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Valorisation of food waste via fungal hydrolysis and lactic acid fermentation with *Lactobacillus casei* Shirota

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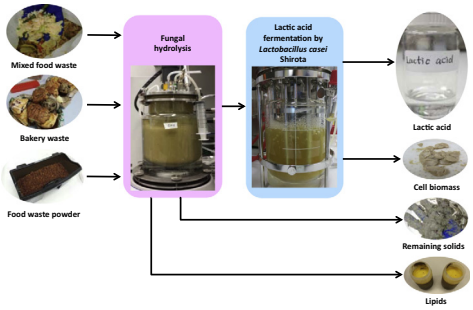
HIGHLIGHTS

- We investigated bioconversion of different types of food waste to lactic acid.
- Hydrolysates were rich in glucose, fructose and free amino nitrogen.
- Food waste powder produced by commercial food waste machine can be used as feedstock.
- The overall yields were 0.23–0.27 g lactic acid g^{-1} food waste.
- We proposed a novel decentralized approach for food waste bioconversion in urban area.

GRAPHICAL ABSTRACT



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ABSTRACT

Food waste recycling via fungal hydrolysis and lactic acid (LA) fermentation has been investigated. Hydrolysates derived from mixed food waste and bakery waste were rich in glucose (80.0–100.2 g L^{-1}), fructose (7.6 g L^{-1}) and free amino nitrogen (947–1081 mg L^{-1}). In the fermentation with *Lactobacillus casei* Shirota, 94.0 g L^{-1} and 82.6 g L^{-1} of LA were produced with productivity of 2.61 g L^{-1} h^{-1} and 2.50 g L^{-1} h^{-1} for mixed food waste and bakery waste hydrolysate, respectively. The yield was 0.94 g g^{-1} for both hydrolysates. Similar results were obtained using food waste powder hydrolysate, in which 90.1 g L^{-1} of LA was produced with a yield and productivity of 0.92 g g^{-1} and 2.50 g L^{-1} h^{-1}. The results demonstrate the feasibility of an efficient bioconversion of food waste to LA and a decentralized approach of food waste recycling in urban area.

1. Introduction

There is an increasing interest in recycling food waste due to massive amount of generation and the valuable organic content to be recycled for various applications such as composts, animal feed and biogas (Lin et al., 2014). According to a study commissioned by the United Nations Food and Agriculture Organisation in 2011, roughly one-third of food produced for human consumption was lost or wasted globally, which results in the generation of 1.3 billion tonnes of food waste per year (FAO, 2011). In Hong Kong, daily food waste generation has reached 3640 tonnes, accounting for 37% of municipal solid waste generation in 2015 (EPD, 2015). Although there are a number of food waste recycling technologies available, none of them can eradicate the food waste problem in highly urbanized city like Hong Kong due to low selling price of regenerated products, scattered food waste generation sources and high transportation costs (Kwan et al., 2014; Pleissner, 2016). Therefore, the development of a practical approach to turn food waste into value-added products is highly desired.

Food waste, which is defined as any waste and by-products produced during the food production, processing, wholesale, retail and

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consumption (FAO, 2011), consists of 30–60% starch, 5–10% proteins and 10–40% lipids (w/w) (Pleissner and Lin, 2013). Due to the nutrient-rich composition of food waste, its utilization as feedstock in biorefineries for chemicals, materials and fuels production has been proposed and demonstrated in the recent years in order to reduce the amount of organic waste that needs to be treated and to help alleviating the over-dependence on petroleum (Lin et al., 2013). In our previous study, a process for the production of generic fermentation feedstock from food waste via fungal hydrolysis in submerged fermentation by *Aspergillus awamori* and *Aspergillus oryzae* was firstly introduced (Pleissner et al., 2014a). Compared to the traditional food waste recycling technologies, fungal hydrolysis owns a lot of environmental and social advantages including free of air pollutant formation, free of unpleasant smell and not energy intensive. Most importantly, it allows recycling of nutrients in food waste through the use of the hydrolysate as fermentation feedstock for the production of value-added bio-based products. For example, we previously demonstrated the utilization of waste bread hydrolysate as fermentation feedstock for succinic acid production by *Actinobacillus succinogenes* (Leung et al., 2012) and biodegradable polymer polyhydroxybutyrate by *Halomonas boliviensis* (Pleissner et al., 2014b). Pleissner et al. (2013) reported cultivation of *Chlorella pyrenoidosa* using mixed food waste hydrolysate as culture medium for the production of algal biomass. Techno-economic analyses have been carried out to investigate the economic feasibility of pilot scale operation by using simulation software. It was noted that the economic profitability was not attractive for upscaling due to prolonged fermentation time and low concentration of products (Lam et al. 2014, Kwan et al. 2015). Nevertheless, Kwan et al. (2015) indicated that fermentative lactic acid production using food waste as raw material could lead to a highly attractive economic profitability since the duration of lactic acid fermentation is relatively short and high concentration of lactic acid can be achieved easily.

Lactic acid (LA) was identified as one of the twelve most promising value-added building blocks derived from sugars with a high potential to be a key building block for the production of both commodity and specialty chemicals (DOE, 2004). It has diverse applications including preservative, pH adjusting agent, a starting material in the production of lactate ester, active ingredient in personal care products and monomer in the production of biodegradable polymer polylactic acid. These diverse applications of LA lead to the growing industrial application at a rate of 5–10% per year (Corbion purac, 2015). There are a number of studies of LA fermentation using different carbon sources as raw materials such as food industry by-products (e.g. kitchen waste, whey), agro-industrial residues and by-products (e.g. cottonseed hulls, corn cob, corn stalks, wheat bran, brewer's spent grains) and renewable resources (e.g. Jerusalem artichoke hydrolysates) (Venus, 2006; Venus and Richter, 2006; Wang et al., 2011). Different processes including enzymatic hydrolysis and fermentation, simultaneous hydrolysis and fermentation, open fermentation and direct fermentation have been intensively studied with different LA producing microorganisms (Pleissner et al., 2016; Uçkun Kıran et al., 2015). However, the bioconversion of food waste for LA production via fungal hydrolysis and microbial fermentation has not been reported. Furthermore, most of these studies highlighted the cost-efficiency of using waste as raw material and emphasized on the potential to develop economically feasible processes. Techno-economic evaluation has not been carried out due to the lack of the mass balance of the whole process.

Starting from July in 2013, Environment and Conservation Fund operated by Environmental Protection Department in Hong Kong has allocated HK$ 50 million as subsidy to encourage the separated collection and recycling of food waste (EPD, 2011). The subsidy provides funds to support various recycling activities as well as setting up on-site food waste treatment machines. By using the food waste treatment machines, up to 70% volume reduction can be achieved by shredding, grinding and dehydrating at over 100 °C. As one of the most populated cities in the world, the use of food waste treatment machines can facilitate a decentralized process of food waste recycling and also save transportation cost of food waste collection, which can account for more than 70% of the operation cost of recycling food waste according to a local food waste recycling company (HKOWRC, 2015). In view of that, the incorporation of the food waste treatment machines in the bioconversion of food waste could be an advantageous approach for recycling food waste in urban area.

This study aims to demonstrate the bioconversion of mixed food waste and bakery waste to LA via fungal hydrolysis and fermentation by *Lactobacillus casei* Shirota. Feasibility of using food waste powder produced by food waste treatment machine as raw materials for LA production is explored for a decentralized approach for food waste recycling in urban area. The proposed bioprocess can be integrated in a traditional transesterification for the production of biodiesel and an important platform chemical.

2. Methods

2.1. Microorganisms

A. awamori ATCC 14331 was purchased from the American Type Culture Collection (Rockville, MD, USA). *A. oryzae* was isolated from a soy sauce starter provided by the Amoy Food Ltd., Hong Kong (Leung et al., 2012). Spore solutions of both fungi were produced as described earlier (Lam et al., 2013). *L. casei* Shirota was obtained from Prof. Nagendra Prasad SHAH at School of Biological Sciences in University of Hong Kong. It was cultivated in MRS broth with 20 g L^{-1} initial glucose concentration in a shaking incubator at 200 rpm for 18 h at 37 °C.

2.2. Food waste handling

Mixed food waste was collected from Asia Pacific Catering located in the Hong Kong Science Park and bakery waste was collected from Starbucks outlet located in Sha Tin. The mixed food waste was the leftovers consisting of rice, noodles, meat and vegetables, while the bakery waste was unsold products including cakes, breads and pastries. These wastes were separately blended and stored at 4 °C until use, but for no more than one week. Food waste powder was produced using blended mixed food waste processed by a commercial food waste treatment machine (SPZ-3000D, Spinz, Korea) donated by Eco-Greenergy Limited. The process included shredding and dehydration at 100–150 °C. Two output streams consisted of food waste powder and wastewater effluent generated during the cleaning step of food waste machine.

2.3. Solid state fermentation

Solid state fermentation was carried out to produce fungal solid mashes, which were used as enzyme sources in submerged food waste hydrolysis. For 8.5 g (Dry weight) of mixed food waste or bakery waste, 1 mL of spore solution of *A. awamori* (4.6×10^5 spores mL^{-1}) or 1 mL of spore solution of *A. oryzae* (6.3×10^5 spores mL^{-1}) was added, mixed, and incubated for 7 days at 30 °C. It was performed as described in our previous publication (Lam et al., 2013; Pleissner et al., 2014a).