



ELSEVIER

Contents lists available at ScienceDirect

## Food and Bioproducts Processing

journal homepage: [www.elsevier.com/locate/fbp](http://www.elsevier.com/locate/fbp)ICChemE  
ADVANCING  
CHEMICAL  
ENGINEERING  
WORLDWIDE

# High fructose syrup production from mixed food and beverage waste hydrolysate at laboratory and pilot scales



Tsz Him Kwan<sup>a</sup>, Khai Lun Ong<sup>a</sup>, Md Ariful Haque<sup>a</sup>, Wentao Tang<sup>a</sup>, Sandeep Kulkarni<sup>b</sup>, Carol Sze Ki Lin<sup>a,\*</sup>

<sup>a</sup> School of Energy and Environment, City University of Hong Kong, Hong Kong

<sup>b</sup> Independent Sustainable Packaging Consultant, 4501 May Apple Drive, Alpharetta GA 30005, United States

## ARTICLE INFO

## Article history:

Received 6 March 2018

Received in revised form 14 June 2018

Accepted 2 August 2018

Available online 8 August 2018

## Keywords:

Adsorption

Food and beverage waste

Ion exchange chromatography

Isomerisation

Simulated moving bed system

Saccharification

## ABSTRACT

Conversion of food and beverage (F&B) waste into high fructose syrup (HFS) was proposed in this study. Hydrolysate obtained from saccharification of mixed F&B waste is rich in glucose ( $260.3 \pm 7.8 \text{ g L}^{-1}$ ) and fructose ( $54.1 \pm 1.6 \text{ g L}^{-1}$ ) but also contains trace preservatives, caffeine, colourants, ions and soluble proteins. Over 99% of these impurities were removed by adsorption and ion exchange chromatography, followed by enzymatic isomerisation where glucose was converted to reach 50% of fructose content. Pilot scale downstream processing was successfully conducted with more than 89% of sugars recovered from the hydrolysate. Mass balance analysis indicated an overall conversion yield of 0.08 kg HFS per kg of mixed F&B waste and meanwhile the HFS also conforms to industrial standards. This proposed process is believed to promote the development of a circular economy by recycling F&B waste as a renewable resource for HFS production.

© 2018 Institution of Chemical Engineers. Published by Elsevier B.V. All rights reserved.

## 1. Introduction

The food waste problem has become one of the biggest environmental challenges in recent years. About 1.3 billion metric tons (MT) of food waste is generated around the globe per year, which accounts for roughly one-third of food produced for human consumption (FAO, 2011). Although food waste is produced throughout the supply chain, a large proportion is wasted at the consumption stage in the developed regions mainly because of consumer behaviour such as insufficient purchase planning and stringent quality standards (FAO, 2011). The average per capita food waste by household in Taipei, Hong Kong and Seoul is 0.07–0.13 MT year<sup>-1</sup> (Environment Bureau, 2014), which is 10 times higher than that in South and Southeast Asia. This not only represents a waste of resources, but also intensifies the food crisis. The global population is projected to reach more than 9 billion by 2050, boosting the demands on agriculture for access to adequate food. It is estimated that global food production has to be doubled by turning

another 20% of land on the Earth to farming in order to fulfil the food demand (Ramankutty and Rhemtulla, 2012). As food waste currently claims a significant proportion of agricultural output (i.e. 30% for cereals, 40–50% for root crops, fruits and vegetables, and 20% for oil seeds, meat and dairy), food waste recycling for nutrient recovery is inevitably needed in order to increase the efficiency of the whole food chain (FAO, 2017).

Sugar has been a historically important commodity in the human diet since the 18th century. Currently, high fructose syrup (HFS) is one of the most popular sweeteners in the food and beverage industry due to a number of advantages (White, 2014). First, it is relatively stable in low pH beverages and requires less labour to handle it. Then, it has a high tendency to develop colour which is useful in manufacturing baked products. Furthermore, the sugars have already pre-dissolved and are resistant to crystallisation and microbial growth as one of the traditional preservation methods. Most importantly, fructose is the sweetest dietary sugar which is nearly 1.2 times as sweet as sucrose

\* Corresponding author at: School of Energy and Environment, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong.

E-mail address: [carollin@cityu.edu.hk](mailto:carollin@cityu.edu.hk) (C.S.K. Lin).

<https://doi.org/10.1016/j.fbp.2018.08.001>

0960-3085/© 2018 Institution of Chemical Engineers. Published by Elsevier B.V. All rights reserved.

(Hanover and White, 1993). Nowadays, HFS is primarily made from corn such that more than 7600 MT have been produced annually in the US since 2001 (USDA, 2017). Different grades of HFS including 42%, 55% and 90% of fructose content are commercially available for various applications (Long, 1986). Meanwhile, our recent study also turned 100% HFS into 5-hydroxymethylfurfural (HMF) by catalytic dehydration (Yu et al., 2018). Exploration of other possible agricultural feedstock for HFS production is reported in the literature such as cassava, sweet potato, wheat and rice (Johnson et al., 2009, 2010). However, the intensive farming system to grow corn or other agricultural crops for HFS production often draws public criticism for being unsustainable, as it leads to serious environmental problems including massive deforestation, water scarcities, soil depletion and high levels of greenhouse gas emissions (FAO, 2017; Ramankutty and Rhemtulla, 2012). Also, these studies mainly focused on the sugar recovery by saccharification and fructose conversion by isomerisation whereas the downstream processing and calculation of the overall conversion yield were seldom addressed, which prevented further industrial development. Therefore, this study proposes utilisation of the waste stream generated in the industrial sectors for sustainable HFS production and demonstrates the entire conversion process accompanied with mass balance calculation.

In fact, food and beverage (F&B) waste is an ideal feedstock for HFS production but the possibility of such conversion has never been explored. F&B waste is generated due to lack of coordination between different actors in the food supply chain and high expectation of quality by customers (FAO, 2017). As reported by Quested et al. (2013), 60% of the beverage waste in the United Kingdom is avoidable. Over 75% of the F&B waste disposed of from oatmeal manufacturing plant is actually edible (Hyman, 2009). Our recent studies analysed the composition of a number of F&B wastes including potato chips, oatmeal, bakery products, juices, energy drinks, and soft drinks (Haque et al., 2017; Kwan et al., 2018). It was found that most of them either contain large amounts of starch (30–60%, w/w) or high levels of free sugars (~100 g L<sup>-1</sup> fructose, glucose and sucrose) (Haque et al., 2017; Leung et al., 2012; Kwan et al., 2018). Valorisation of F&B waste by saccharification not only provides an environmentally-benign waste treatment method, but also produces sugar-rich hydrolysates that can be converted into HFS by isomerisation and downstream purification processes. As reported in our recent studies, the F&B hydrolysate contained high levels of glucose (260.7 ± 9.4 g L<sup>-1</sup>) and fructose (54.7 ± 1.9 g L<sup>-1</sup>), and about 0.17 g of sugars were recovered from a gram of F&B waste by saccharification, clarification and filtration (Kwan et al., 2018; Yu et al., 2018). Although the HFS derived from F&B waste might not be socially acceptable for human consumption, it is an ideal feedstock for the production of HMF and bio-based plastics via different polymerisation pathways (Kaur et al., 2018; Yu et al., 2018). Kaur et al. (2018) recently proposed the conversion of F&B waste into bio-based plastics, such as polyethylene furanoate, polyethylene terephthalate, and poly(lactic acid), which casts insights into the transformation of the plastics industry into a circular economy. However, there are a few drawbacks that have to be investigated and overcome. First, the preservatives, additives and colourants originated from the F&B waste should be removed from the hydrolysate. Then, a composition analysis is needed to check if the HFS derived from F&B waste conforms to existing industrial standard. Lastly, generation of by-products and sugar recovery should be evaluated by mass balance analysis since the F&B waste contains around 10% of crude protein and 20% of crude lipids which will end up in the by-product streams and a portion of sugars could be lost during downstream processing.

In this context, the aim of this study was to produce HFS using mixed F&B waste hydrolysate by isomerisation and a cascade of downstream processing technologies including adsorption, ion exchange chromatography and ligand exchange chromatography. Mixed F&B waste hydrolysate was prepared and obtained from our recent studies (Yu et al., 2018). A laboratory-scale study was first conducted to evaluate the technical feasibility, followed by a pilot scale investigation to explore the feasibility of upscaling. The HFS derived from mixed F&B waste was analysed according to industrial standards to check the appropriateness for application in the F&B industry. Lastly, mass

balance analysis was conducted to summarise the entire conversion process from mixed F&B waste to HFS with calculation of the conversion yield and identification of by-product streams.

## 2. Materials and methods

### 2.1. Preparation of mixed food and beverage waste hydrolysate

Saccharification of mixed F&B waste was carried out in a 10 L paddle mixer at 50 °C and 50 rpm for 24 h. The solid-to-liquid ratio was set to be 70% (w/v). The hydrolysis broth was harvested and centrifuged at 10,000 rpm for 15 min to separate the remaining solids and crude lipids, followed by clarification and filtration for removal of suspended solids. The hydrolysate was frozen at -20 °C until used in downstream processing. The handling of F&B wastes and results of saccharification were reported in our recent studies (Kwan et al., 2018; Yu et al., 2018). Composition analyses of the hydrolysate were conducted in triplicate as described in Section 2.6.

The composition for the food and beverage waste used in this study was reported in our previous publication (Kwan et al., 2018). In general, the food waste which was prepared by mixing oatmeal, potato chips, cakes, breads and pastries contains around 50–60% (w/w) carbohydrate, 9% (w/w) crude protein and 20% lipids, while the mixed beverage waste (fruit juices, energy drinks, and soft drinks) contains 36 g L<sup>-1</sup> glucose, 45 g L<sup>-1</sup> fructose, and 12 g L<sup>-1</sup> sucrose. Colourant, preservatives and caffeine were also detected (Kwan et al., 2018).

### 2.2. Adsorption and ion exchange chromatography

Adsorption treatment was carried out in a 240 mL glass column (Φ16 × 700 mm inner column, Huamei, Shanghai, China) packed with 110 g of macroporous adsorption resin (Lewatit VP OC 1064 MD PH, Lanxess). The column was washed with two bed volumes (BV) of 70% methanol, followed by 3 BV of DI water before loading the 0.45 μm membrane-filtered hydrolysate. Ion exchange chromatography was carried out in two 240 mL glass columns (Φ16 × 700 mm inner column, Huamei, Shanghai, China) separately packed with 60 g of weak base anion resins (Dowex monosphere 66 resins) and strong acid cation exchange resins (Dowex monosphere 88 resins). The anion exchange resins and cation exchange resins were activated or regenerated with 1 M NaOH and 1 M H<sub>2</sub>SO<sub>4</sub> for 3 BV for 30 min respectively, followed by 5 BV of DI water. The mobile phase was DI water and the flow rate was set to be 4 mL min<sup>-1</sup> in both treatments. Composition analyses of the hydrolysate were conducted before and after the treatment as described in Section 2.6.

### 2.3. Isomerisation

Isomerisation of glucose to fructose was carried out in a 120 mL glass column (16 × 400 mm inner column, GE healthcare, UK) packed with 20 g of glucose isomerase. The temperature of the column was controlled to be 60 °C. Fructose percentage was compared among the use of defined medium, raw hydrolysate and purified hydrolysate as feedstock obtained after adsorption and ion exchange treatment. The defined medium was prepared by dissolving glucose (VWR, USA) and fructose (VWR, USA) in DI water to reach the identical concentrations of hydrolysates. The feedstock

Download English Version:

<https://daneshyari.com/en/article/10999802>

Download Persian Version:

<https://daneshyari.com/article/10999802>

[Daneshyari.com](https://daneshyari.com)