the woody and fibrous portion of the mash. It also serves to pulverise the caked mash into loose, damp mash with uniform granule or particle sizes. Traditionally, the pressed fermented mash is broken up into granules by forcing the lumps through abamboo cane sieve, applying a moderate hand pressure in a rotating motion. The aperture size of the sieve has been found to correspond to 400 microns (0.157mm), which is ASTM (America Society for Testing Materials) mess NO. 5 [27].

Roasting: The processing of cassava into *gari* involves series of unit operations, the most tedious, time and energy consuming of which is roasting [28]. Roasting reduces the moisture content of the *gari* and so extending its shelf life. The fermented, dewatered and sifted mash is roasted in either a shallow slightly concave cast-iron pan on a dugout hearth both of which utilisers wood as the energy source. The flames from lighted wood fuel expertly placed in the stove holes heat the mounted pan, which transfers the heat by conduction to the sifted mash in the pan. The pan is sometimes smeared with oil, usually palm oil, and the sifted material is spread thinly in the pan in lots of 2.3kg at a time [12].

Each lot or batch is allowed to dry before the next batch is added. It is continually stirred to effect partial gelatinisation of the starchy granules. Stirring of the mash continues until a rustling sound is heard, indicating that almost all of the moisture has been driven off through roasting. This method of roasting may cause the processors (mostly women) to suffer from such ailments as headaches, bodily pains, fever, heat rashes, diarrhoea, reddening of the eyes, profuse sweating or even miscarriage due to close contact with the heat and smoke emanating from the roasting process [29]. The vapour driven off during the process also contains some cyanide and continuous inhaling of the vapour may also be a health hazard to the processor [21].

There is a high heat energy loss in most of the village *gari* roasting operation because of lack of the control of the wood fire intensity. Consequently there are high losses of heat and therefore energy consumption per unit output of *gari* is relatively high [21].

With the local roaster, the operator is by far exposed to smoke and heat and thus generating a lot of sweat which sometimes may contaminate the *gari* [30].

Final Sieving: The roasted *gari* is sieved again to remove large *gari* particles. Improper roasting results in unusual large amounts of crumbs or oversized particles [12]. The finished product is relatively an easy operation, since well-roasted gari is a free-flowing material. Trays made locally of bamboo or raffia is quite suitable for successful village level sieving.

3.2 Assessment of waste generated from the operating units

Starting with a basis of 100kg, Figure 2 represents the waste streams and the quantity of waste generated in the production of *gari* from cassava. A complete *gari*processing system consists of a number of unit operations of processes arranged in a certain sequence. Essentially, the unit operation consistsof peeling, washing, grating, fermentation anddewatering, sieving and roasting.

Peeling: Peeling usually results in the removal of some flesh along with the peel and/or imperfect removal of the peel hand peeling is slow, time-consuming and labour-intensive. Peels are used to feed sheep/goats.

Washing: Washing is done manually and is aimed at removing dirt (sand, etc) from the peeled tubers to avoid contamination of the final product. Washing process results in the generation of waste water.

Grating: Grating is achieved mechanically or manually depending on the quantity of cassava. The grating machine (mechanically or manually) holds back some quantities of the cassava in its grater and wooden part of the equipment.

Fermentation and dewatering: In the traditional operations fermentation and pressing (dewatering) are done in one operation. The waste liquid may be allowed to run into a nearby dug pit or collected in a container. Apart from the fetid stench that emanates from this liquid, it serves a breeding breeding grounds for mosquitoes. The riskof cross-contamination of disease microbes from this stagnant waste exists [15]. During dewatering some soluble cyanide and organic acid is removed with the press liquor. It also contains some starch and may be used as a base for starch production and the fremented liquor can also be used in the coagulation of rubber latex.

Sieving: After pressing the de-watered cassava mash is a solid cake which has to be broken up and sieved to remove the large lumps and fibre (from the central vascular strands) and to obtain an homogenous product. The sifted mash and chaff are continuously separated as they are produced. In most cases the chaff are sold to people that will further grind the particles for consumption.

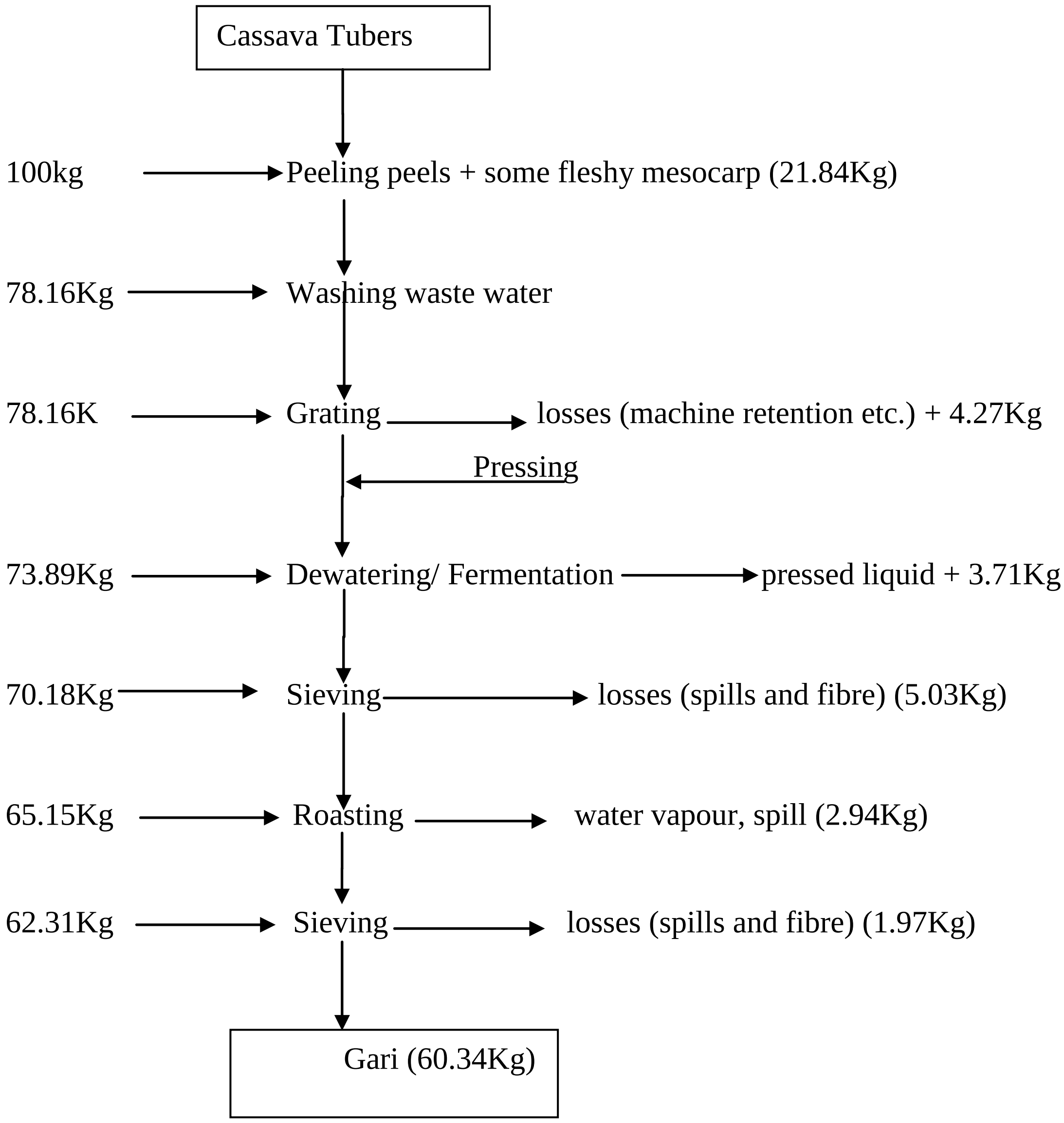

Figure 2: Waste Streams and material balance in the traditional method of cassava processing for Gari production

Roasting:The sieved cassava mash is spread thinly in the pan in 2-3kg batches. A piece of calabash is often used to press the mash against the hot surface of the pan but it must be scraped quickly and stirred constantly to keep the material moving to prevent it burning until frying is completed when it reaches a temperature of 80° to 85°C [31]. The rapid heating partially gelatinises the *gari* which is dried during the operation of frying. The process takes 30-35 minutes, with the moisture content of the final product reduced to about 18% [31-32]. Gelatinisation is complete in about 15 minutes and the rest of the time spent inside the roaster is used to reduce the moisture content to the desired level (8-11%) suitable for long-term storage [12]. The process of roasting usually results to spilling of *gari* particles especially during the constant stirring to prevent it burning.

Final Sieving: The roasted *gari* is sieved again to remove large *gari* particles. Improper roasting results in unusual large amounts of crumbs or oversized particles [12]. The *gari* chaff is often sold to people who may grind it for consumption.

3.3 Cleaner Production Options: Learning tp Prevent Waste Generation

The traditional method of cassava processing for *gari* production is made up of the following steps: peeling of the tubers, washing of peeled tubers, grating the washed tubers into mash, dewatering the mash, pulverization of dewatered mash and sieving, roasting of dewatered mash and cooling and final sieving. In that sense, the main environmental issues of the *gari* production process are primarily related to:

- Water pollution due to indiscriminate discharges of untreated effluents;
- Odour emission from poorly managed effluents treatment systems, especially if they are located in close proximity to neighboring residential areas;
- Some noise from the milling processes; and
- Loss of some quantity of cassava.

After an in-depth analysis of the above mentioned waste streams, According to [3], cleaner production options can be divided into 5 types:

• Good housekeeping: Improvements of work practices and proper maintenance can reduce the use of materials and energy and produce benefit.

• Substitution of raw and auxiliary materials: Replacing hazardous materials with more environmentally benign materials to avoid environmental problems. These options may require changes in process equipment.

• Modifications of products: Changing product design can result in benefits throughout the life cycle of the product, including reduced consumption of raw material and energy, reduced use of hazardous substances, elimination of production steps with major environmental impacts.

• Process modifications: Minimize waste generation through improved operating efficiencies including internal reuse/recycling or introduction of waste into external recycling networks.

• New technology: Adopting new technologies can reduce resource consumption and reduce waste generation.

In this study, the following Cleaner Production options were suggested;

i. Use of sharp knife to peel the roots and remove the skin;
ii. To reduce the quantity of cassava being lodged in the holes and within the torn flanges, a grater made of stainless steel and of small mesh size is suggested;
iii. Clean woven polythene sacksof smaller mesh size to hold the cassava mash after grating;
iv. Extra-fine siever of 0.25 mm to 0.5 mm aperture sieve should be used. Uniform particle size is important because it makes for a more uniform roasting of individual particles during the frying operation, smaller particles taking less time and less energy in roasting;
v. Improved fireplaces for the frying operation consisting of an elongated fireplace built of burnt-clay bricks and with a three meters high chimney at one end to remove smoke and fumes from the fire. The traditional cast iron pans for frying are set into the top of the fire place. The improved fireplace are said to reduce wood consumption by 55% and the frying time by about half [33].
vi. Good housekeeping measures: The following good housekeeping measures were recommended:
    - Keeping work areas tidy and uncluttered to avoid accidents;
    - Reusing relatively clean wastewater from the washing unit;
    - Construct an anaerobic pond in the area. Since a large portion of the easily biodegradable organic content in the wastewater is removed in the anaerobic digestion tank, effluent from this unit process will contain organic matter that is less biodegradable (low BOD/COD ratio). The objective of the anaerobic pond is to remove suspended solids and BOD/COD from the wastewater. The anaerobic digestion pond is used for pretreatment of contaminated wastewater and recovery biogas.

3.4 Barriers to CP Adoption

After discussing with the members of the gari processors in the study area on the waste and pollution prevention activities, the following constraints were expressed:

• The majority still perceives environmental protection as generating unnecessary costs, which they are not willing to bear.

• The farmers lack the resources to start prevention programs and lack the initiative to seek external assistance. Moreover, financial obstacles are crucial.

• The farmers lack the basic knowledge of good (environmental) management and adequate evaluation toolssuch as environmental audits and impact assessments.

• Lack of information on pollution prevention techniques and methodologies amongst the farmers.

4. Conclusions

Cassava processing for gari production requires large volumes of water. It also generates a large amount of solid waste and wastewater. This study suggests that the implementation of clean technology in the selected cassava processing mill can successfully reduce loss of cassava tubers, gari particles and sources of wastewater. The proposed measures of clean technology include good housekeeping, reuse of the wastewater from a polishing pond for plant cleanup, and recycling of water in the production line. In addition to water conservation measures, a technological change such as; Use of sharp knife to peel the roots and remove the skin; the use of a grater made of stainless steel and of small mesh size; the use of clean woven polythene sacksof smaller mesh size to hold the cassava mash after grating; the use of extra-fine siever of 0.25 mm to 0.5 mm aperture sieveand the application of improved fireplaces for the frying operation consisting of an elongated fireplace built of burnt-clay bricks and with a three meters high chimney at one end to remove smoke and fumes from the fire. This study shows that the adpotion of cleaner production is a viable and potential alternative to combat environmental problems related to cassava processing for gari production.

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