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VALUE ADDITION TO FOOD AND AGRICULTURAL WASTES: A BIOTECHNOLOGICAL APPROACH

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ABSTRACT

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The vast quantities of wastes generated as a result of diverse agricultural and food industrial practices represent one of the most energy-rich resources on the planet. Accumulation of this biomass in large quantities results not only in environmental degradation, but also in the loss of potentially valuable material which can be processed to yield a number of value added products. Current global best management practice is to convert these wastes into useful products through the use of appropriate technology thus, contributing to food security, environmental protection and sustainability. This review focuses on developments on the utilization of the vast food and agricultural waste for the production of variety of highly valued products such as biofuels, industrial chemicals, food/feed, biofertilizer, reducing sugars, antimicrobial compounds, enzymes, flavouring compounds, capacitor electrode, exoplolysaccharides, biocomposites, bioinsecticides, secondary metabolites, biosorbents, using biotechnological approaches.

Keywords: *Biocomposite, biofuel, biosorbsent, chitosan, fructooligosaccharide, food wastes, value-added products.*

INTRODUCTION

Waste management problem has increased at an alarming rate around the world in direct response to rising population growth and industrialization. Waste disposal and by-product management in food and agriculture pose problems in the areas of environmental protection and sustainability (Russ and Pittroff, 2004). This has even worsened with the adoption of the quick to use and quick to discard consumer habits which generate an endless stream of liquid and solid wastes. Developed countries exercise the best management practices in waste handling and disposal, while the less developed countries, generally lack adequate means to handle and dispose of many wastes in an environmentally safe manner. In spite of efforts of public agencies, waste management problem persists. Until recently, some countries had not been concerned with waste disposal; their concern had not gone beyond physical removal of waste from the streets. It has been and still common practice to dispose of refuse by the most expedient method available. Such methods might be by open burning or the use of an open dump, but with an increasing population and rapid urbanization, industrialization, and demands of some products, wastes generated from food and agricultural sectors are piling up faster than finding satisfactory places to dump them.

In the recent past , there has been great social and environmental pressure for efficient reutilization of food and agricultural waste (Santana-Meridas *et al.,* 2012) due to the global intensification of food production that has led to the creation of large quantities of food and agricultural wastes (Kasapidou *et al*., 2015). The utilization of food and agro industrial by/co-products in farm animal nutrition reduces the environmental impact of the food industry and improves profitability and valorization of food and agricultural residues. Value addition is a process of increasing the economic value and consumer appeal of a commodity (Parveen *et al*., 2014). It is a production/ marketing strategy driven by customer needs and preferences. Through value addition, food and agricultural wastes are changed from its original form to a more desirable form, thus, increasing the economic value of the product. The primary reason for processing food and agricultural wastes is to convert these wastes to a more useful form.

Interestingly, recent advances in technology, particularly biotechnology have led to the utilization of these wastes into value- added products. Food and agricultural wastes can potentially be bio-converted into value-added products such as food, bioactives, fuels, animal fed and bio-fertilizer among others, through the action of enzymes (Cohen *et al.,* 2002) and/or anaerobic digestion of these wastes, thus contributing to food security and sustainable development. In nature, there is no such thing as waste, even the dead or discarded material from one part of an ecosystem is always used to benefit other parts. This paper reviews a variety of value-added products from food and agricultural wastes.

FOOD WASTES

Food wastes are waste arising from the processing of biological materials to marketing, distribution and consumption of final product (Okonko *et al.,* 2006). Food processing industries release a large amount of waste materials because they process the crude raw materials (fruits, vegetables, animals, spices, condiments, cereals or pulses) into finished products. For example, the fruits and vegetable processing industries release 50% of the weight of raw materials as waste products in the form of peels, stones or fibres. Similarly animal processing industries (e.g. slaughter houses) release a lot of waste products in the form of and hides, blood, fats, horns, hoofs, hairs, feathers, shells, bones, liver, intestines etc. Ezejiofor *et al*. (2014) reported that some of them are of much use while others are not. Industrialization of food production has resulted in a generation of large quantities of food waste that can be classified into the following six categories: (a) crop waste and residues; (b) fruit and vegetables by-products; (c) sugar, starch and confectionary industry by-products; (d) oil industry by-products; (e) grain and legume by-products; and (f) distilleries' and breweries' by-products (Kasapidou *et al*., 2015).

Food wastes are also generated from catering units, enterprises, canteens and families in the process of food processing and dining. The composition of wastes emerging from food processing factories is extremely varied and depends on both the nature of the product and the production technique employed. For example, wastes from meat processing plants will contain a high fat and protein content, while waste from the canning industry will contain high concentrations of sugar and starches. Also, the waste may not only differ from site to site but also vary from one time of the year to another. Furthermore, the volume and concentration of the waste material will not be constant. This may cause some problems in managing a consistent working process due to fluctuations in the nature, composition and quantity of raw materials.

AGRICULTURAL WASTE

Agricultural activities produce many types of wastes in their daily operations. This includes biological waste, solid waste, hazardous waste, and waste water. It is important that these wastes are identified and managed properly to protect the dwellers in the community as well as the environment. Various waste management options have been adopted at various times by different countries, industries and organizations, and all of these have applied various levels of technologies, depending on what is available and accessible at a given time in terms of available technology (Kasapidou *et al*., 2015). The by-products of agricultural activities are usually referred to as "agricultural waste" because they are not the primary products. These wastes take the form of crop residues (residual stalks, straw, leaves, roots, husks, shells, etc) and animal waste (manures). Agricultural wastes are widely available, renewable and virtually free, hence they can be important resources (Sabiiti *et al.,* 2005). They can be converted into valuable products with the use of appropriate technology.

SOURCES AND NATURE OF FOOD AND AGRICULTURAL WASTES FOR BIOPRODUCT DEVELOPMENTS

In the food industry, wastes may occur in the various unit operations such as raw material handling, processing operations to packaging, distribution and consumption of the final product. Also in agricultural sector, wastes may occur at various stages including pre-harvest and post-harvest activities either in the farm, poultry or pen.

Food and agricultural wastes contain three primary constituents: cellulose, hemicellulose and lignin, and can contain other compounds (e.g. extractives). Cellulose and hemicellulose are carbohydrates that can be broken down by enzymes, acids, or other compounds to simple sugars, and then fermented to produce ethanol, renewable electricity, fuels, and biomass based products (Van Wyk, 2001). When the amount of organic agricultural waste, such as corn stalks, leaves and wheat straw from wheat-processing facilities, sawdust and other residues from wood mills, is also considered, this component of solid waste could be a principal resource for bio-development (Van Wyk, 2001).

LIGNOCELLULOSE WASTES

Lignocellulose wastes (LCW) refer to plant biomass wastes that are composed of cellulose, hemicelluloses, and lignin. They may be grouped into different categories such as wood residues (including sawdust and paper mill discards), grasses, waste paper, agricultural residues (including straw, peelings, cobs, stalks, nutshells, non-food seeds, bagasse, domestic wastes (lignocelluloses garbage and sewage), food industry residues, municipal solid wastes and the like. Currently, the second generation bio-products such as bioethanol, biodiesel, biohydrogen and methane from lignocellulose biomass are increasingly being produced from wastes rather than from energy crops (jatropha, switchgrass, hybrid poplar and willow) because the later competes for land and water with food crops that are already in high demand (Mtui, 2009). The use of food crops such as corn and sugarcane to produce biofuels is increasingly being discouraged due to the current worldwide rise in food prices. In order to minimize food-feed-fuel conflicts, it is necessary to integrate all kinds of biowastes into a biomass economy (Mahro and Timm, 2007). The lignocellulose biomass which represents the largest renewable reservoir of potentially fermentable carbohydrates on earth is mostly wasted in the form of pre-harvest and post-harvest agricultural losses and wastes of food processing industries. Due to their abundance and renewability, there has been a great deal of interest in utilizing food and agricultural waste in the form of LCW for the production and recovery of many value-added products (Pandey *et al.,* 2000; Das and Singh, 2004; Foyle *et al.,* 2007).

WASTES TREATMENT OPTIONS

A wide range of methods are available for the treatment of food and agricultural wastes prior to utilization. Some of these methods include mechanical, physical, chemical, as well as biological.

Physical treatment

The most successful physical treatments of food and agricultural wastes such as straws, stalks, peels, nutshells, saw dust, etc, are by subjecting the waste to high temperatures and irradiation, which will then decompose the hemicellulosic, cellulosic and lignin materials of the waste for further processing.

Mechanical treatment

This type of waste treatment is aimed at reducing the size of food and agricultural wastes to facilitate subsequent processing. This can be achieved by using mechanical chopper, miller, etc. Mechanical treatment increases the digestibility of the wastes components and enhances enzymatic digestibility with lower enzyme loads.

Chemical treatment

A wide range of chemicals such as acids, alkalis, salts, H_2O_2, etc, can be used to degrade food and agricultural wastes such as rice straw, sugarcane bagasse, cassava peel, corn cob and peanuts wastes, etc, thus, facilitating saccharification and improving enzymatic hydrolysis of these wastes materials. Studies have shown that when acids are combined with alkali, they play a more effective role in wastes pretreatment than acids and alkalis alone (Damisa *et al.,* 2008).

Biological treatment

Biological treatment of waste involves the use of microorganisms (fungi and bacteria) or enzymes in the treatment of food and agricultural wastes. Mtui (2009) reported that fungi are the most effective microorganism for biological pretreatment of food and agricultural waste materials. Recombinant stains of *Saccharomyces cerevisiae* have been genetically engineered to carry out simultaneous saccharification and fermentation (SSF) to produce extracellular enzymes which are used in the degradation of food and agricultural wastes and subsequent production of valuable products (Paris *et al.,* 2014). This method also improves the digestibility of wastes materials prior to further processing. These treatment methods can also be used in combination depending on the nature and choice of the final product, thus leading to cost effective and energy efficient processes. Advances in technology offer potential opportunities for economic utilization of food and agro-industrial residues. Bio-development of bio-waste provides a wide range of affordable renewable value-added products from food and agricultural wastes (Pandey *et al,* 2000; Van-Wyk, 2001; Howard *et al.,* 2003). These include;

Reducing sugars

Fermentable sugars comes first in the value chain of processed food and agricultural wastes with glucose, xylose, xylitol, cellobiose, arabinose, pentose and galactose being the main reducing sugars produced (Akmar and Kennedy, 2001; Yáñez *et. al.,* 2004; Tabka *et al.,* 2006; Hanchar *et al.,* 2007; Li *et al.,* 2008; Kim *et al*., 2008). Glucose seems to be the major monosaccharide product from food and agricultural wastes. In these sugar producing processes, hydrolysable sugars yield of up to 83.3% has been achieved at the reaction temperatures of 37-50°C for 6 -179 h at pH 5 - *6.* The size of substrate added determines the amount of the saccharification products (Baig *et al*., 2004). In the enzymatic hydrolysis, a degree of saccharification of 100% has been achieved (Marques *et al.,* 2008). Some transgenic plant residues have been reported to yield nearly twice as much sugar from cell walls compared to wild-types (Chen and Dixon, 2007). The challenge facing depolymerization of hemicelluloses into fermentable sugars is the requirement for a consortium of enzymes to complete the hemicelluloses hydrolysis, leading to high enzyme costs. Efforts to overcome the problem include process improvement and the use of modified microorganisms that produce the required hemicelluloses enzymes (Haan *et al.,* 2007).

Various bioconversion methods have been explored for the production of xylitol from hemicellulose using microorganisms or their enzymes. Xylitol is naturally found in low concentrations in the fibres of many fruits and vegetables and can be extracted from various berries, oats and mushrooms as well as fibrous waste materials such as corn husks and sugarcane bagasse and birch. Its production starts from xylan (a hemicellulose) extracted from fibrous waste materials, which is hydrolyzed into xylose and catalytically hydrogenated into xylitol. Xylitol is roughly as sweet as sucrose with 33% fewer calories. It is actively beneficial for dental health by reducing caries (cavities) to a third in regular use and helpful to remineralization (Ritter *et al.,* 2013).

Enzymes

Enzyme production has evolved rapidly and nowadays, enzymes are the most important products obtained for human needs through microbial sources. Due to the large industrial application and significant cost, there is a necessity to develop processes that could minimize the production costs. In this regard, the utilization of food and agricultural waste for the production of enzymes via solid state fermentation (SSF) has gained renewed interest from researchers as it solves solid waste disposal problem and also produce lesser waste water (Ezejiofor *et al*., 2014). Agricultural and food wastes present the most inexpensive and highly energy rich substrates for fermentation. In nature, solid organic substrates such as animal and plant residues, crop residues, fruits, etc., undergo complex microbial degradation and transformation by various microbiological processes. Agro-food industrial residues are generally considered the best substrates for the SSF processes for the production of enzymes (Ezejiofor *et al*., 2014).This is an important aspect which allows the reuse of a variety of low cost wastes for the production of this value-added product. A number of such substrates have been employed for the cultivation of microorganisms to produce lots of enzymes. These include: wheat bran used for the production of B-xylosidase, β-glucosidase, xylanase, cellulase, acid protease, α-amylase; bagasse used for the production of laccase, Mn-peroxidase, phenol oxidase, cellulase, β- glucosidase (Mtui, 2012); apple pomace used for the production of xylanase (Pandy and Pandy, 2002; Dhillon *et al*., 2012); wheat straw used for the production of xylanase, Carboxymethl cellulase, laccase, Mn-peroxidase, aryl-alcohol oxidase; coffee processing plant waste used for the production of xylanase, cellulase, α- arabinofuranosidase, β-xylosidase; rice husk used for the production of cellulase; rice bran used for the production of protease; soy-hull used for the production of cellulase; cassava waste used for the production of fructosyltransferase (Lateef and Kana, 2012); soybean meal waste used for the production of alkaline protease (Ezejiofor *et al*., 2014); cellulose, starch cellulosic wastes used for the production of cellulose, amylase, β- glucosidase; sugar beet pulp used for the production of polysaccharide degrading enzymes and tea production wastes used for the production of carboxymethl cellulase, xylanase, laccase (Ezejiofor *et al*., 2014).

Palm oil mill effluent (POME) has been reported to be utilized as a medium for industrial enzyme production by different microorganisms (Salihu and Alarm, 2012). White rot fungus *Phanerochaete chrysosporium* was used for lignin peroxidase production using POME as the main substrate in the presence of wheat flour as the co-substrate (Alam *et al*., 2006). Protease production by *A. terreus* IMI 282743 using pre-filtered POME yielded a maximum activity of 129 U/ml after four days of fermentation in a medium containing 75% (v/v) retentate of pre-filtered POME at 37^{o}C, 250 rpm and 5% (v/v) of temperature, agitation and inoculum concentration respectively (Wu *et al*., 2006). Based on this, Wu *et al.* (2009) explored the use of statistical experimental design to optimize the medium and process conditions. The optimum conditions of 37.95 ^{o}C, 1.30% (v/v) and 3.83 days for temperature, inoculum concentration and fermentation time respectively resulted in 4.37-fold increase in extracellular protease production. Rashid *et al*. (2009) studied the production of cellulase in the presence of POME as a basal medium. The results revealed that *T. reesei* RUT C-30 resulted in the filter paper cellulase and carboxymethylcellulase activity of 0.917 U/ml and 2.51 Uml^{-1} respectively after 5 days of fermentation.

Cellulase production from LCW has been extensively studied (Wen *et al.,* 2005; Muthuvelayudham and Viruthagiri, 2006; Daroit *et al*., 2007). Phytases, mannanases, amylases and other enzymes can also be produced by microorganisms using fibrous materials of food and agricultural wastes as the main feedstock (Bhavsar *et al.,* 2008; Mabrouk *et al*., 2008).

On the other hand, hemicellulolytic enzymes, mainly xylanases, are produced from a wide range of wastes biomass (Elisashvili *et al.,* 2006; Dobrev *et al.,* 2007). Pectinases such as endo-polygalacturonase (endo-PG), exo-polygalacturonase (exo-PG) and pectin lyase are mainly produced from solid state fermentation processes utilizing agricultural residues (Botella *et al.,* 2005, 2007), while protease has been produced by *Penicillium janthinellum* in submerged cultures (Oliveira *et al.,* 2006). Among the ligninases produced from food and agricultural wastes, laccases are the mostly studied (Nazareth and Sampy, 2003; Moides *et al.,* 2003, 2004) followed by manganese peroxidase and lignin peroxidase (Asgher *et al.,* 2006; Elisashvili *et al.,* 2008). Very high enzymes activities (31,786 U/L) have been reported under optimal conditions **(**pH 5.5 – 6; temperature 30 - 45°C). Recovery of pure enzymes is achieved through 50-80% $(NH_4)_2S0_4$ saturation followed by chromatographically purification techniques (Mtui and Nakamura, 2008). Several efforts have been made to increase the production of enzymes through strain improvement by mutagenesis and recombinant DNA technology. Cloning and sequencing of the various genes of interest could economize the enzymes production processes (Kumar *et al.,* 2008).

Studies by Rajagopalan and Krishnan (2008) showed that sugar cane bagasse hydrolysate (SBH) can be used for amylase production. Utilization of sugar cane bagasse has not been possible for amylase production by *Bacillus* sp. and there is no previous report for the production of amylase from *Bacillus* sp. in submerged or solid state fermentation. This is due to the fact that hydrolysis of sugar cane bagasse forms simple sugars primarily glucose, xylose and arabinose that repress amylase synthesis through catabolic repression. A new isolate of *Bacillus subtilis* KCC103 showed absence of repression by glucose during amylase synthesis. The level of amylase produced in sugar cane bagasse hydrolysate medium was equivalent to that in starch medium, therefore replacement of starch by SBH in production medium is highly feasible to produce amylase at low cost. Optimization of inulinase production by *Kluyveromyces marxianus* NRRL Y-7571 using sugarcane bagasse as substrate was studied by Marcio *et al*. (2006). The best fermentation conditions found after optimization was 36°C and 20% of corn steep liquor, which yielded about 390 Ug^{-1}. Maximum productivity was 3.34 Ug^{-1}h^{-1}. Sugarcane bagasse seems to present a great nutritional potential for growth of *K. marxianus* NRRL Y-7571 and production of inulinase. The use of solid state fermentation for the production of thermostable lipases is an interesting alternative to the valorization of bagasse and olive oil cake. Lipase production could be optimized by adding the appropriate precursors found in olive oil cake. Ezejiofor *et al.* (2014) reported that olive oil cake and sugar cane bagasse were used for lipase production using thermostable fungal cultures of *Rhizomucor pusillus* and *Rhizopus rhizopodiformis.*

Xanthan gum

Xanthan gum is an extracellular polysaccharide secreted by the micro-organism *Xanthomonas campestris*, commonly used as food thickening agent, in salad dressings and as a stabilizer in cosmetic products to prevent ingredients from separating. Xanthan gum is produced by fermentation using glucose as the base substrate but theoretically these same products could be manufactured from lignocelluloses waste materials of food and agriculture. The waste is hydrolyzed to fermentable sugars (glucose). It is then inoculated with bacterium

Xanthomonas campestris. The medium is well-aerated and stirred, and the polymer is produced extracellularly by the organism, into the medium. After fermentation which can vary from one to four days, the polymer is precipitated from the medium by the addition of isopropyl alcohol, and the precipitate is dried and milled to give a powder that is readily soluble in water or brine.

Biofuels

Worldwide, there is a growing concern over the fossil oil prices increase, the security of the oil supply and the negative impact of fossil fuels on the environment, particularly greenhouse gas emissions (Hahn-Hãgerdal *et al.,* 2006). Biofuels are renewable fuel and electricity produced from it can be used to attract renewable energy subsidies in some parts of the world. Conversion of fibrous materials of food and agricultural wastes to biofuels provides the best economically feasible and conflict-free second- generation renewable alternatives (Rubin, 2008**.** Significant advances have been made towards bioconversion of plant biomass wastes into bioethanol, biodiesel, biohydrogen and biogas (methane). Production of ethanol from sugars or starch from sugarcane and cereals, respectively, impacts negatively the economics of the process, thus making ethanol more expensive compared with fossil fuels. Hence, the technology development focus on the production of ethanol has shifted towards the utilization of residual lignocellulosic materials of food and agricultural origin to lower production costs (Howrard *et al*., 2003).

Currently, research and development of saccharification and fermentation technologies that convert food and agricultural wastes to reducing sugars and ethanol, respectively, in eco-friendly and profitable manner have picked tempo with breakthrough results being reported (Lin and Tanaka, 2006; Tahezaden and Karimi, 2007). Ethanol yield of 6 **-** 21% has been obtained through fermentation of agricultural and municipal residues (Akin-osanaiye *et al.,* 2005; Li *et al.,* 2007; Mtui and Nakamura, 2008; Cara *et al.,* 2008). While microaeration enhances productivity of bioethanol from wastes using ethanologenic *E. coli* (Okuda *et al.,* 2007), simultaneous saccharification and fermentation (SSF) using recombinant *Saccharomyces cereviasiae* result to as high as 62% of the theoretical value (ltoh *et al*., 2003). The principal benefits of performing the enzymatic hydrolysis together with the fermentation, instead of in a separate step after the hydrolysis, are the co-fermentation of both hexoses and pentoses during SSF, reduced end-product inhibition of the enzymatic hydrolysis and the reduced investment costs (Kádár and Réczey, 2004; Olofsson *et al.,* 2008). Life Cycle Assessment (LCA) shows that bio-ethanol from fibrous agricultural waste results to reductions in resource use and global warming (Von Blottnitz and Curran, 2007). The long-term benefits of using waste residues as lignocellulosic feedstocks will be to introduce a sustainable solid waste management strategy for a number of lignocellulosic waste materials; contribute to the mitigation in greenhouse gases through sustained carbon and nutrient recycling; reduce the potential for water, air, and soil contamination associated with the land application of organic waste materials; and to broaden the feedstock source of raw materials for the bio-ethanol production industry (Champagne, 2007).

Biodiesel is a renewable fuel conventionally prepared by transesterification of pre-extracted vegetable oils and animal fats of all resources with methanol, catalyzed by strong acids or bases (Liu and Zhao, 2007). They are fatty acid methyl or ethyl esters used as fuel in diesel engines and heating systems (Ito *et al.,* 2005). Production of biodiesel from agricultural residues such as olive oil wastes had been successful and is geared towards improving the thermal waste treatment systems and cleaner energy production (Arvanitoyannis *et al.,* 2007a, 2007b). Since the current supplies from wastes based oil crops and animal fats account for only approximately 0.3%, biodiesel from algae is widely regarded as one of the most efficient ways of generating biofuels and also appears to represent the only current renewable source of oil that could meet the global demand for transport fuels. Biodiesel is a substitute for fuels that produce a lot of soot and carbons. These poisonous elements are, associated with regular diesel fuel emissions (especially buses). However, biodiesel has been around for decades as a supplement that is added to conventional diesel fuel to improve the lubricity of diesel engines. Many car manufacturers are considering creating vehicles that can accommodate a biodiesel product by creating a diesel car that is friendly to the use of vegetable oil blended with diesel fuel. In addition to displacing North America's reliance on imported petroleum, the use of biodiesel product has been shown to reduce air pollution and greenhouse gases (Lapuerta *et al*., 2008).

Hydrogen has also been considered a potential fuel for the future since it is carbon-free and oxidized to water as a combustion product (Najafpour *et al.,* 2004). While conventional burning or composting seem to be the most cost-effective hydrogen production methods, bacteria such as *Enterobacter aerogenes* and *Clostridium* sp isolates can convert saccharified food and agricultural biomass into biohydrogen (Ito *et al.,* 2005). Biohydrogen production from agricultural residues such as olive husk pyrolysis (Ca lar and Demirba, 2002); conversion of wheat straw wastes into biohydrogen gas by cow dung compost (Fan *et al.,* 2006); bagasse fermentation for hydrogen production generate up to 70.6% gas yields (Singh and Asthana, 2007). System optimization for accessibility of polysaccharides in agricultural wastes and the use of genetically efficient bacterial strains for agrowaste-based hydrogen production seem to be the ideal option for clean energy generation. Hydrogen generation from inexpensive abundant renewable biomass can produce cheaper hydrogen and achieve zero net greenhouse emissions (Zhang *et al.,* 2007). Overall, the success of biofuels production from food and agricultural wastes is dependent on the optimal performance and cost effectiveness of pretreatment and product generation processes.

Organic acids

An organic acid is an organic compound with acidic properties. They are weak acids and do not dissociate completely in water. Lower molecular mass organic acids such as formic and lactic acids are miscible in water but higher molecular mass organic acids such as benzoic are insoluble in molecular (neutral) form. Organic acids are some of the products of food and agricultural residues fermentations via environmentally friendly integrated processes. Volatile fatty acids including acetic acid, propionic acids and butyric acid are produced from a wide range of agricultural wastes such as cereal hulls (Jin *et al.,* 2006); bagasse residues (Henrique *et al.,* 2005); food wastes (Lim *et al.,* 2008) and sisal leaf decortications residues (Mshandete *et al.,* 2008). In addition, lactic acid is produced from waste sisal stems (Muruke *et al.,* 2006), sugarcane bagasse and kitchen waste (Ohkouchi and lnoue, 2007) using *Lactobacillus* isolates. Furthermore, formic acid, levulinic acid, citric acid, valeric acid, caproic acid and vanillinic acid are obtainable from bioprocessing of food and agricultural waste (Olson, 2001; Chaudhary and Sharma, 2005; Mshandete *et al.,* 2008; Ibrahim *et al,* 2008). Generally, organic acids production requires batch or continuous incubation conditions, the average reaction parameters being 35°C, pH 6.0, hydraulic retention time (HRT) of up to 8 days and organic loading rates of 9 g l^{-1} (Lim *et al.,* 2008). Product yields of about 39.5 g l^{-1} have been reported (Lim *et al.,* 2008).

Citric acid has been in continuous production from sugar cane molasses using a combination of submerged immobilized and surface stabilized cultures of *Aspergillus niger,* KCU520 (Pohnerkar and Desai, 2014). Some studies have reported the production of oxalic acid by *Aspergillus oryzae* using wheat kernels as support (Biesebeke *et al*., 2002), and the production of gluconic acid by *Aspergillus niger* ARNU using tea waste as support and sugarcane molasses as carbon source (Sharma *et al*., 2008). Both compounds have great industrial applications. The main application of the oxalic acid, for example, includes cleaning or bleaching, especially for the removal of rust. It is also used in the restoration of old wood and is an important reagent in lanthanide chemistry. Gluconic acid is utilized as a food additive, acting as acidity regulator. It is also used in cleaning products where it dissolves mineral deposits especially in alkaline solution.

Compost

Compost, a nutrient-rich, organic fertilizer and soil conditioner, is a product of humification of organic matter. This process is aided by a combination of living organisms including bacteria, fungi and worms which transform and enhance food and agricultural wastes into humic-like substances. Vermicomposting is the bio-oxidation and stabilization of organic matter involving the joint action of earthworms and microorganisms, thereby turning wastes into a valuable soil amendment called vermicompost (Benitez *et al.,* 2005). Waste materials such as cereal straw and bran, urban wastes, water hyacinth, lemon tree prunings, cotton waste and brewery waste, horticultural wastes, olive, palm and grape wastes have been reported by Mtui (2009) to be suitable substrates for making humus-rich compost. While bacteria inoculants such as *Bacillus shackletonni, Streptomyces thermovulgaris* and *Ureibacillus thermosphaericus* are used to improve the composting process (Mtui, 2009), ligno-cellulolytic fungi inocula (e.g. *Trichurus spiralis)* may also be used in a pretreatment process before composting in order to reduce the resistance of the substrate to biodegradation (Mtui, 2009). A new earthworm strain of *Perionyx sansibaricus* is able to humify a substrate combination of guar gum industrial waste, cow dung and saw dust (Mtui, 2009). Composting can, therefore, be considered as a low-cost technology to convert agro industrial wastes into value-added biofertilizers.

According to Ezejiofor *et al*. (2014), the biodegradation of sewage sludge was studied by decrease of volatile solids (VS), content of organic carbon and auto fluorescence of coenzyme F420. The best fertilizer was obtained when sewage sludge was thermally pretreated, mixed with food waste, chalk, and artificial bulking agent. The fertilizer was a powder with moisture content of 5%. It was stable, and not toxic for the germination of plant seeds. Addition of 1.0 to 1.5% of this fertilizer to the subsoil increased the growth of different plants tested by 113 to 164% (Ezejiofor *et al*., 2014).

Biocomposites

A biocomposite is a material formed by a matrix (resin) and a re-enforcement of natural fibres (usually derived from plants or cellulose), with wide-ranging uses from environmental – friendly biodegradable composites to biomedical composites for drug/ gene delivery, tissue engineering applications and cosmetic orthondontics. Biocomposites are characterized by the fact that; the petrochemical resin is replaced by a vegetable or animal resin, and/ or, the bolster (fiber glass, carbon fibre or talc) are replaced by natural fibre (wood fibres, hemp, flax, sisal, jute, etc.).

Biodegradable polymers constitute a loosely defined family of polymers that are designed to degrade through the action of living organisms. Such commercially available biodegradable polymers are polycaprolactone, poly (lactic acid), polyhydroxyalkanoates, poly (ethylene glycol), and aliphatic polyesters like poly (butylene succinate) (PBS) and poly (butylene succinate-co-butylene adipate) (Tserki *et al.,* 2006). Lignocellulosic material-thermoplastic polymer composites are among the emerging products of food and agricultural wastes. In most cases, Iignocellulosic biomass flour is used as the reinforcing filler and polypropylene as the thermoplastic matrix polymer to manufacture particle-reinforced composites. Natural fibres from food and agricultural wastes are considered to be of low-cost by-products, environmentally friendly and practically sustainable raw materials (Georgopoulos *et al.,* 2005). Evaluations of lignocelluloses waste (LCW) fiber plastic composites utilizing wood fibre wastes, wheat and rice straw, jute cotton, sisal/cotton and ramie/cotton hybrid fabrics, non-wood plant fibres waste, newsprint paper, flax and hemp, oil palm wastes, cotton gin waste, banana fibres, cereal husks, tissue paper wastes and corn peels, bagasse and nanofibers from the agricultural residues as reported by Mtui (2009) have shown that such composites are suitable for making products that have improved biodegradability, mechanical strength, thermal stability, electrical conductivity and recyclability. Treated waste materials are also used in the construction industry for manufacturing of light-weight agro-gypsum panels and lightweight sand concretes with improved structural and thermal properties. Biocomposites are very promising in producing sustainable current and future green materials to achieve durability without using toxic chemicals. The challenge facing the biocomposite industry is to make materials that have better rubber/fiber interface, improved wettability and compatibility.

Food and feed

Various food processing industries produce a lot of wastes which can be of use in the production of food and animal feed. Notable amongst the processing factories are the palm oil/vegetable oil industry, cereal/grain processing plants as well as factories that process legumes. In the palm oil processing plants, after the extraction of palm oil from the palm fruit, the palm nuts are cracked to obtain the palm kernels. The latter are crushed and pressed or extracted to recover the palm kernel oil. The palm kernel cake (PKC) is usually discarded as waste. However, these days, PKC has found use in animal feed formulation, especially for the poultry. The cake is formulated with other supplements and given to birds as feed. Studies have shown that birds fed with such feeds have remarkably improved carcass weight (Ezejiofor *et al*., 2014). Soya bean cake which is obtained after extraction of the soy bean milk has also been used in the formulation of poultry feed. Cereals/grains milling factories generate a lot of wastes in the form of husks and chaff. These are further processed into animal feed for poultry. The use of fermented and unfermented mango peels (*Mangifera indica*-R) as animal feeds was reported by Ojokoh (2005). Ripe mango peels (*Mangifera indica*-R) was naturally fermented for 96 hours at room temperature (30 °C). Ojokoh (2005) used the fermented and unfermented samples to feed albino rats and found that there was an increase in the daily weight of the albino rat feds with these mango peels.

A slightly different approach to the valorization of animal and fishery waste is the hydrolysis and conversion of wastes to single cell protein. Horn *et al*. (2005) used hydrolysate of cord viscera which constitutes about 17% of the fish biomass to grow *Lactobacillus* spp. and demonstrated that the medium so formulated was as effective as commercial peptone based media used in the cultivation of the organism. This underscores the potential for the use of fishery waste of this kind for the cultivation of even fastidious organisms for the production of microbial biomass. Kuhn *et al*. (2008) fed microbial biomass produced from fish effluent to shrimps and demonstrated that the process improved the economics of shrimp production. In addition, the process led to the effective treatment of the resulting effluent. Single cell protein production for feed use has been achieved by cultivation of organisms on ram horn hydrolysate (Kurbanoglu *et al*., 2002, 2003). Composted fish waste has been used for the production of *Scytalidium aciabphilum* biomass in submerged fermentation with good protein yield for animal feeding. Amar *et al*. (2006) also employed bacterial digestion of fish waste to produce feed for the production of Indian white prawn and in the process achieved both treatment and reuse of the fish waste. Schneider *et al*. (2006) produced protein enriched bacterial biomass for animal feed from a suspended growth process using aquaculture waste and in the process achieved treatment of a particularly recalcitrant waste stream. Viera *et al*. (2005) used microalgae to treat fish pond waste water effluent, and demonstrated that the protein rich algal biomass could be used as feed for the production of abalone.

Bioconversion of food and agro-residues through single cell protein (SCP) production offers the potential for converting these residues into protein-rich palatable food and reduction of the environmental impact of the wastes. It offers a potential substrate for conversion of low-quality biomass into an improved animal feed and human food. SCP is the protein extracted from cultivated microbial biomass. It can be used for protein supplementation of a staple diet by replacing costly conventional sources like soymeal and fishmeal to alleviate the problem of protein scarcity. Moreover, bioconversion of agricultural and industrial wastes to protein-rich food and fodder stocks has an additional benefit of making the final product cheaper. Removal of nucleic acids and toxins from SCP is key to ensuring safety of the food and feed. Among the SCP obtained from LCW using agricultural wastes as the main growth media, *Saccharomyces cerevisiae, Trichoderma reesei* and *Kluyveromyces marxianus* top the list (Chaudhary and Sharma, 2005). SCP yield of 51 and 39.4% efficiency of conversion of beet-pulp into protein has been reported from the above strains (Mtui, 2009). Solid state fermentation of food and agricultural waste seems to be the most preferred culturing method, while cloning is being considered as a suitable technique for improvement of SCP production.

Bioconversion of food and agro-residues through mushroom cultivation provides an economically acceptable alternative for the production of food of superior taste and quality which does not need isolation and purification. Cultivation of edible mushrooms such as *Lentinus* spp, *Lentinula* spp, *Leonotis* spp, *Pleurotus* spp, *Agaricus* spp, *Agrocybe* spp, *Volvariella* spp, *Lentinus* spp and *Grifola* spp is achievable on a wide range of food and agricultural waste substrates such as wood waste, corncob meal, wheat straw, barley straw, soybean straw, cereal bran, cotton waste, sorghum stalk, banana pseudostem, hazelnut husks, waste tea leaves, dry weed plants, peanut shells, waste paper and olive mill wastewater (Mtui, 2009). Mushrooms with increased number of fruit bodies and high contents of protein and total carbohydrates are obtained when wastes substrates are used in combination.

Aroma compounds and other important industrial chemicals

The world of aroma is very attractive especially because it concerns the taste of what we eat (Aguedo and Ly, 2004). Aroma compounds can be extracted from fruits or vegetables but they are required in the product in concentrations comparable to those in the source material, and this utilizes high amounts of materials and is generally not economically realistic. Most of them can also be synthesized in a chemical way, resulting in chemical compounds that are not well perceived by consumers whose demand is the flavour of natural products. As an alternative, biotechnology proposes to use enzymes or whole cells to produce aroma compounds.

Several researchers have studied the production of aroma compounds by several microorganisms such as *Neurospora* sp, *Zygosaccharomyces rouxii* and *Aspergillus* sp., using pre-gelatinized rice, miso and cellulose fibres, respectively (Medeiros *et al.,* 2001). Ezejiofor *et al.* (2014) reported that fruity aroma was produced by *Ceratocystis fimbriat* in solid-state cultures using several wastes (cassava bagasse, apple pomace, amaranth and soybean), and found that the medium with cassava bagasse, apple pomace or soybean produced a strong fruity aroma. Soares *et al*. (2000) also reported the production of strong pineapple aroma when solid state fermentation (SSF) was carried out using coffee husk as a substrate by this strain. Other important industrial chemical compounds such as acetaldehyde, ethanol, ethyl acetate (the major compound produced), ethyl isobutyrate, isobutyl acetate, isoamyl acetate and ethyl-3-hexanoate were identified in the headspace of the cultures. The addition of leucine increased ethyl acetate and isoamyl acetate production, and then a strong odour of banana was detected. Christen *et al*. (2000) described the production of volatile compounds such as acetaldehyde and 3-methylbutanol by the edible fungus *Rhizopus oryzae* during SSF on tropical agricultural waste substrates. The production of 6-pentyl-a-pyrone (6-PP), an unsaturated lactone with a strong coconut-like aroma, was studied using liquid and solid substrates by De Araujo *et al*. (2002). While sugarcane bagasse was adequate for growth and aroma production, it has been demonstrated that, by solid-state fermentation process, it is possible to produce 6-PP at higher concentration than that reported in literature for submerged process (Ezejiofor *et al*., 2014).

Kluyveromyces marxianus produced fruity aroma compounds in SSF using cassava bagasse or giant palm bran (*Opuntia ficuindica*) as a substrate (Medeiros *et al.,* 2000). Solid substrate fermentation was found to be very suitable for the production of pyrazines. The biosynthesis of 2,5- dimethylpyrazine (2,5-DMP) and tetramethylpyrazine (TMP) using cultures of *Bacillus substilis* on soybeans waste using SSF showed that SSF was suitable in converting soybean waste to 2,5-DMP and TMP. Production of dairy flavour compounds, such as butyric acid and lactic acid in mixed cultures of *Lactobacillus acidophilus* and *Pediococcus pentosaceus* growing on a semisolid maize-based waste culture has been reported (Escamilla-Hurtado and Valdes-Martnez, 2005). Several methods have been developed in order to enable vanillin and furanone or pyranone derivatives of natural origin to be produced from agricultural wastes. Pfaltzgraff *et al.* (2013) reported that food and agricultural wastes biomass are very good resources for the production of high-value chemicals.

Production of secondary metabolites

The vast quantities of wastes that are generated as a result of diverse agricultural and food industrial practices can be used as a natural bioresource for the production of bioactive compounds such as secondary metabolites from various selected microorganisms. Secondary metabolites are excreted by microbial cultures at the end of primary growth and during the stationary phase of growth. Secondary metabolites represent some of the most economically important industrial products and are of huge interest. The best known and most extensively studied secondary metabolites are the antibiotics, steroids and alkaloids (Azbar, 2004).

Oxytetracycline and other antibiotics have been produced by variety of methods. Some may be obtained from a semi solid culture where low water content and high degree of aeration at the surface favours the production of antibiotics. Oxytetracyclines had been produced from a wide range of organic compounds by various strains of *Streptomyces* organism predominantly found in the soil and decaying vegetation. Several food processing wastes and by-products such as sweet potato residue, saw dust, rice hulls and corn cob, cassava peel, corn pomace, corncob, and groundnut shell (Asagba *et al.,* 2005) and cocoyam peels (Ezejiofor *et al.,* 2012) have all served as effective substrates for the production of antibiotics by solid-state fermentation. Oxytetracycline, a broad-spectrum antibiotic, is a bacteriostatic antibiotic that inhibit protein synthesis by binding reversibly to the 30S ribosomal subunit of the microorganism. It is therefore a very important class of antibiotics, and is used in human and veterinary medicine and as a supplement in poultry and swine production, preservation of fish, meat and poultry (Humber, 2001). It is also used in non-therapeutics for the control of plant diseases, stimulation of amino acid fermentation and inhibition of material biodeterioration (Archer *et al.,* 2001; Asagba *et al.,* 2005).

Biosorbents

Biosorbents are biological materials used to remove metal or metalloid species, compounds and particulates from solution (Wang and Chen, 2009). Adsorbents obtained from plant wastes are feasible replacements for costly conventional methods of removing pollutants such as heavy metals ions, dyes, ammonia and nitrates from the environment. The use of lignocellulosic food and agro wastes is a very useful approach because of their high adsorption properties, which results from their ion-exchange capabilities. Agricultural wastes can be made into good sorbents for the removal of many metals, which would add to their value, help reduce the cost of waste disposal, and provide a potentially cheap alternative to existing commercial carbons. Chemically modified plant wastes such as rice husks/rice hulls, spent grain, sugarcane bagasse/fly ash, sawdust, wheat bran, corncobs, wheat and soybean straws, corn stalks, weeds, fruit/vegetable wastes, cassava waste fibres, tree barks, azolla (water fern), alfalfa biomass, coir pith carbon, cotton seed hulls, citrus waste and soybean hulls show good adsorption capacities for Cd, Cu, Pb, Zn and Ni. They are usually modified with formaldehyde in acidic medium, NaOH, KOH/K_2CO_3 and CO_2, or acid solution or just washed with warm water (Tsai *et al.,* 2001).

Food and agricultural wastes have also been shown to be able to adsorb dyes from aqueous solutions. Adsorption of reactive dyes by sawdust char and activated carbon, ethylene blue by waste R*osa canina* sp. seeds, anionic dyes by hexadecyltrimethylammonium modified coir pith (Namasivayam and Sureshkumar, 2006) and methylene red by acid-hydrolysed beech sawdust have been reported and proven effective (Batzias and Sidiras, 2007). Ammonia and nitrate removal by using agricultural waste materials as adsorbents or ion exchangers have also been studied and reported (Mtui, 2009). Pre-hydrolysis enhances the adsorption properties of the original wastes material due to the removal of the hemicelluloses during sulphuric acid treatment, resulting in the ‘opening’ of the lignocellulosic matrix’s structure, the increasing of the surface area and the activation of the material’s surface owing to an increase in the number of dye binding sites.

Fructooligosaccharides

Fructooligosaccharides (FOS), also called oligofructose or oligofructan, are oligosaccharides that, when ingested, promote enormous benefits to the human health. They can be used as artificial or alternative sweetener and are considered a small dietary fibre with low caloric value. Additionally, FOS has important functional properties due to their capacity of serving as a substrate for microflora in the large intestine, increasing the overall gastrointestinal tract health. FOS also promotes calcium and magnesium absorption in animals and human gut, and increases the levels of phospholipids, triglycerides and cholesterol. In a recent study, some agro-industrial wastes including corn cobs, coffee silver skin, and cork oak were used as support and nutrient source during the FOS production by *Aspergillus japonicus* under SSF conditions. Among the wastes, coffee silver skin was the most suitable support for FOS production. Furthermore, the highest enzymatic activity results were also achieved when using coffee silver skin as solid support (Mussatto and Teixeira, 2010). These results were considered of great importance for the development of an efficient strategy to produce FOS on industrial scale with higher yield and productivity than that currently obtained.

Bioinsecticides

Biological pest control agents have received considerable attention as a potential alternative to develop eco-friendly pesticides and provide a sustainable agriculture. The identification of a suitable fungal strain that possess pesticide activity is the most important aspect to take into account when developing pesticides. In the last years, bio-pesticides agents for controlling insects and pests have been produced with *entomopathogenic* and *mycoparasitic* fungi (Mussatto *et al*., 2012). Besides the microorganism, the understanding of the molecular aspects of fungus-fungus, and fungus-insect interactions, the role of hydrolytic enzymes, especially chitinases in killing processes, and the possible use of chitin synthesis inhibitors are crucial aspects to be taken into consideration while making fungi, either singly or in combination, as an effective biopesticide agent. Several agro-industrial wastes (potato waste, coffee husks and sugarcane bagasse) have been used in SSF to produce spores from *Beauveria bassiana* to obtain biopesticides for biocontrol of pests of banana, sugarcane, soybean, and coffee (Santa *et al*., 2005). *Colletotrichum truncatum* is another fungus that has been studied and that possesses characteristics to be used as myco-herbicide against the difficult weed *Sesbania exaltata* (Pandey *et al*., 2000).

Carotene

Carotene is a pro-vitamin, which is converted in the body to a vitamin. The β-carotene is a precursor of vitamin A, whose function in the body plays major roles in the maintenance of strong bones, healthy skin, teeth and hair (Ahmad *et al.,* 2010). It is also known as a potent antioxidant, protecting the cells against effects of free radicals in the body. Salihu and Alam (2012) reported the extraction of carotene from palm oil mill effluent (POME). The process was carried out using different solvent systems; the most important ones with high extraction potentials are petroleum ether with a mean concentration of 417.9 ppm, and *n*-hexane whose mean concentration was found to be 394.8 ppm. Thus, the amount of carotene extracted from POME is closely related to that obtained from the crude palm oil; whose carotene concentration ranges between 400 and 3500ppm. Carotenoids have been extensively used in food, cosmetic and pharmaceutical industries.

Utilization of animal blood

Animal blood has a high level of protein and heme iron, and is an important edible by-product (Wan *et al.,* 2002). In Europe, animal blood has long been used to make blood sausages, blood pudding, biscuits and bread. In Asia, it is used in blood curd, blood cake and blood pudding (Ghost, 2001). It is also used for non-food items such as fertilizer, feedstuffs and binders. According to the Meat Inspection Act of the United States, blood is approved for food use when it has been removed by bleeding an animal that has been inspected and passed for use in meat food products. These animal bloods have been successfully utilized into value-added products as mentioned above.

Gelatin

This is a translucent, colourless, brittle (when dry), flavourless foodstuff derived from collagen obtained from various animal by-products. It is commonly used as a gelling agent in food, pharmaceuticals, photography and cosmetic manufacturing. It is used for the clarification of juices such as apple juice. Gelatin is produced by the controlled hydrolysis of a water insoluble collagen derived from protein. It is made from fresh raw materials (hides or bone) that are in an edible condition. Both hides and bones contain large quantities of collagen. The processing of gelatin from hide consists of three major steps. The first step is the elimination of non-collagenous material from the raw material. This is followed by controlled hydrolysis of collagen to gelatin. The final step is recovery and drying of the final product. Gelatin extracted from animal skins and hides can be used for food (Choa *et al.,* 2005). The raw material can also be rendered into lard. In the United States, Latin America, Europe and some Asian countries, pork skin is immersed, boiled, dried and then fried to make a snack food (porrinds) and in U.K they are called "pork scratching". Collagen from hides and skins also could have been used as an emulsifier in meat products because it can bind large quantities of fat. This makes it a useful additive or filler for meat products. Collagen can also be extracted from cattle hides to make the collagen sausage used in the meat industry

Meat and bone meal

Meat and bone meal (MBM) was widely recommended and used in animal nutrition as a protein source in place of proteinaceous feeds because of its content of available essential amino acids, minerals and vitamin B_{12}. However, MBM and related rendered protein commodities have potential for use in applications other than animal feed, including use as a fuel or a phosphorus fertilizer (Jayathilakan *et al.,* 2012).

Fish protein hydrolysate

Fish waste is a great source of minerals, proteins and fat. Potential utilization of waste fish scraps from 5 marine species (white croaker, horse mackerel, flying fish, chubmackerel, Sardine) to produce fish protein hydrolysate by enzymic treatment was investigated by Khan *et al.* (2003) and indicated that fish protein hydrolysate could be used as a cryoprotectant to suppress the denaturation of prolizard fish surimi during frozen storage. Ohba *et al.* (2003) reported that collagen or keratin contained in livestock and fish waste may be converted to useful products by enzymic hydrolysis, providing new physiologically functional food materials. Collagens containing yellow tail fish bone and swine skin wastes were used as raw materials for production of protein hydrolysates and peptides. These hydrolysates could be of potential use as food ingredients (Morimura *et al.,* 2002). Enzymes and bioactive peptides were obtained from fish waste or by-catch and used for fish silage, fish feed or fish sauce production (Gildberg, 2004). Auto-hydrolysis of waste fish viscera to produce peptone hydrolysates and their use in microbiological media to support growth and bacteriocin production by lactic acid bacteria are reported by Vanquez *et al,* (2004).

Chitin and chitosan

Chitin is a naturally occurring high molecular weight linear homopolysaccharide composed of N-acetyl-D-glucosamine residues in α (1-4) linkage. Chitin and chitin derivatives are biodegradable and biocompatible natural polymers that have been used in virtually every significant segment of the economy (e.g. water treatment, pulp and paper industry, biomedical devices and therapies, cosmetics, biotechnology, agriculture, food science and membrane technology). Chitin can be found in a variety of species in both the animal and plant kingdoms. The traditional source of chitin is shellfish waste from shrimp, Antarctic Krill, crab and lobster processing. Chitosan is a natural, non-toxic, co-polymer of glucosamine and *N*-acetyl glucosamine obtained after partial de-*N*-acetylating of chitin, which, in turn, is a major component of the shells of crustaceans and found commercially in the offal of marine food processing industry (Tharanathan and Kitture, 2003). However, the production of chitin and chitosan from bio-waste had been demonstrated by Khanafari *et al*. (2008). Fermentation of this bio-waste using lactic acid bacteria for the production of chitin has been studied and reported (Rao *et al.,* 2000). These studies showed that, chitin and chitosan is a value added product from shrimp waste.

Capacitor electrode

A high performance capacitor's electrode was prepared from the modified activated carbon derived from cassava peel (Ismanto *et al*., 2010). The activated carbon was prepared from cassava peel with KOH–CO_2 activation and modified by surface treatment, using nitric acid, sulfuric acid and hydrogen peroxide. It was found that the preparation of capacitor's electrode from cassava peel-based activated carbon with surface modification by acidic and oxidative chemical agents is an effective process for the production of high performance and low cost activated carbon electrode materials for the Electric Double Layer Capacitor (EDLC). EDLCs also known as super capacitors, are a new breakthrough in energy storage device technology that have attracted considerable attention because of their high capacitance, power delivery performance and long lifecycle (Tamai *et al*., 2005; Yansu *et al*., 2008). With all of these advantages, EDLCs have been widely used in the information technology industry, for electronic devices, electric vehicles, and military equipment where high power energy storage device with an ever-decreasing size is needed (Yafei *et al*., 2008). According to Ismanto *et al*. (2010), cassava peel waste is a potential raw material for the preparation of capacitor electrode.

CONCLUSION

Food and agricultural wastes are generated in large quantities every year in many developing countries. Their use has still been limited, being basically used as feeds for animals, or simply as landfills. With the use of biotechnology, wastes generated from food and agriculture serve as potential resources for use in several bioconversion processes for producing value-added products such as food, feed, fuel, organic acids/industrial chemicals, biosorbent, biofertilizers, antimicrobial compound, etc., in order to benefit mankind, reduce environmental pollutions, eliminate food-feed-fuel conflict as a result of using energy crops in the production of biofuels, enhanced food security, environmental sustainability, cost and energy effectiveness. Efforts should be made to explore the use of nanotechnology, genetically engineered microbes and/or new and improved microorganisms and other novel technology to degrade, convert and recycle wastes as much as possible to valuable products with minimum cost and energy.

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