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Characteristics of food processing wastes and their use in sustainable alcohol production

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ABSTRACT

Food processing operations produce large amounts of waste that are rich in nutrients, and although these wastes are utilized to produce value-added products to some extent, the majority of the waste is discarded. This paper provides a comprehensive review of the characteristics of food processing waste for micro- and macro-nutrient composition, and utilization of these materials in alcohol production. The feasibility of producing alcohols, mainly ethanol and butanol, was investigated while identifying the research gaps and suggesting future directions for food processing waste utilization. Ethanol and 1-butanol are the most studied alcohols produced by fermentation of food processing wastes. Methanol is used to a much lesser extent as fuel and produced using chemical conversion methods. Propanol and isobutanol from fermentation of food processing waste are gaining interest more recently, and there are fewer published articles on these products. Alcohols have high market demand as fuels and industrial solvents. Effective utilization of food processing wastes in alcohol production can significantly affect the production economics by not having a need to grow crops for raw materials or acquiring biomass at a high cost. Although theoretically alcohol production from food processing waste appears to be feasible, the technology still has to overcome several constraints.

1. Introduction

In food processing industries, waste is produced from the separation of desired products from undesired by-products [1,2]. Such food industry wastes are product specific and therefore the composition of the waste does not vary significantly as the final product must have a consistent quality [3]. Numerous efforts have been made to utilize the biodegradable fraction of food processing waste (FPW) to produce useful products. Food waste valorization to useful products not only offers economic benefits, but also provides a solution to nuisances created by food waste degradation in the environment and landfills. FPW may be produced in solid, liquid or semi-solid form. Liquid wastes are generated as a result of use of large amounts of water for many applications, including temperature control, cleaning, process water, sanitation, transportation, cooking and as auxiliary water [4]. The effluent consists of suspended solids, organic matter and nitrogen in several forms, fats and oils and other inorganic materials [5]. Common liquid effluents include whey from cheese and yogurt production, whey from tofu production, bakery effluent from equipment washing, brewery effluent, oil mill effluent, soda industry effluent, potato processing wastewater, and apple pomace sludge. Some of the major solid wastes are tomato waste, apple pomace, inedible dough, waste bread, potato waste, soybean curd residue and grape pomace from wineries. Solid food wastes are rich in starch, lignin, cellulose and monosaccharides, mainly fructose and glucose, whereas the nutrients in liquid food wastes are available in diluted form. Generation of large amounts of food waste has an adverse impact on natural resources like water, land and biodiversity [6].

While both solid- and liquid-phase FPW would appear to have significant potential for conversion to alcohols or other renewable fuels, there are some barriers to widespread adoption of this practice. The feedstock for fuel production must be abundant and should not compete with food resources for humans or animals [7]. Also, high moisture content has been identified as a major obstacle to FPW management [2]. Another major barrier is obtaining FPW data in terms of volumes produced, often considered proprietary by the food manufacturers. Knowing waste volumes produced is important, as substrate availability is a major constraint in waste conversion processes. However, the amount of food processing waste generated is increasing every year as food production increases to support a growing population. Moreover, there is

Abbreviations: FPW, Food processing waste; RCM, Reinforced clostridial medium; ATCC, American type culture collection; NRRL, Northern Regional Research lab; YPD, Yeast extract-Peptone-Dextrose; ABE, Acetone-Ethanol-Butanol; UFLC, Ultra flow liquid chromatography; COD, Chemical oxygen demand

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a trend of increased consumption of processed food items, especially as standards of living rise worldwide. Fig. 1 shows increasing trend of FPW volume and a linear forecast based on current increase in the waste generation rate from four representative sectors. The United States Department of Agriculture's (USDA) database[1] was used to obtain quantities of cheese produced, and tomatoes and potatoes processed from year 1970 to 2010. Several assumptions were then used to calculate the amount of waste produced from cheese production and processing of potatoes and tomatoes. Based on previous data, food waste volumes were linearly extrapolated to year 2040. The extrapolation shows that "business as usual" food waste generation will continue to increase significantly. Increasing food waste volume is a serious concern in terms of greenhouse gas emission, water footprint, land conversion and economics.

Recent declines in fossil fuel prices, depleting natural resources and rising prices of raw materials stress the need to incentivize production of fuels from renewable energy sources. Production of biofuels, particularly fuel alcohols using lignocellulosic biomass, has gained increased interest over the last decade. While household and institutional food waste could be effectively treated using anaerobic digestion [3,8,9], alcohol production might be a good option to treat processing wastes. Because the costs involved in processing lignocellulosic raw material are high, it is necessary to evaluate cheaper raw materials to produce renewable alcohols. One such raw material is food waste that has low or zero cost of procurement. Food waste is a rich source of nutrients for microbes and can be converted to useful products like biofuels through biodegradation pathways. Carbohydrates and certain amino acids in food waste can be converted to a mixture of fuel alcohols -ethanol, butanol and propanol through fermentation. Such an approach would not only contribute to overcoming fuel supply constraints, but also help in reducing the wastes produced by food processing industries and the associated disposal costs. Commercializing biofuels using food waste substrates can be attractive because of these dual economic benefit. Although alcohol production is a potentially efficient option to convert food waste, careful evaluation of the technology and optimization of process economics is important before scale-up and commercialization.

In this paper, various FPWs that could potentially provide raw materials for alcohol production have been evaluated. The major physical characteristics, organic and inorganic nutrient content of FPW were analyzed using statistical methods to approximate the composition of these wastes based on reported literature data. FPWs were divided into two categories: liquid effluents that are low in solids, and wastes that are rich in solid content. The liquid effluents analyzed included tofu processing wastewater, cheese and yogurt whey, potato processing wastewater and sweet beverage industry effluents. Waste materials that are rich in solids included apple pomace, tomato pomace, grape pomace, spent coffee grounds and bread waste. Beyond assessing the technical feasibility of food waste-to-alcohol conversion, the paper also considers the sustainability implications of production in terms of environmental and economic impacts. Bioenergy production from household and commercial food waste were reviewed before with the main focus being hydrogen and biomethane [10]. Other reviews evaluated various pathways of food waste conversion into new products, reducing the burden on virgin raw materials and assessment of challenges in large scale implementation of food waste recycling [11]. Several reviews focused on producing high value added products from food [12–16]. This review is believed to provide comprehensive information on major types of food processing wastes, physical and chemical characteristics, and their use in production of ethanol, 1-butanol, 3-methyl 1-butanol and organic acids.

The composition of representative food wastes was estimated by averaging reported values from literature. Standard deviation was calculated for a given number of samples; however, as the data distribution was random, the standard deviation values were high for certain food waste due to outliers. Therefore, it was determined that reporting median values would be the most appropriate approximation of the composition of food wastes. Median values were calculated by ranking the numbers in ascending order and choosing the middle value. Median values, however, were calculated only for those properties that have a sample size of more than 3 reported values. Average, mean and median values were reported by analyzing the data from various literature for the micro and macro nutrients present in FPWs. Macro nutrients include carbohydrates, proteins and lipids. Micro nutrients include the minerals calcium (Ca^{2+}), potassium (K^+), sodium (Na^+), magnesium (Mg^{2+}), iron (Fe^{3+}), manganese (Mn^{2+}), zinc (Zn^{2+}), phosphorus (P) and sulfur (S). In addition, certain physical and chemical properties like pH, total solids, ash content and COD were also reported from existing literature. This paper also summarizes literature data on ethanol, 1-butanol, 3-methyl 1-butanol and organic acid production from various FPWs. For consistency, all the values reported in Tables 1 through 5 were reduced to a common number significant figures.

2. Properties of food processing waste

The wastewater from food processing industries can be considered nontoxic as it contains no or very few hazardous and non-biodegradable compounds [17]. As wastewater mainly contains organic materials, it can be treated conveniently using fermentation; however it may sometimes contain low concentrations of cleaning products that could be toxic. Tofu processing wastewater results from cooking soybeans and pressing tofu curds into blocks that are then prepared for sale. One kg of soybeans used in a typical tofu production operation generates 10 l of wastewater and 0.25 kg of solid waste known as tofu curd residue [18]. Tofu wastewater is rich in nitrogen, but low in carbon. It contains some complex polysaccharides in small amounts which make pretreatment necessary before conversion via fermentation. Whey is a food processing byproduct representing the strained liquid portion after coagulation of cheese or yogurt. Both cheese and yogurt whey are rich in lactose. Although lactose cannot be directly fermented by all microbes, certain microbes like *Kluyveromyces* can directly utilize lactose in whey to produce ethanol. Potato processing wastewater results from different operations. Silt water is a result of washing raw potatoes, while processing water results from peeling, cutting, cooking, grinding and packing [19]. Potato processing wastewater is rich in starch which theoretically makes a good substrate for alcohol production. Tomato waste is one of the most produced and least explored types of waste. The majority of tomato pomace produced is used in animal feed, and its application in fuel production is not well studied. An average 40% of the weight of processed tomatoes ends as waste, and is obtained after pressing of fresh tomatoes, and typically contains 33% seeds, 27% skin and 40% pulp [15]. In addition, dried tomato pomace contains fermentable simple sugars like fructose, glucose and sucrose [20]. Apple pomace is produced as a result of apple processing and includes peel, core, seed, calyx, stem and soft tissues [15]. Commercial technologies are becoming effective in reducing the amount of pomace produced, however 12–20% of the original weight of processed apples end up as pomace produced by the juice industry [21]. Grape pomace is the solid residue that remains after juice extraction or wine production from grapes [22]. Typically pomaces are composted, processed into animal feed or used in extraction of oil from seeds. Though many of these wastes have some degree of utilization, not all are utilized to their full potential. Therefore using these wastes in alcohol production could be a promising option.

2.1. Physical and chemical properties and organic content

The physical and chemical parameters reported here are, pH, COD, total solids, total carbohydrates, proteins, lipids and ash content. The pH of the waste is indicative of its freshness, as pH always changes upon storage or hydrolysis. Regardless of the pH of fresh waste, it is

[1] USDA-Economic Research Service, http://www.ers.usda.gov/.