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Effects of moisture content of food waste on residue separation, larval growth and larval survival in black soldier fly bioconversion

Jack Y.K. Cheng, Sam L.H. Chiu, Irene M.C. Lo *

Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Hong Kong, China

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A B S T R A C T

In order to foster sustainable management of food waste, innovations in food waste valorization technologies are crucial. Black soldier fly (BSF) bioconversion is an emerging technology that can turn food waste into high-protein fish feed through the use of BSF larvae. The conventional method of BSF bioconversion is to feed BSF larvae with food waste directly without any moisture adjustment. However, it was reported that difficulty has been experienced in the separation of the residue (larval excreta and undigested material) from the insect biomass due to excessive moisture. In addition to the residue separation problem, the moisture content of the food waste may also affect the growth and survival aspects of BSF larvae. This study aims to determine the most suitable moisture content of food waste that can improve residue separation as well as evaluate the effects of the moisture content of food waste on larval growth and survival. In this study, pre-consumer and post-consumer food waste with different moisture content (70%, 75% and 80%) was fed to BSF larvae in a temperature-controlled rotary drum reactor. The results show that the residue can be effectively separated from the insect biomass by sieving using a 2.36 mm sieve, for both types of food waste at 70% and 75% moisture content. However, sieving of the residue was not feasible for food waste at 80% moisture content. On the other hand, reduced moisture content of food waste was found to slow down larval growth. Hence, there is a trade-off between the sieving efficiency of the residue and the larval growth rate. Furthermore, the larval survival rate was not affected by the moisture content of food waste. A high larval survival rate of at least 95% was achieved using a temperature-controlled rotary drum reactor for all treatment groups. The study provides valuable insights for the waste management industry on understanding the effects of moisture content when employing BSF bioconversion for food waste recycling.

1. Introduction

Globally, approximately 1.3 billion tonnes of food is wasted each year, equivalent to an annual economic loss of about USD 1 trillion (FAO, 2014, 2013). Apart from the huge financial cost, food waste also cause numerous environmental problems, such as depletion of the limited landfill space, creation of odour nuisance as well as generation of leachate and landfill gases (Lee et al., 2007). In view of the significance of the global food waste problem, the United Nations have agreed on a global agenda for achieving sustainable management of food waste through the Sustainable Development Goals in 2015, of which Goal 12 states that the amount of food waste per capita has to be reduced by half by 2030 (UN, 2016). Therefore, there is a pressing demand for developing multiple potential food waste valorization technologies in order to meet this reduction target as well as to mitigate the adverse effects of food waste.

Within the scientific literature, there is no commonly agreed definition of food waste (Girotto et al., 2015). According to the Food and Agricultural Organization of the United Nations (2011), the wastage of food encompasses both "food loss" and "food waste". "Food loss" refers to the decrease in edible food intended for human consumption, which takes place at production, post-harvest and processing stages in the food supply chain, whereas "food waste" refers to the food discarded at the retailer or consumer level. In this study, the definition of food waste is adopted from the Hong Kong Government. Food waste is defined as any waste generated during food production, distribution, storage, meal preparation or meal consumption (HKEB, 2014).

In Hong Kong, food waste has also become an inescapable problem that demands serious attention. It makes up the largest fraction of the municipal solid waste in Hong Kong at 37%, which is approximately equal to 3600 tonnes per day (tpd) (HKEPD,

* Corresponding author.
E-mail address: cemclo@ust.hk (I.M.C. Lo).

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2015a). In order to address such a tremendous amount of food waste, the Hong Kong Government has proposed building modern, large-scale organic waste treatment facilities, in phases, to turn source-separated food waste into useful resources. The first two phases apply anaerobic digestion and composting to convert 500 tpd of food waste into biogas for energy recovery and compost products (HKEPD, 2015b). However, since there still remains 3100 tpd of food waste, other recycling alternatives must also be considered in order to boost the food waste recycling rate.

Converting food waste into fish feed can be a viable option for Hong Kong. Cheng and Lo (2016) reported that such method is feasible in Hong Kong due to the negligible public health risk and a high demand for fish feed in mainland China. Among the various technologies for the conversion of food waste into fish feed, black soldier fly (BSF) bioconversion was found to be the most favourable one for Hong Kong, compared to the other available options such as heat drying, heat sterilization, fermentation and earthworm production (Cheng and Lo, 2016). This is because through BSF bioconversion, food waste can be converted into high-protein insect biomass in the form of BSF larvae or prepupae, both of which contain a high level of protein (Diener et al., 2009), with prepupae often harvested instead of larvae due to the ease of harvesting (Diener et al., 2011a). These prepupae contained a high crude protein content of 40–44% (Makkar et al., 2014), which can be used as a high-protein feed ingredient for valuable fish species like sea bass (AFCD, 2009). In practical terms, insect biomass is being used as a feed ingredient in mainland China as evidenced by the Catalogue of Feed Materials of China, which includes a category for "insect and processed insect products". It is therefore believed that the high-protein insect biomass product can gain market acceptance in mainland China easily. Along with the production of the insect biomass, a residue composed of the larval excreta and the undigested material is also produced (Diener et al., 2009). Due to the low protein content of the residue, it cannot be used for feeding valuable fish species and needs to be separated from the insect biomass. However, the residue can be used as a plant fertilizer after separation (Newton et al., 2005). In addition to food waste, BSF bioconversion can also be a promising option for the treatment of other biodegradable wastes such as the residual biodegradable material excavated from landfill mining. Such waste requires additional stabilization treatment due to its emission potential (Raga et al., 2015). As long as the biodegradable materials have negligible heavy metals or other toxic contaminants, BSF bioconversion can be a suitable and economically viable solution.

The conventional method of BSF bioconversion is to feed the BSF larvae with food waste directly without any moisture adjustment (Diener et al., 2011a,b; Kalová and Borkovcová, 2013; Nguyen et al., 2013; Warburton and Hallman, 2002). While this may be simple and time-saving, it can lead to difficulty in the separation of the residue from the insect biomass as the residue can become too wet (82–86% moisture content) and too viscous for sieving (Diener et al., 2011b). In order to produce fine residue for sieving, one possible solution is to adjust the moisture content of the food waste fed to the larvae because it can affect the moisture content of the residue, which in turn affects its particle size distribution. This is because the size of the residue particles is influenced by the adhesive property of the water molecules. When the moisture content is high, the residue particles tend to aggregate readily and increase in size, and vice versa. However, there is a lack of literature data on the most suitable moisture content of food waste in BSF bioconversion for effective residue separation.

In addition to the residue separation problem, the moisture content of the food waste may also affect the performance of BSF bioconversion. There are reported studies showing that the moisture content of some organic wastes, such as poultry manure and faecal sludge, can significantly affect larval growth and survival. Banks (2014) evaluated the effects of the moisture content of the faecal sludge in BSF bioconversion at 65%, 75% and 85% moisture content, and reported that the moisture content has a significant effect on the prepupal dry weight, with the heaviest prepupae obtained at 85% moisture content. Fatchurochim et al. (1989) assessed the effect of the moisture content of the poultry manure on the larval survival rate at moisture levels of 20–90%, and found that the larval survival rate varied significantly for different moisture levels, with the highest rate at 40–60% moisture content. Since the moisture content of the BSF diet plays an important role in the larval growth and survival, it is vital to understand the effects of the moisture content of the food waste on BSF bioconversion for effective food waste treatment.

When examining the effect of the moisture content of the food waste on the larval survival rate, it is important not to overheat the BSF larvae. This is because exposure to high temperature can lead to low larval survival rates. Newby (1997) reported that when the temperature rose beyond 47 °C, the larval survival rate would fall rapidly. Further, due to the continuous heat release during the bioconversion process, the temperature in the larval environment could exceed the lethal value (Lardé, 1989). Therefore, in order to minimize the chance of larval death due to overheating, a rotary drum reactor with an aeration control system is proposed in this study to provide thorough mixing and aeration cooling so as to maintain the temperature in the larval environment well below the lethal temperature of 47 °C. Ideally, the temperature should be kept at around 35 °C because it is the optimal feeding temperature for BSF larvae (Newby, 1997).

The objectives of this study were to (i) determine the most suitable moisture content of food waste in BSF bioconversion so as to improve the sieving efficiency of the residue; (ii) assess the effects of the moisture content of the food waste on larval growth in BSF bioconversion; and (iii) evaluate the effect of the moisture content of the food waste on larval survival in BSF bioconversion. Ultimately, it is expected that this study can provide significant insights for the waste management industry on understanding the effects of moisture content when applying BSF bioconversion for food waste recycling.

2. Material and methods

2.1. Black soldier fly larvae

In order to produce BSF larvae for the experiments, a BSF colony was established using eggs obtained from a local fish farm which raises BSF larvae for fish feed. In each treatment group, 2000 BSF larvae were used for the bioconversion of the food waste. The initial wet weight of each larva was approximately 5 mg because a larva with a weight below 5 mg is difficult to be handled and observed. The age of the larvae was 4–5 days after egg hatching. The experiment was terminated when more than 90% of the larvae turned into prepupae because larvae cease to feed after turning into prepupae (Newton et al., 2005). The percentage of prepupae was determined daily by examining 100 samples of insect biomass and counting the number of dark brown ones since there is a morphological colour change from white to dark brown as the BSF larvae turn into prepupae (Oliveira et al., 2015).

2.2. Food waste

Two types of food waste were used in this study, namely pre-consumer and post-consumer food waste. The pre-consumer food waste was collected from the canteen kitchen at the Hong Kong University of Science and Technology, and comprised vegetable trimmings, spent coffee grounds and tea leaves. Meat scrap was

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