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Review

Cassava wastes: treatment options and value addition alternatives

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Value addition of cassava and cassava wastes is necessitated by rapid post-harvest spoilage, deterioration, low protein content and environmental pollution caused by the effluent and the other associated wastes that poses aesthetic nuisance. Biogas plants of all sizes and varying levels of technical sophistication not only recover the energy contained in cassava wastes but also eliminate most of the animal and human health problems associated with contamination. Studies have shown the technical feasibility and nutritional desirability of converting carbohydrates and their residues into products containing a large amount of protein by means of microorganisms. Wastes transformation offers the possibility of creating marketable value-added products. There exists a great potential in the use of microorganisms such as fungi for the production of high quality feedstuffs from the abundantly available agro-industrial wastes, particularly carbohydrate residues. Cassava wastes can be processed and converted into value-added components such as methane (biogas), pig meat, ethanol, surfactant and fertilizer etc. Attention is now focused on the by-products of the anaerobic decomposition of the waste that takes place in a biodigester, which are the liquid fraction called biol and the solid fraction or biosol, which are excellent fertilizers for a variety of crops. The present review addresses the progress that has been made in each of these aspects with emphasis on the advantages of biol and biosol fertilizers.

Key words: Carbohydrate residue, waste transformation, biofertilizers.

INTRODUCTION

Cassava processing is generally considered to contribute significantly to environmental pollution and aesthetic nuisance. The two major wastes of cassava processing in Nigeria are cassava sievates (a product from garri processing), and cassava offal (wastes from fufu production). About 10 million tonnes of cassava are processed for garri annually in Nigeria alone (Okafor, 1992). In the processing of cassava fermented products, the roots are normally peeled to rid them of two outer coverings: a thin brown outer covering, and a thicker leathery parenchymatous inner covering. These peels are regarded as wastes and are usually discarded and allowed to rot. With hand peeling, the peels can constitute 20 - 35% of the total weight of the tuber (Ekundayo, 1980). The wastes generated at present pose a disposal problem and would even be more problematic in the future with increased industrial production of cassava products such as cassava flour and dried cassava fufu. Products of fermentation of cassava peels from such heaps include foul odour and sometimes poisonous and polluted air, which when inhaled by man or animals may result into infection and diseases that may take a long time to manifest. In the same vein, vegetation and soil around the heaps of cassava peels are rendered unproductive and devastated due to biological and chemical reactions taking place between the continuously fermenting peels, soil and the surrounding vegetation. Since these peels could make up to 10% of the wet weight of the roots, they constitute an important potential resource if properly harnessed biotechnologically (Obadina et al., 2006).

Fermentation has been identified as one of the less expensive means of detoxification and increase of the protein quality of cassava. The use of microorganisms to convert carbohydrates, lignocelluloses and other Industrial wastes into foodstuffs rich in protein is possible due to the following characteristics of microorganisms: ability for a very fast growth rate, can be easily modified genetically for growth on a particular substrate under particular cultural conditions, high protein content varying from 35 to 60%, ability to grow in slurry or on solids and their nutritional values are as good as other conventional foods rich in protein. Barana (2000) reported that cassava liquid residue contains minerals (nitrogen, carbon, phosphorus, potassium, calcium, magnesium, sulphur, zinc, manganese, copper, iron and sodium) which, after anaerobic biodigestion, can still be used for fertirrigation, since the digestion processes does not substantially decrease the mineral content. Many attempts have been made to aggregate economic value to the liquid residue by considering its utilization as a fertilizer (Ponte, 2001), herbicide (Fioretto, 1985), insecticide (Ponte et al., 1992), nematicide (Ponte and Franco, 1983; Sena and Ponte, 1982), biosurfactant (Santos et al., 2000) or substrate for microorganism growth (Wosiacki et al., 1994). The production of biogas (Larceda, 1991; Fernandes, 1989; Fernandes, 1995; Barana, 1996; Barana, 2000), single-cell oil (Wosiacki et al., 1994), microbial protein (Menezes, 1994) and recently, aromas (Damasceno, 1998) can be sited as examples of its use.

TREATMENT OPTIONS FOR CASSAVA WASTES AND VALUE ADDED PRODUCTS

The problems of pollution from cassava processing are more social and economic in nature than technological. Interventions, usually from the government, are required. Most governments recognize the need to control waste produced by cassava factories, but they are equally aware of the economic risk involved in such a strategy.

Accessible technologies for most scales of processing are available; however, the cost of implementing the technology is, in many cases, prohibitive. According to starch processors, the installation of pollution control devices can be 20 - 50% of the total investment cost of a large-scale factory. Full implementation of strict environmental controls too quickly can have negative consequences, forcing the industry to forfeit its competitiveness. Dealing with environmental problems resulting from processing is generally regarded as a necessary expense with no direct return.

Waste materials from cassava processing (e.g. starch) are divided into four categories:

a) Peelings from initial processing
b) Fibrous by-products from crushing and sieving (pulp waste)
c) Starch residues after starch settling and
d) Waste water (effluent).

Ensiling of solid residues

A residue is a substance resulting from the processing of a product. It becomes a co-product or a by-product when profitable use is made of it. If this is not the case, the residue becomes a waste, which is defined as a material with no apparent market, social, or environmental value, that constitutes an environmental nuisance and a source of pollution. In starch processing, pulp waste is the main problem, especially for the bigger factories, which produce massive quantities. Dealing with this waste is difficult, as it is not easily dried, due to its high moisture and starch contents (Sriroth et al., 2000). On a dry weight basis, pulp constitutes about 20% of the original roots.

Ensiling of cassava residues is done by washing, drying and grinding of the residues. Ensiling is followed immediately after addition of 0.5% salt (of the fresh weight of the residue) before placing them either in a pit dug out of the ground, in a cement container or in plastic bags. These are filled with the residues as quickly as possible and compacted properly to eliminate air, so as to minimize the loss of nutrients by oxidation. Usually a polyethylene sheet is used to cover the ensiled material, to create anaerobic conditions for fermentation. During ensiling, anaerobic bacteria multiply rapidly, accelerating fermentation. Ideally the microorganisms which grow most rapidly will be predominantly *lactobacilli* species which produce lactic acid from the fermented residues.

The produced lactic acid lowers the pH and fermentation ceases after 3 to 4 weeks when the pH becomes so low that all microbial growth is inhibited. If ensiling procedures are such that lactic acid producing bacteria are not favoured, C*lostridal* type of microorganisms will grow. These organisms utilize water-soluble carbohydrates, lactic acid and protein for growth and produce butyric acid. However, the quality of silage is greatly reduced if a *Clostridal* type of fermentation predominates. In addition to *Lactobacilli* and *Clostridal* microorganisms, silage also contains yeasts, molds, coliforms, bacilli and propionic acid producing bacteria.

Apart from utilization of sugars as energy sources, silage microorganisms degrade protein to amino acids, amines and ammonia during fermentation. Literally hundreds of fermentation products are formed in addition to lactic and butyric acids. In case of cellulosic materials with high lignin components, digestion by animals is minimal. In such cases, a small amount of fermentable carbohydrates such as corn meal or molasses is added to produce silage, thus ensuring rapid fermentation. Silage making normally serves as one of the effective means of conserving high-moisture products for animal feed. Many crop residues are deficient in protein and minerals. It is therefore not uncommon for farmers to add products such as urea and minerals at the time of ensiling.

Ensiling lowers the cyanide level to non-toxic level, leads to a reduction in pH to 4.0 and allows lactic acid to build-up. Increased ensiling time decreased the levels of organic acids (acetic and butyric acids) while that of lactic acid is increased. The product can be subsequently used as animal feed (Nguyen et al., 1997).

Fermentation of cassava peels

Cassava peel wastes are generated in the production of farihna, garri and chikwangue. Inappropriate storage of the peels for long periods is the main issue especially with heavy rainfall. Utilization of the peel is limited by its low digestibility and toxicity from extremely high levels of hydrocyanic acid. Fermentation not only reduces toxicity, but the enzyme-resistant lingo-cellulose material is converted into a more digestible substrate. Following fermentation, cassava peel can be formulated into pig and poultry feed (Ofuya and Obilor, 1993).

Oboh (2006) studied the nutrient enrichment of cassava peels using a mixed culture of *Saccharomyces cerevisae* and *Lactobacillus* spp. solid media fermentation techniques. Three treatments (mixing of 150 ml of wastewater from fermented cassava pulp with 200 g of washed, dried and ground cassava peels and mixing of 150 ml of wastewater from the fermented inoculated pulp with 200 g of washed, dried and ground cassava peels) were observed for fermentation. The unfermented cassava peels served as control. The result of the analysis of the fermented cassava peels revealed that there was an increase in the protein content of the cassava peels fermented with wastewater from fermented cassava pulp when compared to unfermented peels (8.2%) (Oboh, 2006). This increase was highest in the peel fermented with wastewater from the inoculated cassava pulp (211.1%). The increase in the protein content of the cassava peels fermented with wastewater from the inoculated fermented cassava pulp could be attributed to the possible secretion of some extracellular enzymes (proteins) such as amylases, linamarase and cellulase (Oboh et al., 2003) into the cassava mash by the fermenting organisms (Raimbault, 1998), as well as increase in the growth and proliferation of the fungi/bacterial complex in the form of single cell proteins (Antai and Mbongo, 1994; Oboh et al., 2002). Conversely, a decrease in the carbohydrate content of the cassava peels fermented with wastewater from the inoculated cassava pulp (51.1%) was observed when compared to the unfermented cassava peels (64.6%). The decrease could be attributed to the ability of the fungi/bacterial complex to hydrolyze starch into glucose and ultimately the glucose will be used by the same organisms as a carbon source to synthesize fungi/bacteria biomass rich in protein (Oboh et al., 2002). However, Oboh (2006) observed that there was no discernable trend in the fat, crude fibre, ash and the mineral content of the cassava peels.

Cassava peels normally have higher concentration of cyanogenic glucosides than the parenchyma (pulp) and this makes the peel unsuitable for animal feed. Its fermentation with wastewater from the fermented cassava pulp reduced the cyanide content of the peels when compared with the unfermented cassava peels (Oboh, 2006). However, the cassava peels fermented with wastewater from cassava pulp fermented with a mixture of *S. cerevise*, *Lactobacillus delbruckii* and *Lactobacillus coryneformis* had a lower cyanide content (6.2 mg/kg) than those cassava peels fermented with wastewater from the naturally fermented cassava pulp (23.5 mg/kg). Results showed that wastewater from the inoculated cassava pulp were very efficient in cyanide detoxification than that of naturally fermented cassava.

The fermented cassava peels could be considered safe in terms of cyanide poisoning in view of the fact that the cyanide was below the deleterious level of 30 mg/kg (Tweyngyere et al., 2002). A decrease in phytate content of the fermented cassava peels (705.1 – 789.7 mg/100 g) was reported by Oboh (2006) and this decrease was more in cassava peels fermented with wastewater from naturally fermented cassava pulp (705.13 mg/100 g), while the unfermented cassava peels had 1043.56 mg/100 g phytate content. Such a decrease could be as a result of possible secretion of the enzyme phytase by the microorganisms in the wastewater. This enzyme is capable of hydrolyzing phytate thereby decreasing the phytate content of the fermented cassava peels (Oboh et al., 2003). In view of the increase in protein content of the cassava peels fermented with wastewater from fermented cassava products (inoculated and natural) and the significant decrease ($p < 0.05$) in the anti-nutrients (residual cyanide and phytate), this by-product could be a good supplement in compounding animal feed provided that it is acceptable and highly digestible.

Aerobic and anaerobic lagoons

Biological treatments of waste water though practiced by some starch factories in Thailand, Brazil, Vietnam and Kerala in India is based on a simple process in which mixed populations of microorganisms utilize the nutrients in the waste. They are of varying efficiency, require a large area of land and are capital intensive. Their efficiency is extended by the use of chemical engineering techniques that allows the basic process to be intensified and accelerated. Waste water containing both organic material and a source of nitrogen is brought into contact with a dense population of microorganisms. Sufficiently long contact times are engineered into the process so that the microorganisms can breakdown and remove the organic materials to a desirable level. This process can occur in the presence of oxygen (aerobic) or absence of oxygen (anaerobic). Aerobic systems create carbon dioxide and a large amount of biomass (microorganisms) while anaerobic systems produce biogas (methane, carbon dioxide and small amounts of hydrogen sulphide and ammonia) and biomass (microorganisms).

Lagoons are the simplest form of biological treatment, and the type of lagoon used is dependent on the available area and amount of waste to be treated. In view of the high organic content of cassava waste, anaerobic lagoon is preferred. Again depending on soil type, the need for lining, consisting of either clay or synthetic material, will add significantly to construction costs and electricity is only required to run the pumps. Various types of lagoons exist but in this context anaerobic and aerated lagoons are addressed.

Anaerobic lagoon/digestion

Traditionally anaerobic digesters have been used for the treatment of agricultural wastes. These processes require large tanks or bioreactors and long retention times of 20 - 25 days. Anaerobic digestion is a complex two-stage biological process in which the organic matter is reduced in an anaerobic environment. Its facilities may range from a simple, unmixed, unheated open tank (low rate digestion) to a mixed and heated covered tank (reactor), incorporating collection and utilization of the gas produced, followed by a secondary digester for liquid/solids separation (high rate digestion). Essentially an anaerobic lagoon is a crude uncontrolled anaerobic digester. The lagoon system is the most popular treatment system used by cassava starch processors for treatment of wastewater. The combined waste water is often collected in a storage pond from where it is pumped through a screen into a pretreatment pond. The wastewater is again pumped through a series of treatment ponds, the first 2 - 3 being anaerobic, where organic substances are successively degraded by natural breakdown processes. Such treatment produces wastewater with BOD as low as 15 mg/l and can be used for irrigation.

Recent advances in treatment technology and knowledge of microbial process control have led to the development of high-rate anaerobic treatment processes, some of which are being contemplated or used by the cassava starch industry. High-rate anaerobic treatments make use of microbial films to achieve high cell residence time. These processes operate in low hydraulic retention time and can process large amounts of organic material.

Biofilm processes used by the industry comprise different engineered configurations, such as fixed bed, moving bed, fluidized bed, recycled bed and up-flow anaerobic sludge blanket (UASB). All these reactors can handle loads up to 20 – 30 kg COD/m^3/day. All of these processes require a relatively small reactor size, and a vastly reduced requirement for land and capital.

Alazard (1996) described a laboratory-scale evaluation of different anaerobic treatments for wastewater from starch extraction in Colombia. These studies include comparison of UASB, UASB with phase separation, a 'transfilter' process (Farinet, 1993) and a rustic biofilter 'bamboo horizontal flow'. All these processes seem to be efficient in lowering the organic load of the waste. In all cases, efficient biodegradation (up to 90%) at an organic loading of 5 g COD/l/day is attainable, while maintaining a hydraulic retention time of 9 h. The production of biogas with 70% methane is about 350 l/kg of COD removed.

Given the low investment costs of the bamboo horizontal flow method, and its comparable efficiency with other more expensive procedures, this technique has potential for small-scale processors. Anaerobic digestion can yield a final product which is relatively odourless and rich in microbial biomass-a useful agricultural fertilizer. The gaseous product (biogas, sewer gas) may contain more than 50% of methane, and it can contribute most or all of the energy needs of the treatment process (Singleton, 1999).

Aerated lagoon

Another form of lagoons is the aerated lagoons with an aerobic surface layer, generally maintained by floating surface aerators, with an anaerobic zone below. As the organic material in the wastewater makes close contact with surfaces that bear a biofilm containing large numbers of bacteria, the sprayed organic material carries with it dissolved oxygen, so that some organic material in the waste water can be oxidized by its organisms and by those in the biofilm. The process is a controlled form of mineralization (Singleton, 1999). After treatments, the effluent has a much lower BOD with minimal odour.

Composting of cassava solid wastes

Recycling through composting is a largely neglected form of management. Yet, for something to be compostable, it must be biodegradable. Composting is the accelerated degradation of heterogenous organic matters by a mixed microbial population in a moist, warm, oxygenated environment under controlled conditions. Composting of biodegradable products like cassava wastes and paper wastes along with other organic compostable materials such as food and agricultural wastes can help to generate much-needed stable profitable carbon-rich compost that can be used for soil rejuvenation and conditioning. Compost soil increases organic carbon, water and nutrient retention, with the consequent reduction in chemical inputs, and suppression of plant diseases.

The disposal of various solid wastes is an ever-increasing problem, both financially and environmentally. A typical composting cycle usually includes the following processes: the cassava wastes are piled into heaps of approximately 500 m^3 and left to 'age', thereafter water and nitrogen (usually in the form of urea) are added to initiate composting. Temperatures within the heaps rise dramatically with peak sometimes as high as 80°C. Subsequently the heaps are watered and turned or mixed weekly for aeration, for a period of about three months as composting continues (stabilization). The finished product is then screened to obtain particles of a uniform size.

Composting processes are generally developed empirically, and the biological component is often regarded as a simple chemical reaction rather than the complex set of interactions that actually occur. Key factors that affect the rate of composting, such as temperature, pH, moisture and nutrient availability are all factors that profoundly influence microbial growth and activity. It is generally accepted that composting occurs in three stages: readily degradable organic compounds are utilized; followed by the thermophilic stage when temperature rises and the stabilization period when temperature drops. The self-heating that takes place is due to heat liberation from microbial metabolic activities.

The optimal moisture content for most composting processes is 50 - 70% (w/w), and the oxygen concentration should be maintained at greater than 0.1% preferably 5 -12%. Waste substances for composting that have high C:N ratios generally require the addition of a nitrogen source to initiate the intense microbial activities associated with composting. Other organic wastes such as chicken and piggery manure, and soy waste may be added. If a suitable nitrogen source is not added, the high temperatures associated with composting will not occur.

At all stages of composting, bacterial populations usually outnumber fungal propagules. Mesophilic and thermophilic fungi are killed off as the temperature of the organic waste increases to a maximum. On the other hand, thermophilic bacteria and actinomycete populations outnumber mesophilic populations during the latter part of composting. Bacteria are more important particularly in the initial stages and bacterial metabolism is responsible for the dramatic temperature increases that occur in composting while fungi may as well be important in the later stages.

The numbers of mesophiles and thermophiles may be similar at the start of composting but there may be subtle changes in the microbial species making up the populations during the aging period or changes due to degradation of organic constituents. Cassava solid wastes degradation is generally initiated by mesophilic heterotrophs, which, as the temperature rises, are replaced by thermophilic microorganisms. Thermophilic microorganisms that are prominent in the composting process includes *Bacillus stearothermophilus*, *Thermomonospora* spp., *Thermoactinomyces* spp. and *Clostridium thermocellum* while *Geotrichum candidum, Aspergillus fumigatus, Mucor pusillus, Chaetomium thermophile, Thermoascus aurantiacus* and *Torula* spp. are among the group of fungi implicated in the process. ‘Sour’ composting may result from anaerobic decompositions which liberate less heat and generate different end products from their aerobic equivalents. Composting has the advantage of being suppressive to many pathogens, production of a well balanced fertilizer, destruction of weed seeds and disease germs during the heating phase, pH increase in acid soils, reduction in waste volume, increase in soil organic matter content and also can reduce the phytotoxic properties (e.g. high C:N ratio). A major draw back of composting is the necessity to separate organic material from other wastes.

Therefore, it is probably economically advantageous only when organic material is collected separately from other wastes.

VALUE-ADDING OF CASSAVA WASTE PRODUCTS

The dwindling food and feed reserves in the world have increased interest in the exploitation of carbohydrate residues that at present largely go to waste and are pollution hazards. The conversion of organic waste and residues into livestock feed reduces the environmental hazards associated with crop and agro-industrial wastes. Within the past decade fresh impetus has been given to the serious study of these carbohydrate residues as substrates for the production of protein enriched foods or feeds through microbial fermentation and other forms of value addition. Part of this impetus has stemmed from wider recognition of malnutrition in the developing countries and efforts to combat it. At the same time, with the ever-increasing seriousness of the waste problems from the processing of food and natural carbohydrate sources, the production of microbial protein from these wastes and by-products could be a profitable way of overcoming this difficulty.

Carbohydrate residues are available in large quantities in many parts of South-East Asia. Some of these residues have been used as substrates to grow microorganisms, and their nutritive value has been documented (Stanton et al., 1969). In some countries like Malaysia, and in many of her neighbouring countries and in Africa, there are increasing needs for protein sources. Protein consumption has been reported to be about 45 g/day/person and to consist of not more than 17 g of animal protein. Efforts have been made to increase animal protein sources, such as meat from poultry and beef. Realizing these facts, considerable research has been conducted and is currently being intensified to maximize the use of various agro-industrial wastes, including those of carbohydrate residues, for useful animal feed and thus, indirectly, for food. Value addition of cassava and cassava wastes is necessitated by rapid post-harvest spoilage, deterioration, and environmental pollution caused by the effluent and the other associated wastes that poses aesthetic nuisance. Similarly, biogas plants of all sizes and varying levels of technical sophistication not only recover the energy contained in cassava wastes but also eliminate most of the animal and human health problems associated with contamination.

Production of animal feed from cassava wastes

Studies have shown the technical feasibility and nutritional desirability of converting carbohydrates and their residues into products containing a large amount of protein by means of micro-organisms. The residues from cassava processing include the solid and liquid wastes.

The liquid wastes are obtained from the wash tank (root wash water) and from the extraction and separators during the starch extraction process (separator wastewater). Yeast was among the micro-organisms considered as potential protein sources using wastewaters from cassava starch factories. A process for growing *Torula* yeast (*Torula utilis*) on separator wastewaters has been developed. Large numbers of yeast cells have been successfully recovered from this yeast propagation, amounting to about 40% of the total solids in the wastewaters. This process could contribute to greater use of organic nutrients in waste effluents, thus providing an economical means for minimizing their pollution hazards.

The two outer cassava waste materials that constitute the raw materials are; the brown outer peel which consists of lignified cellulosic material and the white inner portion which consists of parenchymatous material and contains most of the toxic cyanogenic glucosides (Okafor et al., 1998). It is suggested that they should first be sun-dried to reduce the moisture content to about 10% or less. Dried in this manner, they would be better susceptible to grinding and would also store better. The dried-ground peels are mixed thoroughly with the liquid from the fermenting mash and fermentation is spontaneous. The liquid contains a heavy load of microorganisms capable of hydrolyzing the glucosides (Okafor, 1998). The microorganisms in the fermenting liquid are able to produce linamarase, lysine and amylase. The amylase breaks down any starch granules escaping with the fluid, while the lysine will provide nourishment for the organisms. Fermentation period is for about 48 h, during which a slurry, rich in sugars, lysine and protein derived from the microbial biomass will result. Lysine is usually short in animal feed unless components such as soya bean cake are present. The resulting product can be dried and used as animal feed, whose wastes can be used for biogas production and the effluent and sludge from biogas digester used as fertilizer for the cassava plant, thus providing an integrated system.

Ethanol production from cassava waste

Cassava residue (starch-processing wastes) from cassava starch plant is a good raw material for ethanol production. The experiment was performed in two steps: enzymatic hydrolysis-which converts cellulosic materials and starch to fermentable sugar and ethanol fermentation which converts fermentable sugar to ethanol by *S. cerevisiae* TISTR5596 (Teerapatr et al., 2004). Cassava residues were hydrolyzed by mixed-enzyme of cellulase and pectinase at 28°C for 1 h, followed by α-amylase at 100°C for 2 h and finally glucoamylase at 60°C for 4 h. It was found that cassava residue with initial concentration of 11% non-water-soluble carbohydrate (w/v) could yield 122.4 g/l of reducing sugars. The increased amount of produced reducing sugars resulted from synergistic action of cellulase, α-amylase and glucoamylase. Pectinase did not directly promote the hydrolysis but its mixing with cellulase helped to reduce viscosity and eased the process of solid filtration (Teerapatr et al., 2004).

The optimum ethanol concentration obtained was 3.62% (w/v), corresponding to 91% of theoretical yield after 24 h fermentation of initial reducing sugars concentration of 89.2 g/l. The production cost of one liter of ethanol using cassava residues as a raw material was 1.5 fold higher than the one from cassava root. However, considering the negative impact of cassava waste and the fact that landfill operation could be decreased up to 81%, the process is environmentally sound and of immense economic benefit. Thus, utilization of cassava residue for ethanol production could provide the most effective use of natural resources and lead to technology development for further cost reduction.

Production of surfactant from cassava wastewater

Production and properties of a biosurfactant was synthesized by *Bacillus subtilis* LB5a strain, using cassava wastewater as substrate according to Marcia et al. (2006). The micro-organism was able to grow and produce surfactant on cassava waste, reducing the surface tension of the medium to 26.6 mN/m and giving a crude surfactant concentration of 3.0 g/l after 48 h. The surface-active compound retained its properties during exposure to elevated temperatures (100°C), high salinity (20% NaCl) and a wide range of pH values. The surfactant was found to be capable of forming stable emulsions with various hydrocarbons (Marcia et al., 2006). The successful production of the surfactant proved cassava wastewater to be a suitable substrate for biosurfactant biosynthesis, providing not only bacterial growth and product accumulation but also a surfactant that has interesting and useful properties with potential for many industrial applications.

Processing of cassava waste for improved biomass utilization

Cassava pulp is the solid waste produced as a consequence of starch production. This pulp contains a high starch content (50 - 60% dry basis), causing an environmental problem with disposal. In order to recover this starch, physical or biological treatment of the material must be employed. Pulp can be treated either by sonic or incubation with a multi-enzyme mixture of cellulase and pectinase (Sriroth et al., 2000). Both methods were found to improve efficiency of starch extraction by disrupting the complex structure of polysaccharides associated with and entrapping starch granules. In the enzymatic treatment, the content of cellulase and pectinase for high efficiency of starch extraction determined the yield of liberated starch was investigated using response surface methodology (Sriroth et al., 2000). Use of either cellulase or pectinase alone reportedly failed to effectively improve starch extraction. Sriroth et al. (2000) observed that cellulase concentration seemed to have a greater effect on efficiency of starch yield than pectinase concentration. Treatment of pulp with 15 Novo cellulase units (NCU) of cellulase and 122.5 polygalacturonase (PG) units of pectinase per g dry pulp for 60 min resulted in 40% starch recovery. Quality characteristics of the liberated starch, including paste, viscosity and thermal properties were reportedly comparable to a primary starch obtained by root extraction. Susceptibility of the liberated starch to α-amylase was inferior to that of a primary starch. Cellulase and pectinase, however, increased α-amylase susceptibility of the starch remaining in the pulp.

Waste to worth/wealth

Wastes transformation offers the possibility of creating marketable value-added products. Anecdotal information suggests that cassava wastewater can produce problems in some crops. The potential of wastewater as a nutrient-rich irrigation source for certain crops is currently being evaluated, along with a detailed assessment of the functioning of the existing ‘sedimentation’ ponds and channels as treatment processes for the wastewater (Peters et al., 2000).

Henry and Howeler in 1996 reported that cassava peel can be utilized as a medium for mushroom cultivation or can be used to produce compost. The waste holds moisture and its nutrients are available for growing mushrooms. In Guangxi, China, the pulp which is generally used as an animal feed, is used as a raw material for the production of ethanol. In Vietnam, solid waste (mainly pulp) is sun dried and used as fuel for production of maltose. Already more than 80% of the cassava solid waste is being used productively, primarily as pig and fish feed and also for other innovative purposes. The literature is replete with ‘novel’ technologies for treating agricultural waste, including that produced by cassava processing, many involving fermentation by bacteria or yeast for production of biofuel, such as ethanol (Tanticharoen et al., 1986; Abraham and Muraleedhara, 1996) or biogas. Other technologies involve the production of single cell protein from cassava waste Pham et al. (1992) and Demo-os et al. (2000) were able to increase the protein level by 10 - 20 folds when manufacturing livestock feed with protein-enriched cassava or sweet potato starch solid waste. This could be a potential avenue for processing and adding value to the cassava waste. However, Pham’s and Demo-os’s research were conducted in laboratories with chemical substances and sophisticated equipment, and therefore the process may need major modification before it can be applied on-farm. Such modifications and development of the technology for field implementation may need huge financial investment.

CONCLUSION AND RECOMMENDATIONS

There exists a great potential in the use of micro-organisms such as fungi for the production of high quality feedstuffs from the abundantly available agro-industrial wastes, particularly carbohydrate residues. Processes of traditional fermented food preparation in Asia and Africa can be modified, improved, and adopted for this purpose.

Residues from cassava, sago, and sugar cane processing, by virtue of their relatively low cost and abundance, are considered to be suitable substrates for microbial fermentation. The use of moist-solid fermentation for the enrichment of carbohydrate residues has several advantages over the submerged liquid-type fermentation adopted elsewhere. This process is relatively simple, does not involve sophisticated equipment, and is, therefore, more suited to village-level operation. It is hoped that a group of dominant micro-organisms can be discovered that will grow under a highly specific set of environments so that sterilization of the substrates before fermentation is not required. It is also recognized that, since the product is prepared in moist-solid form, there is no necessity for the tedious and expensive step of extracting the final product from the liquid mixture as required in submerged fermentation. To minimize the cost further, the drying step could be omitted by mixing the end-product with compounded feed before feeding farm animals.

Screening of micro-organisms with high conversion efficiency of protein from carbohydrate residues should be worthy of further investigation. From the safety and nutritional point of view, microbially enriched carbohydrate residues such as fermented cassava have great potential for feeding livestock. Cassava wastes can be processed and converted into value-added components in terms of methane (biogas), pig meat and fertilizer etc. Attention is now focused on the by-products of the anaerobic decomposition of the waste that takes place in a biodigester, based on an integrated system approach (Cassava peels → animal feed → biogas production → effluent and sludge as fertilizers) which are the liquid fraction called biol and the solid fraction or biosol, which are excellent fertilizers for a variety of crops. Biol contains many essential elements for plant growth, such as nitrogen, phosphorus, potassium and calcium. It also offers additional benefits to plants because it contains plant growth regulators such as auxines and gibberelin, as well as other substances that stimulate plant development (Gomero et al., 2000). The solid part, biosol, has similar nutrient contents. Both fertilizers favour rooting, development of the foliage and flowering, and activation of seed germination.

However, the nutrient content of the liquid fertilizer can be easily modified by adding chopped alfa-alfa, fish entrails, marine seaweed or human urine to the biodigester. According to Gomero et al. (2000), biol can also be enriched with mineral salts to provide additional nutrients to a crop or for other purposes. For example, copper sulphate can be added to the liquid fertilizer to control diseases such as leaf rust in the coffee crop. Biol and biosol fertilizers can be used as a fertilizer for a wide variety of plants and crops. The concentrated boil can be diluted by mixing four litres of the liquid fertilizer with ten litres of water (Gomero et al., 2000). Proper sieving is recommended to prevent clogging of the spraying nozzle.

The application can be directed to the foliage, the soil, the seed and/or the roots. It can also be applied to the irrigation water and between three and five applications are optimums during the vegetative development of the plants. The application of biosol, the solid by-product fertilizer of biodigester is simply the same procedure as that of our normal compost manure.

In the past, biodigesters have been considered mainly as a way to produce combustible gas from waste organic matter. Due to the increasing emphasis on the sustainable use of natural resources in farming systems, it is now appreciated that biodigesters should be considered in a much wider perspective, and specifically in their potential role for the recycling of plant nutrients. This can help to reduce dependence on inorganic fertilizers and make it easier to grow organically (Preston and Botero, 1995). Recent developments have focused on integrating the biodigester within the farming system and have demonstrated that the biodigestion process leads to major improvements in the value of the livestock manure as fertilizer for crops, as well as for water plants or fish cultivated in ponds. The process of fermentation in biodigesters transforms organically bound carbon into gaseous carbon dioxide and methane. The anaerobic process and the long time in the biodigester kill most organisms, including intestinal parasites, which can cause diseases. In this way, livestock manure is improved chemically as well as biologically through the fermentation process.

Similarly, waste stabilization ponds are a low-cost system proven to be most effective in removing pathogens in a warm climate. They can be built and operated without much mechanical equipment, unless wastewater needs to be pumped or machinery is required to desludge ponds. Wastewater can also be held in tanks in which organic matter and suspended solids are allowed to settle before being used for irrigation.

REFERENCES

Abraham M, Muraleedhara M (1996). Bioconversion of tapioca (*Manihot esculenta*) waste and water hyacinth (*Eichhornia crassipes*)-influence of various physico-chemical factors. J. Ferment. Bioeng. 82: 259-263.

Alazard D (1996). Operation 2. Traitment des dechets solides et liquids. In: vaporization des produits et sous-produits et sous-produits de la petite et moyenne industrie de transformation du manioc en. Amerique Latine. Rapport final 1992-1995. Cotrat CEE TS3-CT92-0110. pp. 100-136.

Antai SP, Mbongo PM (1994). Utilization of cassava peels as substrate for crude protein formation. Plant Foods Hum. Nutr. 46(4): 345-351.

Barana AC (1996). Estudo de carga de manipueira em fase metanogenica em reator anaerobio de fluxo ascendente e leito fixo. Botucatu: UNESP/FCA, p. 80 (Dissertacao-Mestrado).

Barana AC (2000). Avaliacao de tratamento de manipueira em biodigestores fase acidogenica e metanogenica. Botucatu: UNESP/FCA, p. 95 (TESE-Doutorado).

Damasceno S (1998). Manipuiera como substrato para desenvolvimento de Geotrichum fragans. Botucatu: UNESP/FCA, p. 117 (Tese-Doutorado).

Demo-os RA, Valdez TSJ, Mapili MC (2000). Feeding value of protein-enriched sweet-potato pulp for broilers. Philipines J. Veteran Anim. Sci 26: 41-50.

Ekundayo JA (1980). In; Fungal Biotechnology. Eds.: Smith JE, Berry D R, Kristiasen B. London: Academic Press. pp. 244-270.

Fernandes Jr A (1989). Ocorrencia de instabilidade e forma de seu controle na digestao anaerobia de manipuiera em reator de bancada de mistura completa. Botucatu: UNESP/FCA, p. 118 (Tese-Mestrado).

Fernandes Jr, A (1995). Digestao anaerobia de manipuiera com separacao de fases: cinetica da fase acidogenica. Botucatu: UNESP/FCA, p. 139. (Tese-Doutorado).

Fioretto RA (1985). Efeito da manipuiera aplicada em solo cultivado com mandioca (Manihot esculenta, Crantz). Botucatu: UNESP/FCA, p. 112 (Dissertacao-Mestrado).

Gomero OL, Velasquez AH (2000). Manejo ecologico de suelos, experiencia y practices para una agricultura sustentable. RAAA, Lima, Peru.

Henry G, Howeler R (1996). Cassava in China in an era of change. A CBN case study with farmers and processors. Working Document No. 155. CIAT, Cali, Columbia. p. 18.

Larceda THM (1991). Estudo cinetico da fase metanogenca de substrato de manipuiera. Botucatu: UNESP/FCA, p. 114 (Tese-Doutorado).

Marcia N, Glaucia MP (2006). Producton and properties of a surfactant obtained from Bacillus subtilis grown on cassava wastewater. Bioresour. Technol. 97(2): .336-341.

Menezes TJB de (1994). Mandioca, residuas e subproducts para producao de biomassa proteica. In: CEREDA, M. P. Residuos da industrializacao da mandioca. Sao Paulo: Pauliceia. pp. 101-108.

Nguyen Thi Loc, Preston TR, Olge B (1997). Cassava root silage for croobred pigs under village conditions in central Vietnam. Livest. Res. Rural Dev. (9)2: 12-19.

Obadina AO, Oyewole OB Sanni LO, Abiola SS (2006). Fungal enrichment of cassava peels proteins. Afri. J. Biotechnol. 5(3): 302-304.

Oboh G, Akindahunsi AA, Oshodi AA (2000). Nutrient and anti-nutrient content of *Aspergillus niger* fermented cassava products (flour and garri). J. Food Compos. Anal. 15(5): 617-622.

Oboh G, Akindahunsi AA (2003). Biochemical changes in cassava products (flour and garri) subjected to *Saccharomyces cerevisae* solid media fermentation. Food Chem. 82(4): 599-602.

Oboh G (2006). Nutrient enrichment of cassava peels using a mixed culture of *Saccharomyces cerevisae* and *Lactobacillus* spp. solid media fermentation techniques. Electron. J. Biotechnol. 9(1).

Ofuya CO, Obilor SN (1993). The suitability of fermented cassava peel as a poultry feedstuff. Bioresour. Technol. 44: 101-104.

Okafor N (1992). Commercialization of fermented foods in Sub-Saharan Africa. In Application of Biotechnology to traditional fermented foods. pp. 165-169. National Academy press, USA.

Okafor N, Umeh C, Ibenegbu C (1998). Amelioration of garri, a fermented food derived from cassava, *Manihot esculenta* Crantz, by the inoculation into cassava mash, of microorganisms simultaneously producing amylase, linamarase, and lysine. World J. Microbiol. Biotechnol. In press.

Peters D, Ngai, Do Duc, Dang Thi An (2000). Agro- processing waste assessment in Peri-urban Hanoi. CIP programme Report, Institute of Ecology and Biological Resources (IEBR) Hanoi, Vietnam.

Pham CB, Lat MRLY, Ramirez TJ, Quinlat MJ, Pham LJ (1992). Enriching cassava protein using solid state fermentation. BIOTECH, University of the Philippines at Los Banos, Philippines.

Ponte JJ da, Franco A (1983). Manipueira, um nematicida nao convencional de comprovada potencialidade. Nematologia Brasileira, 7: 21-25.

Ponte JJ da, Franco A, Santos JHR (1992). Eficiencia da manipueira no controle de duas pragas da citricultura. In: Congresso Brasileiro de mandioca, 7., Recife, Anais. Recife: Sociedade Brasileira de mandioca. p. 59.

Ponte JJ da (2001). Uso da manipueira como insumo agricola: defensive e fertilizante. In: Cereda, M. P. Manejo, uso e tratamento de subprodutos da industrializacao da mandioca. Sao Paulo: Fundacao Carg ill. pp. 80-95.

Preston TR, Botero R (1995). Low-cost biodigester for production of fuel and fertilizer from manure (Spanish) Manuscrito ineditato CIPAV, Cali, Columbia. pp. 1-20.

Raimbault M (1998). General and microbiological aspects of solid substrate fermentation, Eletronic Journal of Biotechnology [online]. Vol.1(3) [cited 28 August 2001]. Available from: http://www.ejbiotechnology.info/content/vol1/issue3/full/9/9.PDF. ISSN 0717-3458.

Santos CFC, Pastore GM, Damasceno S, Cereda MP (2000). Producao de biosurfactantes por linhagens de Bacillus subtilis utilizando manipueira como susbtrato. Revista ciencia e Tecnologia de Alimentos 33: 157-161.

Sena ES, Ponte JJ da (1982). A manipueira no controle da meloidoginose da cenoura. Nematologia Brasileira. 6: 95-98.

Singleton P (1999). In: Bacteria in Biology, Biotechnology and Medicine. 4th edn., John Wiley and sons, Ltd, New York.

Sriroth K, Chollakup R, Chotineeranat S, Piyachomkwam K, Oates CG (1999). Processing of cassava waste for improved biomass utilization. Bioresour. Technol. 7(1): 63-69.

Stanton WR, Wallbridge (1969). Fermented food processes. Process Biotechnol. 4: 45-51.

Tanticharoen M, Lerttriluek S, Bhumirantana Supajanya N (1986). Biogas production from tapioca wastewater. Proc. Asean Conference on Energy from Biomass. pp. 215-224.

Teerapatr S, Chollada S, Bongotrat P, Wichien K, Sirintip C (2004). Utilizatyion of waste from cassava starch plant for ethanol production. Joint International Conference on “Sustainable Energy and Environment (SEE)”, Hua Hin, Thailand.

Wosiacki G, Fioretto AMC, Cereda MP (1994). Utilizacao da manipueira para producao de biomassa oleaginosa. In: Cereda, M. P. Residuos da industrializacao da mandioca. Sao Paulo: Pauliceia. pp. 151-161.