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A holistic approach for food waste management towards zero-solid disposal and energy/resource recovery

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Abstract

This study developed a holistic approach which was based on the ultra-fast hydrolysis of food waste with the fungal mash rich in various hydrolytic enzymes produced in situ from food waste as well. After the 8-h hydrolytic treatment, the solid residue and liquor were separated. It was found that the produced solid residue can meet all the requirements for biofertilizer in terms of NPK and heavy metal contents, while the separated liquor with high soluble organics concentration was further subject to anaerobic digestion for enhanced biomethane production. The results showed that 0.41 kg of biofertilizer with a moisture content of 76.9% and 54.4 L of biomethane could be produced from 1 kg of food waste. As such, it is expected that this study may lead to the paradigm shift in food waste management with the ultimate target of zero-solid discharge.

Keywords: Food waste, Fungal mash, Anaerobic digestion, Fertilizer, Zero-solid disposal.

1. Introduction

Food waste is produced from various sources including food processing, vegetable market, restaurants etc. According to Food and Agriculture Organization(AC, 2013), nearly 1.6 billion tonnes of foods including fresh vegetables, fruits, meat, bakery and dairy products are wasted annually, which is about 27% of the total global agricultural productivity for both food and non-food uses. For example, the amount of food waste generated in Singapore has increased by almost 50% in the past 10 years and is expected to increase with the growing population and economic activity, but only about 13% of the food waste is recycled, and the rest is disposed of at the waste-to-energy plants for incineration (Singapore NEA, 2016). It is obvious that food waste if not managed properly would also cause many problems, e.g. contamination of recyclables, odour nuisance and vermin proliferation, thus the food waste management is becoming a pressing challenge worldwide (Chen and Gu, 2012). Although incineration can substantially reduce the food waste volume by 80-90%, it has the drawbacks of high operation cost, generation of hazardous gases and ashes, suggesting that incineration is not an eco-friendly and sustainable approach of future food waste management (Jin et al., 2015; Seng et al., 2010). On the other hand, in many highly urbanized countries, landfill is no longer a viable option due to the scarcity of usable land (El-Fadel et al., 1997; Nizami et al., 2016).

It should be realized that food waste indeed is a very important source rich in organic matter and nutrients, which can be used as a feedstock for producing high-value products (e.g., biofuels) (Girotto et al., 2015; Kiran et al., 2014). Therefore, extensive effort has been devoted to the production of bioethanol and biomethane from food waste through fermentation and anaerobic processes (Koch et al., 2015; Ma et al., 2016). However, separation and purification of bioethanol at the concentration of 50 to 120 g/L from the fermentation liquor is too costly to be economically viable (Huang et al., 2008). Anaerobic digestion of food waste for biomethane production has been considered as a feasible option, but its economic viability is largely dependent on the efficiency of food waste pretreatment and the scale, and only about 40-70% of VS in food waste can be destructed, i.e. 60-30% of food waste after anaerobic digestion ends up as solid residue (Sosnowski et al., 2003; Zhang et al., 2014). For example, in a study of anaerobic digestion of food waste, Lin et al (Lin et al., 2011) reported a biomethane yield of 0.49 m^3 CH_4/kg VS, but no attention was given to the left-over solid residue. It is obvious that even after energy recovery from food waste, a huge amount of the solid residue still needs to be handled or disposed of properly. Apparently, those approaches previously explored cannot lead to a total solution for future food waste management with the ultimate aim of zero-solid discharge.

In fact, the current strategies for food waste management are mainly driven by the motivation of energy recovery (Pham et al., 2015; Wu et al., 2016), but total solid reduction has not yet been accounted for seriously. In addition to organic matter, food waste indeed is also rich in nutrients essential for plant and crop growth, such as N, P and K, indicating that food waste should be considered as an excellent feedstock for biofertilizer production (Jiang et al., 2015). It should be pointed out that anaerobic digestion of food waste for energy recovery indeed burns all nutrients in food waste up, leading to total loss of nutrients (Bustamante et al., 2012; Bustamante et al., 2013). Alternatively, composting of food waste which indeed is a very slow process can break down nutrients into fiber and greenhouses gases, but without any energy recovery (Adhikari et al., 2008). As such, many research works have been focused on microbial conversion of food waste to a nutrient-rich biofertilizer which potentially can improve soil quality for plant and crop growth (Franke-Whittle et al., 2014), while no energy can be recovered from this microbial process. Moreover, using live microbe to convert food waste to biofertilizer is a slow process requiring very strict culture conditions, e.g. sterilization etc. It is obvious that almost all the technologies developed for food waste management currently cannot realize concurrent resource and energy recovery.

The previous study showed that a fungal mash rich in hydrolytic enzymes could greatly enhance the hydrolysis of food waste (Kiran and Liu, 2015; Kiran et al., 2014). It had been reported that the biomethane yield in anaerobic digestion of food waste pretreated with the fungal mash was about 2.3 times higher than that without pretreatment (Kiran et al., 2015), while the solid residue still need to be incinerated with additional energy input and huge amount of the incineration ash was ultimately disposed of at the landfill. Recently, Yin et al. (Yin et al., 2016) applied the enzymatic pretreatment with fungal mash to enhance hydrolysis of sewage sludge, food waste and their mixture for improving the performance of anaerobic digestion in terms of bimethane production. It was found that the net methane production from food waste was increased by 1.3 times after the pretreatment with fungal mash. However, these studies often purely focused on how to improve the energy recovery or harvesting organic carbon from food waste, but clearly without considering how to concurrently recover nutrients in food waste, such as N, P and K, while minimizing final solid disposal.

Faced up to such a situation, a holistic approach for the food waste management with the aim of zero solid discharge is urgently needed. Therefore, this study attempted to develop a holistic approach for food waste management by which food waste was first pretreated with fungal mash rich in hydrolytic enzymes which indeed produced from food waste itself, and separated solid residue and liquor were used for direct production of biofertilizer and biomethane through anaerobic reaction, with nearly zero-solid discharge. It is expected that this study can shed lights on the total solution for future food waste management.

2. Materials and methods

2.1. Food waste and In-situ production of fungal mash

The food waste used in this study was collected from a canteen at Nanyang Technological University. The collected food waste with a solid content of 23.0±0.5% by total solids (TS) was first homogenized by a blender (Kenwood, China) and then stored in zipped plastic bags at -20℃ for further use.

In this study, the fungal mash rich in hydrolytic enzymes was in-situ produced with cake waste obtained from a local bakery store as described previously (Yin et al., 2016). The produced fungal mash was then directly used to hydrolyze the food waste without any further separation and purification of enzymes.

2.2. Enzymatic Pretreatment of food waste with fungal mass

The collected food waste was first centrifuged for 5 min at 7000 rpm and 4℃. 340 g /L wet mass of the harvested food waste was mixed with 16 g/L of the fungal mash produced in this study. 500 mL of the mixed sample was transferred into 1000 mL of Duran bottles (SCHOTT, German) which were placed in a water bath shaker at 100 rpm and 60℃ for 24 h. 30 mL of mixed sample was taken out at different time intervals of 0 hour (h), 2 h, 4 h, 6 h, 8 h, 16 h, 18 h, 21 h and 24 h and was then centrifuged at 10,000 rpm for 5 min to separate liquor and solid. SCOD, total nitrogen (TN), K and heavy metals including Al, Cu, Mn, Zn, Mo, Cd, Co, Cr, Pb, Ni, Hg and As were all analyzed for the separated liquors and solids at different hydrolysis times, while total phosphorus (TP) reported as P_2O_5 was also determined for the solids.

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The anaerobic sludge taken from a local full-scale anaerobic digester was used as inoculums in this study. The biochemical methane potential (BMP) tests with the liquid separated from the hydrolysate of the food waste pretreated with the fungal mash were carried out by using the automatic methane potential test system (AMPTS)II (Bioprocess Control AB, Sweden). In these tests, 50 mL of the separated liquor with 550 mL of inoculum (13.1 g/L VSS) were filled into a 1000 mL bottle which was then purged with nitrogen gas at N_2 gas at 1 L/min for 5 min. Meanwhile, a blank test with the inoculum only was also performed. All the BMP tests were conducted at 35ºC and 150 rpm.

2.3. Analytical methods

SCOD and TN of liquor were determined by the Hach kits (Hach, US). The metal contents (e.g. Al, Cu, Mn, Zn, Mo, K, Cd, Co, Cr, Pb, Ni, Hg and As) in both the liquors and solids separated from the hydrolysate of the food waste pretreated with the fungal mash were quantified by Microwave Plasma Atomic Emission Spectrometer (MP-OES, Agilent 4100, America). Total carbon of dry solid was determined according to the method by Navarro (Navarro et al., 1993). TN and total phosphorus (TP) in the separated solid was measured using the Chinese standard methods (GB/T 8572-2010; GB/T17767.2-2010), respectively (Chinese National Standard, 2010; Chinese National Standard, 2010).

2.4. Energy content calculation

The potential recoverable electric energy can be estimated as follow:

$$-\Delta Q = M \cdot (-\Delta U) \cdot A \cdot B \tag{1}$$

Where $-\Delta Q$ is the potential recoverable electric energy (kW h), M is the total methane production (m^3), $-\Delta U$ is the energy of combustion at constant volume for methane and equal to 40 MJ/m^3 (Gupta et al., 2015) and A is the conversion coefficient of methane chemical energy to electricity through combustion, equal to 35% (McCarty et al., 2011). B is the conversion coefficient of energy (MJ) to electric energy (kW h), equal to 0.28.

3. Results and discussion

Food waste collected from a university canteen was pretreated with the fungal mash produced in this study over a period of 24 hours. Results showed that after the pretreatment with the fungal mash, 1 kg grams of food waste was converted to 0.41 kg of solid residue and 2.53 kg of liquor equivalent to 2.53 liters (Fig. 1). In this study, the separated liquor with high soluble COD concentration of 99.0±2.6 g/L was anaerobically digested for enhancing biomethane production, meanwhile the solid residue with necessary N, P and K contents was directly converted to biofertilizer, leading to nearly zero-solid discharge. Obviously, this approach realized concurrent resource and energy recovery from food waste.

Fig. 1. Mass balance on 1 kg of food waste after the 8-h pretreatment with the fungal mash.

3.1. Anaerobic digestion of liquor for energy recovery

Fig. 2 shows the concentration profiles of SCOD and TN in the liquors separated from the hydrolysates of the food waste at the different pretreatment times. It can be seen that both SCOD and TN concentrations tended to increase and gradually stabilized at 109.4 ± 2.2 g/L and 596 ± 24 mg/L on average after the 24-h pretreatment with the fungal mash, accompanied with about 65% of total solid reduction. It should be noted that released TN indeed provided a balanced nitrogen source for subsequent anaerobic digestion of the produced liquor for biogas generation. In view of the operational cost and benefit, it appears that 8-h pretreatment of food waste with the fungal mash would be considered as a practical optimum, with the generation of

99.0±2.6 g/L SCOD and 553±10 mg/L TN which was further directed to anaerobic digestion for biomethane. At this stage, about 60% of total solid reduction was achieved.

Fig.2. Time profiles of SCOD and TN concentrations in the liquor produced from the food waste pretreated with the fungal mash.

The liquor produced from the food waste after the 8-h pretreatment with the fungal mash was subject to anaerobic digestion. The highest methane yield was achieved after 11 days, i.e. 217.2±3.2 mL/g SCOD (data not shown). Meanwhile, Table 1 shows the contents of various kinds of heavy metals in the liquor. Obviously, the levels of the heavy metals in the liquor are all below their respective allowable concentrations regulated by the Chinese National Standards (GB8978-1996) (Chinese National Standard, 1996). These suggest that the liquor generated from the pretreatment of food waste by the fungal mash would be safe for direct anaerobic digestion without causing microbial inhibition.

Table 1 Heavy metals in the liquid produced from the food waste after the 8-h pretreatment with fungal mash.

Anaerobic digestion has been considered as an economically viable technology for the treatment of biosolids including food waste and waste activated sludge for energy recovery. It should be noted that the approach developed in this study is totally different from conventional anaerobic digestion of food waste in its solid form, instead the liquor with extremely high soluble COD produced from the pretreatment of food waste by the fungal mash was subject to anaerobic digestion. Obviously, this significantly improved anaerobic digestion efficiency in terms of biomethane yield and reaction kinetics. In addition, it should also be realized that among all the pretreatment methods for enhancing hydrolysis of food waste, enzymatic pretreatment as demonstrated above should be considered as a highly efficient and eco-friendly approach.

3.2. Conversion of solid residue to biofertilizer

The nutrients in the solids separated from the hydrolysates after the pretreatment of food waste with the fungal mash were shown in Fig. 3. It can be seen that the contents of TN, TP as P_2O_5 and TK as K_2O in the solids tended to increase with the pretreatment time until a plateau was reached after 8 h. These observations can be attributed to the mass reduction of food waste over the pretreatment with the fungal mash, which was also in consistence with the soluble COD reported in Fig. 2. After 8-h pretreatment of food waste, the TN and TP contents of solid residue were found to be 2.7% and 2.9%, respectively, which are higher than the standard requirements of urban wastes for agriculture use (GB8172-87) (Chinese National Standard, 1987), and close to the Standards of Organic-Inorganic Compound Fertilizer (GB18877-2009) (Chinese National Standard, 2009). These clearly suggest that the solid residue produced after the 8-h pretreatment of food waste with the fungal mash generally can meet the N&P requirements for fertilizer though the TK content was slightly lower. However, the low K content in the solid residue can be easily adjusted by mixing with commercial fertilizer or adding inorganic potassium. Table 2 further shows the contents of various heavy metals in the solid residues produced after the 8-h pretreatment of food waste with the fungal mash. It appears that the contents of all the heavy metals determined in the solid residues were within the limits of the Chinese National Standard for fertilizer, i.e. GB8172-87 and GB18877-2009 (Chinese National Standard, 1987; Chinese National Standard,2009). These in turn indicate that the solid residues produced from the pretreatment of food waste with the fungal mash developed in this study would be considered to be safe as a fertilizer.

Extensive efforts have been dedicated to anaerobic digestion of food waste or co-digestion of food waste with waste activated sludge (Liu et al., 2015; Naran et al., 2014). It should be realized that almost all nutrients (e.g. NPK) originally in food waste are eventually released into the digester liquor after anaerobic digestion, indicating that the nutrient contents in the solid residues produced are very low and cannot meet nutrient requirements for biofertilizer. Moreover, during anaerobic digestion, food waste is mixed with anaerobic sludge, and this in turn poses serious concern on the quality and safety of solid residues if they are used as fertilizer for agriculture. It should also be realized that the previous study by Yin et al. (Yin et al., 2016) primarily focused on maximizing enzymatic hydrolysis of sewage sludge, food waste and their mixture for enhanced anaerobic digestion, but substantial amount of solid residue (40-50%) was still produced and needed to be disposed of at incineration or landfill, meaning that such an approach would not be able to offer a total solution for food waste management. On the contrary, this study aimed to convert food waste to biofertilizer through the enzymatic pretreatment by the fungal mash, while the liquor generated was further anaerobically digested for recovery of biogas, leading to nearly zero-solid discharge.

Fig.3. The N, P and K contents in the solid produced from the food waste at different pretreatment times with the fungal mash.

Table 2 The characteristics of the solid residues produced from the food waste at different pretreatment times with the fungal mash.

3.3. Total solution for food waste management with zero-solid discharge

In Singapore, about 785,500 tonnes of food waste was produced in 2015, and roughly 87% of which after sorting are incinerated for volume reduction, while the incineration ash is still needed to be disposed of in the landfill (Singapore NEA, 2016). Theoretically, the incineration of this amount of food waste may annually generate about 296,000 tonnes of carbon dioxide if the carbon content in the dry food waste is assumed to be 50%. Supposing that the energy input required for incineration of food waste is about 70 kWh/tonne in a typical incinerator, and generating about 20% ash(Khoo et al., 2010), the annual energy consumption associated with the incineration of food waste would be estimated to be about 48 million kWh together with the production of 32,250 tonnes of ash that needs further disposal at landfill, requiring a land space equivalent to 13 Olympic-size swimming pools every year. However, for a highly populated and industrialized city, like Singapore, land is becoming more and more restrictive for urban solid management in a traditional context.

Due to its high efficiency in volume reduction, many developing countries are considering the incineration of food waste as an alternative to traditional landfill, implying that food waste incineration-associated carbon dioxide emission may wind up. For the purpose of illustration and discussion, if total global food waste of nearly 1.6 billion tonnes was all incinerated(AC, 2013), 693 million tonnes of carbon dioxide would be generated and eventually released into the atmosphere in a global scale, meanwhile 112 billion kWh of energy would also be consumed to drive the incineration of food waste, the production of which eventually may generate 811 million tonnes of carbon dioxide due to the fact that the generation of 1 kWh of electricity from fossil fuel (e.g. coal) could produce 1.05 kg of carbon dioxide. It is obvious that huge amount of carbon dioxide would be generated and emitted to the atmosphere if food waste incineration continues to be a global practice. Therefore, the current strategies which are mainly based on incineration, landfill and conventional anaerobic digestion cannot offer a total solution for the future food waste management in consideration of global climate change.

According to the results obtained in this study, a complete mass balance for the 8 h-pretreatment of food waste with the fungal mass was established (Fig. 1). As can be seen, 0.41 kg of solid residue with a water content of 76.9% and 2.53 L of liquor with a soluble COD of 99.0±2.6 g/L were produced from 1 kg of the food waste after the 8-h pretreatment. As shown in Fig.3and Table 2, the NPK contents in the solid residue with the heavy metal contents below the fertilizer standards can be easily made up to be a safe biofertilizer after simple dewatering. Another alternative is to directly blend this solid residue with commercial fertilizer or compost. For 785,500 wet metric tonnes of food waste produced in Singapore, roughly about 74,390 tonnes of dry biofertilizer would be produced yearly by adopting the approach developed in this study, equivanet to an additional profit of 893 millions Singapore dollars at a unit price of comercial biofertilizer of 12 thousands Singapore dollar per tone. More importantly, nearly zero-solid discharge could be realized, which in turn will significantly reduce the future demands on incineration and landfill, while also largely relieve the environmental burden with significant cut-off of carbon dioxide emission.

Anaerobic co-digestion of food waste and waste activated sludge has been exnsively explored as an altertive of the future food waste management. For example, Yin et al.(Yin et al., 2016) used the fungal mash to pretreat mixed food waste and waste activated sludge prior to anaerobic co-digestion, and found that the bio-methane yield of anaerobic digestion of pretretaed mixed food waste and activated sludge was about 1.6 times higher than that derived from the waste activated slude pretreated in a smilar manner. These clearly suggests that anaerobic co-digestion of food waste and waste activated sludge is a promising option as long as the energy recovery is concerned. However, after the co-digestion, about 40-50% of solid residue would be left over, which definitely need to be further handled properly, either by incineration or landfill. On the other hand, it should also be noted that waste activated sludge in many cases contains much higher heavy metal content than food waste. As such, more and more countries have banned anaerobically digested activated sludge from agricutural uses. Clearly anaerobic co-digestion of food waste and waste activated sludge may seriourly compromise the resource recovery from food waste. As discused above, in the proposed appraoh, after the recovery of solid residue as a safe bioferlizer, the separated liquor with high soluble COD concnetration can be directed to the exisitng anaerobic digester of waste activated sludge for enhancing biomethane produtcion. By adopting this approah, both resource and energy recovery can be realized, which indeed is an essential step towards zero-solid discharge in the future food waste management.

Fig. 1 shows that 54.4 L of methane could be produced from the anaerobic digestion of the liquor generated from the pretreatment of 1kg food waste by the fungal mash, which is equivalent to a potential energy of 2.18 MJ based on the energy content of 40 MJ/m3 methane(Gupta et al., 2015). As about 35% of chemical energy of methane can be converted to electricity through combustion (McCarty et al., 2011), so the potentially recoverable electrical energy was estimated to be 0.21kWh from 1 kg food waste according to the formula (1) in the section 2.4. For the food waste situation in Singapore, with the annual production of about 165 million kWh of electricity could be theoretically produced base on about 785,500 tonnes of food waste was produced annually. According to the Public Utilities Board of Singapore (Singapore PUB, 2014), total volume of used water treated in year 2014 was about

571 million m^3. Given the global specific energy consumption of Ulu Pandan water reclamation plant of about 0.52 kWh/m^3 (Cao, 2011), the total yearly electricity consumed for wastewater reclamation in Singapore was roughly estimated to be 297 million kWh. As shown above, the energy potentially generated from anaerobic digestion of the liquor produced from the pretreatment of the Singapore's food waste along can offset 55.6% of its total wastewater reclamation-associated energy consumption. This implies that anaerobic co-digestion of the produced liquor and waste activated sludge should be a more technically viable and environmentally sound approach without compromising the resource recovery as compared to the traditional co-digestion of food waste and waste activated sludge. More importantly, nearly no solid residues will be left over for further incineration and subsequently landfilling of incinerated ashes. In fact, this may also save another nearly 48 million kWh of electricity required for food waste incineration annually in Singapore. Consequently, the proposed integrated approach as illustrated in Fig. 1 will help to significantly relieve the burden to the incinerator or landfill in Singapore and other highly urbanized mega cities worldwide, with the additional benefits of minimized generation of hazardous gases from incineration and potential contamination of land and groundwater by landfill leachate.

4. Conclusions

This study explored a holistic approach for the sustainable food waste management with the aim of zero-solid discharge. The results showed that after 8-h pretreatment, the solid residue produced had good quality in terms of the NPK and heavy metals contents, which can be directly converted to biofertilizer. On the other hand, the liquor produced with 99.0±2.6 g/L SCOD and necessary nitrogen source ideally can be anaerobically digested for biomethane production. Consequently, nearly zero-solids would need further handling or disposal. It is expected that the approach may open a new windows and inspire new thinking for future food waste management.

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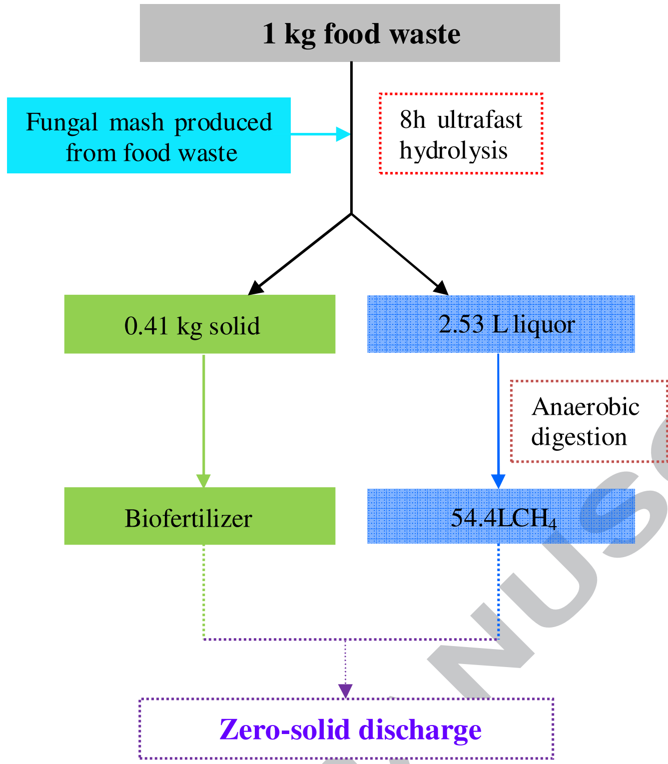
Figures

Fig.1. Mass balance on 1 kg of food waste after the 8-h pretreatment with the fungal mash.

Fig.2. Time profiles of SCOD and TN concentrations in the liquor produced from the food waste pretreated with the fungal mash.

Fig.3. The N, P and K contents in the solid produced from the food waste at different pretreatment times with the fungal mash.



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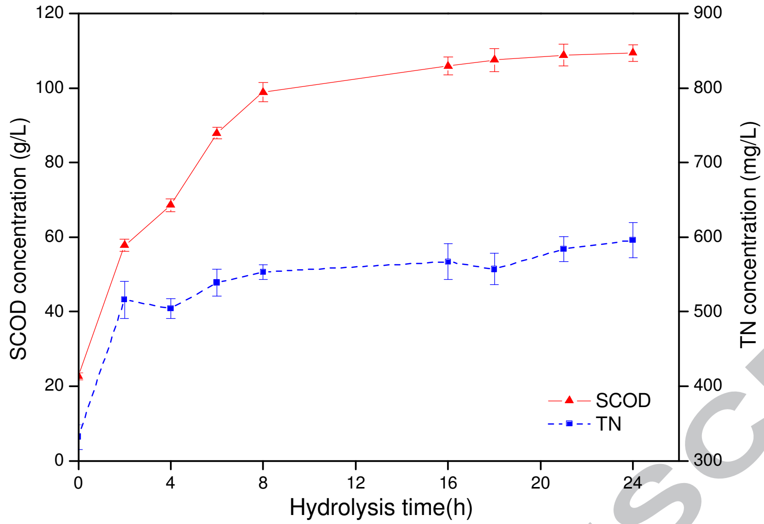

Fig.2. Time profiles of SCOD and TN concentrations in the liquor produced from the food waste pretreated with the fungal mash.

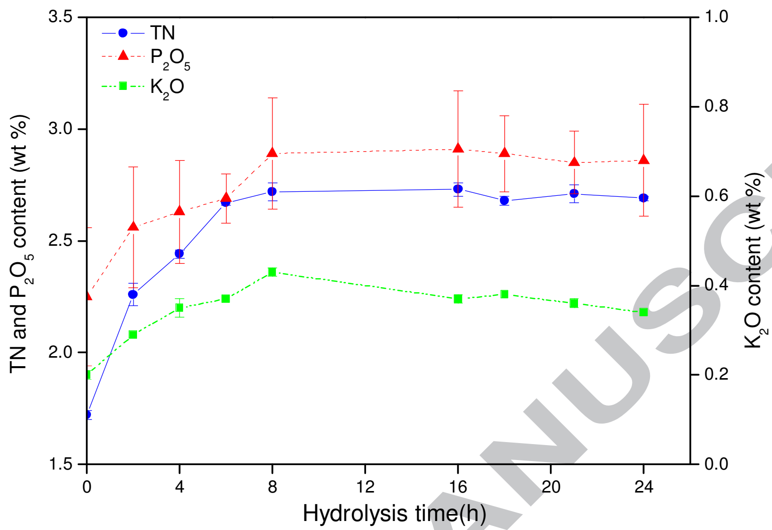

Fig.3. The N, P and K contents in the solid produced from the food waste at different pretreatment times with the fungal mash.

Tables

Table 1 Heavy metals in the liquid produced from the food waste after the 8-h pretreatment with fungal mash.

Table 2 The characteristics of the solid residues produced from the food waste at different pretreatment times with the fungal mash.

Table1
Heavy metals in the liquid produced from the food waste after the 8-h pretreatment with fungal mash.

Heavy metals	GB8978-1996 (mg/L)	Content in liquor (mg/L)
Cd	0.1	-
Hg	0.05	-
Pb	1.0	0.95±0.03
Cr	1.5	0.24±0.01
As	0.5	0.31±0.01
Cu	0.5	0.16±0.01
Mn	2.0	0.64±0.02
Zn	2.0	1.09±0.10
Ni	*	0.52±0.01
Al	*	0.34±0.01
Mo	*	-
Co	*	-

- Not detected; *Standard unavailable

Table2
The characteristics of the solid residues produced from the food waste at different pretreatment times with the fungal mash.

ne (h) r	0	2	4	6	8	16	18	21	
(wt%)	70.8±1.3	78.4±0.9	78.3±1.7	78.3±1.2	76.9±0.7	78.9±1.8	79.1±0.6	79.7±1.2	7
on (wt%)	51.0±0.4	50.8±0.1	51.0±0.6	50.8±0.4	50.7±0.5	50.7±0.6	50.7±0.3	50.7±0.2	5
y (mm)	2	2	2	2	2	2	2	2	
g^{-1})	-	-	-	-	-	-	-	-	
g^{-1})	-	-	-	-	-	-	-	-	
$^{-1}$)	40.2±1.8	43.1±2.5	45.8±1.6	46.2±2.3	48.0±1.1	47.4±1.6	44.3±1.9	48.0±3.1	4
$^{-1}$)	33.6±0.6	35.4±1.6	36.3±0.9	37.5±1.8	37.5±2.0	38.3±0.8	35.2±2.3	38.2±0.4	3
g^{-1})	3.6±0.1	6.4±0.2	9.6±0.2	18.3±0.2	24.0±0.1	26.2±0.1	24.1±0.1	16.5±0.2	2
(wt%)	-	-	-	-	-	-	-	-	
g^{-1})	1.8±0.1	2.7±0.1	2.9±0.1	2.7±0.2	2.8±0.1	2.9±0.0	3.0±0.1	2.8±0.1	2
g^{-1})	9.9±0.2	11.0±0.3	12.5±0.3	14.0±0.3	11.3±0.2	9.7±0.1	9.8±0.3	10.7±0.1	1
$^{-1}$)	51.0±2.9	52.7±2.2	55.5±2.5	53.2±2.4	56.7±2.8	56.1±3.2	54.7±2.1	56.0±2.5	5
g^{-1})	37.6±2.0	39.3±1.5	43.2±1.6	38.4±1.7	39.2±1.2	41.1±1.3	36.9±1.9	39.1±1.5	3
g^{-1})	9.1±0.2	10.1±0.2	10.3±0.1	10.5±0.1	10.7±0.1	10.8±0.1	10.6±0.2	10.5±0.1	1
g^{-1})	3.2±0.2	5.5±0.2	5.8±0.2	5.5±0.2	6.2±0.1	6.5±0.1	5.3±0.2	5.4±0.3	5
$^{-1}$)	9.6±0.2	11.9±0.3	12.5±0.3	11.5±0.2	12.3±0.2	12.2±0.3	12.7±0.3	11.6±0.2	1

- Not detected; [a]Calculated by dry solid except moisture and granularity; [b]Sundries main include plastics, glass, metal and rubber.

Highlights:

- Fungal mash rich in hydrolytic enzymes was produced from food waste
- Ultrafast hydrolysis of food waste was realized in 8 hours with fungal mash
- The solid residue with adequate NPK contents can be readily used as biofertilizer
- The separated liquor with a SCOD of 99 g/L was used for biomehane production
- The method led to nearly zero-solid discharge of food waste with energy recovery