USE OF FOOD WASTE: "CHANNEL TO CANAL"

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ABSTRACT

As the population growing, a large amount of food waste is produced with an increase in population and therefore, increasing industrial processes in order to fulfill the demand of such a big population. However, there is not a proper rules and regulations for this waste management. Whereas current legislations on food waste treatment priorities the prevention of waste rather than its use. Food waste is a reservoir of adequate quantities of carbohydrates, lipids, proteins, and nutraceuticals. Some recent studies for food supply chain waste pave the way for the production of biofuels, enzymes, bioactive compounds, and nanoparticles.

Keywords: Food Waste, Regulations, Carbohydrate, Lipids, Proteins, Nutraceuticals.

INTRODUCTION
Food Waste as a Global Concern

The global population is expanding at an exponential rate every year. There is a huge demand for food and energy to meet the needs of society. Rapid urbanization combined with slow progress in the development of and ineffective waste management strategies leads to the accumulation of food waste. A study published by the EU in 2010 revealed that almost 90 million tonnes of food waste are expelled from the food manufacturing industry every year (1). Food waste, being high in nutritional content, putrefies on accumulation, providing breeding grounds for disease-causing organisms. This poses serious environmental issues and very few options exist today to deal with them. While preventive measures can be taken to reduce the generation of food waste it is important to deal with the existing accumulated food waste. The idea of converting food waste into energy and other chemicals used in our daily activities is an area of research with huge potential and opportunities.

Food Industry Waste as a Renewable Resource

Food industry waste is particularly interesting for renewable energy researchers as it is mostly lignocellulosic in nature, with high cellulose and lignin content (except animal-derived food waste). Many studies have reported on various technologies for the conversion of food waste such as apple pomace and brewers' spent grain into biofuel(2; 3). Cellulose and hemicelluloses on enzymatic breakdown release glucose and xylose, which can be converted into ethanol by fermentative microorganisms (4). Furthermore, lignin on pyrolysis and anaerobic digestion yields H_2 and CH_4 (5). In the quest for renewable energy resources with the backdrop of rising oil prices, one overlooks the fact that food waste is a reservoir of other value-added chemicals. Recent studies suggest that the production of bulk chemicals from biomass waste is 3.5 times more profitable than converting it into biofuel (6). Meanwhile, biorefinery is an emerging concept in the field of biomass waste management suggesting that all kinds of biomass-derived material can be converted into different types of biofuels and chemicals through various conversion processes (7). Various food industry processes (processing, packaging, transportation. and storage) in their current form are highly inefficient considering the volume of waste they generates during their various stages. These wastes are mainly organic in nature and characterised by high biological oxygen demand (BOD) and chemical oxygen demand (COD) and variations in composition and pH owing to seasonal variations and handling processes. Such wastes lead to bacterial contamination due to the high water content and high accumulation rates, not to mention disposal management problems and the cost associated with them (8). The present logistic strategies practised in the food industry are incapable of dealing with the hurdles of waste management. Incorporating technologies to derive value-added products, chemicals, and fuels is a positive step towards dealing with this problem. However, a steady and incoming flow of raw materials is crucial to keep the industry interested in valorisation studies of food waste. Post- consumer leftover food is the most obvious indicator of the available food waste raw material since is visible on a daily basis. However, waste generated from the last link of the food chain raises several problems since it is a mixture of materials that are heterogeneous in nature and not segregated. By contrast, waste from each stage of the production process is consistent in its chemical composition. Therefore, variations in feedstock can be overcome by novel collection and storage strategies, making it easier for valorisation. There are no exact reports on the amount of waste generated from different food processing industries.

Current Legislation on Waste Management

Legislation pertaining to waste management in Europe started in the 1970s with the European Economic Community, the precursor to the EU, trying to define 'waste' as a basis to devise laws and regulations with respect to the production, handling, storage, transport, and disposal of waste by minimising the ill-effects related to waste generation on health and the environment (9). In the legal sense, food waste is treated in the same way as normal waste that is nonhazardous if and only if it does not exhibit any properties that may render it 'hazardous'. This is with the exception of animal byproduct waste. Stringent controls are applied to its transport, handling and storage, treatment, and disposal through Regulation (EC) No 1069/2009. However, animal byproduct waste that is meant for incineration, composting, or plant or biogas production does not come under this regulation (10).

Recent Valorisation Studies on Food Industry Waste

The value of the substrate is determined by the biomass conversion process. The operational cost and the value of the target products are the two main factors that determine whether a biomass conversion process is feasible. It is therefore necessary to evaluate the current trends and recent development of technology in the conversion of food supply chain waste. A large spectrum of commercially important products such as biofuels, enzymes, organic acids, biopolymers, nutraceuticals, and dietary fibres have been developed from the bioconversion of food industry waste (11). This section provides the latest developments in the valorisation of food industry wastes into value-added products.

Biofuels

Plant biomass has been used for the production of fuel ethanol for almost a century. The basic idea behind bioethanol production is that enzymatic hydrolysis of lignocellulose releases fermentable sugars that can be converted into ethanol. The term 'biofuel' encompasses a wide variety of products such as bioethanol, biodiesel, biohydrogen, biobutanol, bioether, biogas, and syngas (12). Pretreatment is a necessary step in bioethanol production since recalcitrant substances in lignocellulose will hinder efficient enzymatic hydrolysis (13). In recent developments, bioethanol was produced from food waste using carbohydrases and Saccharomyces cerevisiae as the fermentative microorganism. The two modes of fermentation - viz. separate hydrolysis and fermentation (SHF) and simultaneous hydrolysis and fermentation (SSF) (14) - were able to obtain ethanol yields of 0.43 g/g and 0.31 g/g, respectively. The prospect of using instant noodle waste as a substrate for ethanol production was probed by Yang et al. (15). Oil removal pretreatment was necessary for this purpose. Glucoamylase and /-amylase were used for enzymatic hydrolysis of the substrate. Employing S. cerevisiae under the SSF mode, a 96.8% conversion rate was obtained with a maximum ethanol yield of 61.1 g/l.

Biodiesel is a value-added product of cooking oil waste. Soy bean oil, canola oil, and cooking oil waste have been successfully converted into biodiesel by various methods.. In a recent study, carbohydrate-derived solid acid catalyst was used for the production of biodiesel from low-cost feedstocks such as palm fatty acid distillate, which is a byproduct of the palm oil industry (16). Besides commercial lipases, microbial enzymes have also been used for biodiesel production. Mixed lipases from *Candida rugosa* and *Rhizopus oryzea* were immobilised on a silica-gel matrix by Lee et al. (17) for the production of biodiesel from soy bean oil. High conversion rates were achieved during this study and the immobilised mixed lipases were reused for 30 cycles. Biohydrogen has been produced using oil palm fruit bunch, sweet sorghum, and wheat straw in separate studies. In all three studies, dark fermentation was used as the mode of hydrogen production. Enterobacter, Bacillus, and Clostridium are the most popular microorganisms used for biohydrogen production (18).

Industrial Enzymes

As in bioethanol production, lignocellulose pretreatment followed by enzymatic hydrolysis is the essential step for enzyme production from food waste. In some cases the enzymatic hydrolysis stage can be omitted for certain fungal organisms that naturally grow on plant biomass. Food waste has been favoured as an ideal candidate for enzyme production and therefore several food supply chain wastes have been used for the production of commercially important enzymes. Oxidative enzymes such as cellulase, laccase, amylase, xylanase, phytase, and lipase have been the focus of production using organic food waste residues(19; 20). The motive behind the utilisation of food waste for enzyme production is the associated cost. Commercial enzyme production is a cost-intensive process, with almost 28% of the operational cost dedicated to raw material procurement (21). In lieu of solving this problem, several studies have focused on the utilisation of lignocellulosic food waste as a raw material for enzyme production. As mentioned above, microbial strains are capable of degrading the complex polymers in plant biomass and utilise the sugars released for their sustenance. This fact is taken advantage of when using food processing industry waste as a raw material for enzyme production. Additionally, high enzyme activity can be achieved by using media optimisation techniques and genetically superior enzyme-producing microbes. The solid state fermentation mode is preferred over submerged fermentation mainly due to the operational cost. According to Singhania et al. (22), the operational cost of solid state fermentation is one-tenth of that of submerged fermentation. Also, solid state fermentation replicates the natural environment for enzyme production in a bioreactor, which has been proved to increase enzyme yield. Food waste is naturally heterogeneous in nature and therefore can cause problems in down-stream processing. This can result in increased costs for enzyme isolation and purification. One- step purification and immobilisation of enzymes is a recent innovation in enzyme recovery. Enzyme immobilisation and purification via one step can be achieved by following three different strategies: immobilisation via one point, employing custom-made supports that are specific to the target protein based on certain structural features, and the application of site-directed mutagenesis in an effort to introduce specific domains into the target protein molecule that show affinity to the heterofunctional supports.

Bioactive/Nutraceuticals

A detailed analysis of studies on the conversion of plant-derived food waste reveals that the extraction of value-added chemicals such as antioxidants and dietary fibres is becoming as popular as liquid fuel and biogas production. Rice bran is a byproduct of the rice milling industry. It is rich in fibre, proteins, minerals, and vitamins, and phytochemicals such asBiodiesel is a value-added product of cooking oil waste. Soy bean oil, canola oil, and cooking oil waste have been successfully converted into biodiesel by various methods. Lipolytic enzymes such as Lipozyme TL IM and Novozym 435 are employed in the trancesterification process to convert cooking oil into biodiesel. In a recent study, carbohydrate-derived solid acid catalyst was used for the production of biodiesel from low-cost feedstocks such as palm fatty acid distillate, which is a byproduct of the palm oil industry. Besides commercial lipases, microbial enzymes have also been used for biodiesel production. Mixed lipases from Candida rugosa and Rhizopus oryzea were immobilised on a silica-gel matrix by Lee et al. for the production of biodiesel from soy bean oil. High conversion rates were achieved during this study and the immobilised mixed lipases were reused for 30 cycles. Biohydrogen has been produced using oil palm fruit bunch, sweet sorghum, and wheat straw in separate studies. In all three studies, dark fermentation was used as the mode of hydrogen production. Genetic enhancement of the fermentative organism resulted in better yields. Enterobacter, Bacillus, and Clostridium are the most popular microorganisms used for biohydrogen production.

Nanoparticles

The development of nanomaterials from food processing residue is a fairly new area of research. In recent studies rice bran and wheat husk have been used as potential components to produce nanoparticles. Biopolymers such as xylan, cellulose, starch, and chitosan have been widely used to synthesise stable nanoparticles owing to being renewable resources. The presence of silica in rice husk makes it an excellent material for nanoparticle production. Several methods have been invented to utilise rice husk for nanoparticle synthesis. Silica extracted from rice husk was used for in situ anchorage of Pt and Ni nanoparticles. Rice husk silica (RHS) texture was tuned using a cationic surfactant (CTAB) and a nonionic surfactant (Span 40). The Span 40 RHS immobilised Ni particles onto its surface and exhibited high dehydrogenation activity and stabilised performance for the production of acetaldehyde. In another study silver nanoparticles were synthesised using xylan obtained from wheat bran as the reducing and stabilising agent. A mild pretreatment was necessary to extract xylan from wheat bran. Silver nanoparticles were prepared by dissolving xylan in sodium hydroxide and then adding 1 ml of silver nitrate into the solution. After stirring for 5 min,the solution was heated to 100°Cfor30 min. The emergence of brown colour indicated the formation of silver nanoparticles. Nanoparticles exhibiting antibacterial activity were developed using a cost-effective approach by Cui et al. They synthesised porous carbon from rice husk by carbonising it at 400 °C in a nitrogen environment for 2 h. The antibacterial activity of the newly prepared nanoparticles was as low as 25 mg/ml, inhibiting microbial growth. In another study nanosilica particles prepared from rice husk at a yield of 81% by a hydrothermal technique were found to be effective in the removal of organic dyes.

Biodegradable Plastics

Polyhydroxyalkanoates (PHAs) are plastic-like materials that are perfect replacements for petroleum-derived plastics. Similar to enzyme production, the main barrier in the commercialisation of PHAs is the high operational cost incurred during their production. Therefore, lignocellulosic materials, preferably food waste and agricultural residue (due to their abundance and zero value), have been used as substrates for the production of PHAs and poly- 3-hydroxybutyrate (PHB). *Burkholderia sacchari* DSM 17165 is a strain that is capable of metabolising glucose, xylose, arabinose, and other reducing sugars to produce PHB. In a study, the efficacy of wheat straw hydrolysate as a raw material for PHB production was tested. Shake-flask-level experiments showed that *B. sacchari* cells accumulated 60% g PHB/g cell dry weight with a yield of 0.19 g/g when wheat straw hydrolysate was used as the sole carbon source [52]. Venkata et al. conducted an optimisation study on PHA production using mixed aerobic and anaerobic cultures and found that the microenvironment had the greatest influence on PHA production. Spent coffee waste is an excellent substrate for PHB production. SCW contains 10% oil, which can be converted to PHB by *Cupriavidus necator*. After oil extraction, the residual solid is rich in cellulose and hemicellulose content. These solids were subjected to pretreatment followed by enzymatic hydrolysis in which the hydrolysate was used a carbon source for PHA production using *Burkholderia cepacia*. The microbe preferred hexoses over pentoses (mainly mannose and galactose), which were the predominating sugars in the hydrolysate.

Chitosan

Chitosan is a derivative of chitin, the second most abundant polymer after cellulose. It possesses intrinsic properties such as antimicrobial activity, biodegradability, and biocompatibility [56]. These features of chitosan make it a widely sought candidate for the food, pharmaceutical, chemical, and textile industries. Its high cationic density and long polymer chains make it an effective coagulant/flocculent and it is used in water treatment facilities (23). Shrimp shells are commercially used as a raw material for the production of chitosan. The process involves the use of strong acids and alkalis to remove the proteins and minerals from the shells. However, this may also lead to depolymerisation of the chitosan. Recently, researchers have started focusing on the use of proteases for the extraction of chitosan from shrimp waste from the fish industry. With the help of fish proteases a group of scientists were able to extract and depolymerise chitin from shrimp waste. By maintaining a high enzyme/substrate ratio (10 U/mg) they were able to achieve 80% protein removal and complete deproteinisation was achieved in 6 h. The chitosan obtained was successfully employed for unhairing effluents from the tanning industry (23).

Collagen

Collagen is one of the most common types of protein in multicellular organisms. It is fibrous in nature and provides structural rigidity in connective tissues as well as internal organs. Collagen, and its denatured form gelatin, are widely used in the cosmetic, pharmaceutical, and leather industries and also for medical applications. Animal food waste such as fish waste are widely used as raw materials for the production of collagen (23). In a study, acid-soluble collagen was extracted from cod bone using 0.1 N NaOH to remove all noncollagenous protein (23). Broiler chicken processing waste was experimented with as a raw material for the production of collagen casings by Munasinghe et al. (23). Using acetic acid and pepsin they were able to extract collagen by centrifugation and subsequent lyophilisation. One of the most popular uses of collagen is in the food industry, where it is used to produce edible casings for meat products and sausages. However, managing the waste derived from biologically resistant collagen casings is becoming a serious problem. While landfill remains the current viable option for its disposal, a technoeconomic analysis has revealed that composting of charred casings was more appropriate with respect to agrochemical and financial aspects (23).

CONCLUSION

The implementation of strict legislation for human health and environmental safety and the emergence of novel techniques for the recovery of commercially important biomolecules has caused enormous interest in food supply chain waste valorisation. The generation of food waste is inevitable, especially during the preconsumption stage. However, environmental damage caused by the formation of greenhouse gases and ground water contamination via food waste decomposition due to landfill can be largely avoided. Studies cited in this review have shown that food waste is a renewable resource for industrially important chemicals and can be used as a raw material for biofuel and enzyme production. Technologies that least affect the environment negatively (intelligent separation techniques), biochemical processing strategies (such as fermentation), and extraction processes for biologically active molecules raise economically interesting prospects for food waste. Technologies for the recovery of high-added-value compounds are pivotal to the utilisation of food waste for commercial applications.

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