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Research article

Effects of storage environment on the moisture content and microbial growth of food waste

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A B S T R A C T

Food waste (FW) has become a critical issue in sustainable development as the world's population has increased. Direct incineration of FW remains the primary treatment option. The moisture content of FW may affect the energy efficiency of incineration. In Taiwan, FW, which includes raw (r-FW) and post-consumer (p-FW) waste, is often stored in freezers before pretreatment. This study evaluated the effects of storage environment on the moisture content and microbial growth of FW. Storage at 263 K was associated with the largest reduction in moisture content in both r-FW and p-FW. At 263 K, the moisture content of r-FW and p-FW was lowest at 96 and 72 h, respectively. The *E.coli* and total bacteria counts were steady over 120 h when stored at 263 K. Storage at 253 K required the greatest electricity consumption, followed by 263 K and 258 K. Based on the reduction of moisture content and increase in energy efficiency, it is suggested that FW is placed in temporary storage at 263 K before (pre)treatment. The results of this study will help waste-to-energy plants, incinerators, and waste management enterprises to implement proper (pre)treatment of FW for sustainable waste management.

1. Introduction

With an increasing world population, food plays an important role in sustainable living. It has been found that one third of all food produced for human consumption is wasted (Lipinski et al., 2013). Each year, 1.3 billion tons of food is wasted (Gustavsson et al., 2011) and it has been predicted that by 2025, food wastage will have increased by 44% from 2005 levels (Adhikari et al., 2006). Food wastage influences global warming, water consumption, land use, and natural biodiversity (FAO, 2013) and is therefore emerging as an important issue in sustainable development (Mourad, 2016). Studies in Germany, Great Britain, Italy, France, Austria, Switzerland, and the US indicate that households are the main contributors to food waste (FW) (Buchner et al., 2012; Lipinski et al., 2013; Monier et al., 2011; Schweiz, 2012).

Many countries are committed to the sustainable management of food without wastage. The European Commission has set a reduction goal of 50% for edible FW in Europe's food chain by 2020 (Liu et al., 2016) and the US Environmental Protection Agency has announced the first ever domestic goal to reduce FW by 50% by 2030 (Liu et al., 2016). France has adopted a new law that bans supermarkets from disposing of unsold food and requires them to donate it to charities or for animal feed (Liu et al., 2016). Food recycling legislation in Japan requires the amount of recycled FW to be reported (Takata et al., 2012). In South Korea and Sweden, landfilling of FW has been banned since 2005 (Woon and Lo, 2016).

Several studies have investigated the physical or chemical pretreatment of FW to alter its properties (Lü et al., 2016). Mechanical grinding has been found to increase the microbial degradation of FW (Izumi et al., 2010). Alkali and acid pretreatment enhances hydrogen production from FW (Lin et al., 2013). Thermal pretreatment is beneficial for FW degradation (Li and Jin, 2015; Wang et al., 2006). High temperature and pressure microwave irradiation was found to enhance the biodegradability of FW (Lin et al., 2013) but did not enhance anaerobic digestion (Shahriari et al., 2013). The influence of enzymatic pretreatment of FW on acid fermentation was investigated by Kim et al. (2006). The effects of ultrasonication on the biodegradability of FW have also been investigated (Cho et al., 2013; Elbeshbishy and Nakhla, 2011). Ozonation is another suggested pretreatment to enhance the anaerobic digestion of FW

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(Ariunbaatar et al., 2014). However, no studies have investigated the effects of storage environment on FW, which is often refrigerated before treatment.

In Taiwan, 2.3 million people generate about 8 million tons of municipal solid waste (MSW) annually (Taiwan EPA, 2017). FW makes a significant contribution to MSW (25–70%) (Pham et al., 2015). On average, an annual production of 621,000 tons of FW in Taiwan comprises 25% raw FW (r-FW) and 75% post-consumer FW (p-FW) (Taiwan EPA, 2017). The r-FW is often used for compost, and the p-FW is used to feed animals (mostly pigs). Most of the MSW in Taiwan is treated by 24 local waste-to-energy (WTE) plants for volume reduction and energy recovery (Chen and Lo, 2016). However, high moisture content, lower heating values, and high heterogeneity of FW (Eriksson et al., 2015; Karmee, 2016; Pham et al., 2015) may reduce the efficiencies of WTE plants. The moisture content of FW ranges from 74 to 90% depending on its composition (Zhang et al., 2007). In Taiwan, the moisture content of MSW is c. 55% (Taiwan EPA, 2017), which makes it unfavorable for direct incineration (Leckner, 2015). Hence, FW should be separated from MSW for better incineration efficiency and resource recovery (Ahamed et al., 2016; Chen and Wu, 2015). Pre-sorting MSW to reduce its moisture content can increase its energy potential and mitigate greenhouse gas emissions (Corsten et al., 2013; Tan et al., 2014). The issue of reducing the moisture content of FW to improve energy efficiency is thus attracting attention.

More and more communities in Taiwan are purchasing freezers for temporary storage of FW. These closed freezers are highly beneficial for reducing unpleasant odors. However, the effects of storage temperature and time on the properties of FW are under-investigated. The aim of this study was to investigate the effects of storage temperature and time on the moisture content and microbial growth of FW. Relationships were found among time, temperature, and electricity consumed in the storage of FW. Some measures to increase the sustainability of energy and resources (mainly FW) are suggested. The results of this study will help WTE plants, incinerators, and waste management enterprises to establish proper (pre)treatment of FW for sustainable waste management.

2. Materials and methods

2.1. Materials and instruments

All chemicals and reagents used in this study were of analytical grade. A grinder was used to crush FW. Sterilized 100-mL polypropylene containers were used to contain the FW for further tests. A freezer (FRT-0661SZ, Frigidaire) maintained the FW within a temperature range of 263–253 K. An electronic scale (SHIMADZU ATX224, minimum display 0.1 mg) and oven (MEMMERT) were used for moisture analysis. Membrane filters 47 mm in diameter and with 0.45 μm porosity and LES Endo agar (Creative Life Science, Ltd.) were used for the *E. coli* analysis. For the total bacteria count, tryptone glucose extract (TGE) agar (Creative Life Science, Ltd.) was used. A low-temperature incubator (721, Taiwan Hipoint Corporation) was used to incubate microorganisms. A digital multimeter (DT83B, SEAT Tools) was used to test the electricity consumption of the freezers. All solutions were prepared with Milli-Q ultrapure water (18 MΩ cm resistivity).

2.2. Food waste preparation

The FW used in this study was a mixture of r-FW and p-FW. The r-FW consisted of 300 g cauliflower, 400 g cabbage, 300 g apples, 200 g bananas, and 300 g guavas. These are commonly used cooking ingredients in households and can be purchased throughout the year. The 1500 g p-FW was randomly collected from cafeterias during dining time. The collected FW was then sliced by the grinder to ensure that the diameters of the samples were <1 cm. The sliced FW was then sealed in sterilized 100-mL polypropylene containers for further tests.

2.3. Temperature experiment

The sample FW was kept in freezers for the duration of the experiment. The storage temperatures were set at 263 K, 258 K and 253 K to reflect the range of most commercial freezers. Samples were taken at 0, 3, 6, 9, 24, 48, 72, 96, and 120 h. As the government waste service teams are only off-duty on weekends, we supposed that households would not keep FW for longer than 5 days (120 h). Samples from the freezer were analyzed daily for moisture content and elemental composition. The experiments were carried out three times. The mean values are reported here.

2.4. Moisture content analysis

Samples averaging 5 g were put into a 50 mL ceramic crucible, weighed (W_1), and then dried in an oven at 378 K for 2 h. After cooling to room temperature, the samples were then reweighed (W_2). All of the samples were tested in triplicate to ensure a reliable and robust outcome. The moisture content of the samples was calculated using Eq. (1):

$$\text{moisture content} = \frac{W_1 - W_2}{W_1} \times 100(\%). \tag{1}$$

The analysis was carried out three times. The mean values are reported here.

2.5. Bacterial analysis

The *E. coli* and total bacteria counts of the samples stored at 263 K were recorded for 120 h. The *E. coli* and total bacteria in the sample FW were tested using a membrane filter method (NIEA E202.55B) and a spread plate method (NIEA E203.56B), respectively. For the *E. coli* analysis, 10 mL leachate from the FW was filtered through 0.45 μm porosity membrane filters that retained the *E. coli* found in the sample. The filters were then transferred to a dish containing LES Endo agar and incubated at 308 K for 24 h. For the total bacteria count, 1 mL leachate from the FW was dropped onto TGE agar and incubated at 308 K for 48 h. Sheen colonies were then counted under magnification and reported. All of the procedures were completed within 48 h of sampling. The number of microorganisms found in the sample was calculated using Eq. (2):

$$\text{microorganisms}\left(\frac{\text{CFU}}{\text{mL}}\right) = \frac{\textit{number of bacteria in the agar}}{\textit{volume of sampling water}}. \tag{2}$$

Colony forming units (CFUs) were counted and expressed in CFU/mL for total bacteria and CFU/100 mL for *E. coli*.

2.6. Electricity consumption

The electricity consumption of the freezers was tested using a digital multimeter. The analysis was carried out three times. The mean values are reported here.

3. Results and discussion

3.1. Effects of storage temperature on food waste

Fig. 1 shows variations in the moisture content of r-FW and p-