A Review on Application of Microorganisms for Organic Waste Management

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The extensive utilisation of microorganisms namely fungi and bacteria for treating organic wastes has been attributed to their efficiency in eliminating pathogen and accelerating the degradation process. Their uses have been found considerably efficient for enhancing waste treatment. Among many methods employed, composting mediated by indigenous microbial communities has gained significant popularity in treating organic waste. Use of cellulolytic microorganisms to expedite the degradation rate of wastes, notably the lignocellulosic components, may prove useful. This paper reviews the application of microorganisms in the waste management technologies that include anaerobic digestion and composting of organic waste with a high lignocellulosic portion, composting of heavy metal contaminated organic waste, and composting at low temperature.

1. Introduction

The rapid population growth, and the increase of municipal solid waste (MSW), agricultural waste and food waste contributed to the emission of Greenhouse Gases (GHG) and challenged the current waste management practices. Composting or anaerobic digestion (AD) of organic waste are alternative solutions instead of direct disposal to landfill which causes an impact on the environment due to the emission of GHG and unpleasant odour (Al Zuahiri et al., 2015).

Organic wastes that are abundant in the organic fraction can be converted into renewable biogas and compost by microorganisms under controlled conditions (Wang et al., 2011). The digestate from the AD system can serve as fertiliser for soil enhancement (Kiran et al., 2014). During agricultural waste composting, lignocellulose, starch, and protein account for the significant part of biomass. The abundant lignocellulose composition often requires pretreatment process such as chemical and industrial enzyme added, thermal treatment or biological treatment using microorganisms before composting or AD. Among the microorganisms, microbes and fungi (MF) are more favourable due to its efficiency in degrading the organic matter (Fan et al., 2017).

Lignocellulose material is the most abundant biomass, yet the degradation rate and biogas production are much lower than other organic waste. It is of great interest to understand the trend on how different types of microbes could effectively treat lignocellulose waste, increase the biogas yield, remediate contaminated organic waste by composting, and facilitate composting at low temperature. This paper reviews mainly the use of bacteria and fungi applicable to the waste treatment system, notably for the composting of agricultural waste and the increment of potential biogas in the AD.

2. Composting

The composting process involves three phases, namely mesophilic, thermophilic, and maturation, which uses diverse microflora, such as mesophilic and thermophilic bacteria, fungi and actinomycetes to convert and
stabilise the organic waste to humus (Zeng et al., 2001). The physiochemical condition during various phases, such as oxygen, temperature, moisture content and nutrient availability, determine the development of microbial populations during composting. The microbial secrete different enzymes to hydrolyse the complex organics matter to a stable and simple form and eventually produce a product such as humus and biogas. Temperature is a significant parameter in the composting process. Composting has a typical temperature profile of a quick increase in temperature of up to 65 or even 80 °C in the first few days. Composting involves a rapid transition from a mesophilic to a thermophilic microbial community and followed by a slow decrease in temperature. As the diversity of microorganisms increases, fungi and mesophilic bacteria re-establish themselves. At the thermophilic stage, thermophilic bacteria can degrade complex material such as lignin, protein, chitin and cellulose.

During the disintegration process, the particulate organic matter was disintegrated into carbohydrates, lipids and proteins and followed by enzymatic hydrolysis to short chained carbohydrates, long chain fatty acids and amino acids (Lauwers et al., 2013). These hydrolytic enzymes including protease, lipases, cellulase and amylase, are secreted by the microorganisms remained in the bulk liquid or attached to particulates (Vargas-Garcia et al., 2010). Challenges remained in the composting process due to high variation of waste composition (Abdullah et al., 2013), long retention/residence time, temperature sensitive (UNEP, 2015), and hygiene concerns/odour control (Wang et al., 2003).

For agricultural waste, challenges arise due to the abundant of lignocellulose composition. Acid and thermal pretreatments of lignocellulose are required before composting process. Pretreatment methods using thermal or chemical is not favourable due to energy consumption and impact of added chemicals to environmental (Rouches et al., 2016). Compared to chemical and thermal methods, the use of an enzyme such as cellulase to treat the lignocellulose waste is desirable, the industrial enzyme is costly if applied at large scale. The application of thermophilic cellulytic microorganisms including fungi and bacteria to expedite the composting process is preferable (Bohacz, 2017). Fungus such as T. reesii has been reported to produce more than 100 g of cellulase per L of culture broth and their ability to grow in liquid and solid medium make it a suitable candidate for treating agricultural waste (Schuster and Schmoll, 2010). This finding suggested that application of thermophilic cellulytic microorganisms in agricultural waste could reduce the dependency on the industrial chemical, thermal and enzymatic pretreatments.

There is no universal method for composting as the types of substrate and its physio-chemical condition can influence the process. Co-composting is an integrated sustainable process that offers some advantages over composting that uses a single substrate. Recent studies have focused on co-composting using different types of agricultural waste. Co-composting of food waste with Chinese medicine herbal residues was reported to enhance the anti-pathogenic property in compost. The process inhibits the activities of Alternaria solani and Fusarium oxysporum that cause early blight and vascular wilt in potato/tomato plants, followed by multiple enzyme, chemical and thermal pretreatments.

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effective than inoculation during the initial days of composting for producing more stabilised and nutrient-rich compost. Table 1 shows the application of microorganisms in composting process.

### Table 1: Application of microorganisms in composting process

<table>
<thead>
<tr>
<th>Name</th>
<th>Type/ Source of Microbe</th>
<th>Temperature</th>
<th>Amount &amp; Concentration</th>
<th>Main Substrate</th>
<th>Research Findings</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudomonas fragi, Pseudomonas simiae, Clostridium vincentii, Pseudomonas jessenii and Iodobacter fluviatilis</td>
<td>Mix strain</td>
<td>10 °C</td>
<td>1 x 10^8 CFU/mL, 1% in dry weight</td>
<td>Food waste &amp; maize straw</td>
<td>Contributed to composting start-up at low temperature</td>
<td>Xie et al. (2017)</td>
</tr>
<tr>
<td>Brevundimonas diminuta CB1, Flavobacterium glacii CB23 Aspergillus niger CF5 and Penicillium commune CF8</td>
<td>Psychrotrophic bacteria (isolated from frozen soil) and thermophilic fungi (isolated from compost)</td>
<td>-2 - 5 °C</td>
<td>1 x 10^8 CFU/mL, 10 mL/kg</td>
<td>Dairy manure &amp; rice straw</td>
<td>Promotes maturity of dairy manure-rice straw composting under cold climate conditions</td>
<td>Gou et al. (2017)</td>
</tr>
<tr>
<td>Pichia kudriavzevii RB1</td>
<td>Mesophilic yeast</td>
<td>27 °C</td>
<td>1 x 10^5 CFU/mL, 10 mL/kg</td>
<td>Model food waste (commercial rabbit food and cooked rice)</td>
<td>Promote degradation of organic acid and accelerating the composting process</td>
<td>Nakasaki and Hirai (2017)</td>
</tr>
<tr>
<td>Phanerochaete chrysosporium</td>
<td>White-rot fungi</td>
<td>25 - 29 °C</td>
<td>2 x 10^6 CFU/mL, 2% in wet weight</td>
<td>Rice straw, bran, vegetables and soil</td>
<td>Stabilise in composting of lead-contaminated agricultural waste</td>
<td>Huang et al. (2017)</td>
</tr>
</tbody>
</table>

### 3. Anaerobic Digestion (AD)

Management of organic waste by biogas production provides twofold advantages including GHG minimisation and renewable energy generation. AD is a technology where organic matter is degraded by a consortium of microorganism and transformed into methane-rich biogas as an alternative to natural gas. The resulting effluent can be used for fertiliser production. The energy conversion efficiencies of the AD, particularly for agricultural waste (crop residues), can be limited due to the lignocellulosic composition which is recalcitrant to biodegradation. The potential biogas yield from lignocellulosic biomass (> 100 m^3/ t) (IEA Bioenergy, 2015) is higher than the other type of feedstock such as cattle slurry (15 - 25 m^3/ t) and poultry (30 - 100 m^3/ t) (NNFCC The Bioeconomy Consultants, 2016). Out of the four stages in AD process (hydrolysis, acidogenesis, acetogenesis and methanogenesis), hydrolysis of lignocellulosic biomass has been commonly determined as the primary rate-limiting step (Christy et al., 2014). The theoretical yield based on the cellulose content of agricultural waste was predicted to be about 90%, but the methane production efficiency is just 50% due to the inefficient hydrolysis of biomass within full-scale biogas reactors (Azman et al., 2015). The highlighted requirement of long retention time, resulting in the higher capital cost for a larger reactor, minimal energy generation efficiency and less feasible for implementation. The effectiveness of biogas production is usually low without additional substrate treatment before or during AD process. Improving the hydrolysis efficiency of lignocellulosic biomass is in need for drastic improvement of AD implementation. Utilisation of microorganism in the AD could substantially increase the enzyme loading and eventually promote the degradation of lignocelluloses in a cost-effective way.

The common fungi class used for biofuel production is white rot fungi (Poszytek et al., 2016) that prefers the aerobic condition and sterilised condition. Fungal treatment mainly attacks lignin, but microbial consortium
forms of bacteria usually have high and hemicelluloses degradation ability. Peng et al. (2014) stated that the economic feasibility of fungal pretreatment is low due to the loss of polysaccharide components during fungal growth and long cultivation period reduce overall productivity. Table 2 shows the various applications of microorganisms in crop residues (lignocellulosic biomass) for biogas yield enhancement.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type/ Source of Microbe</th>
<th>Temperature</th>
<th>Amount &amp; Frequency</th>
<th>Main Substrate of AD</th>
<th>Increment of Biogas Potential</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudobutyrivibrio xylanivorans Mz 5T</td>
<td>Rumen bacteria, anaerobic</td>
<td>37; 35 °C</td>
<td>5 vol%; Once</td>
<td>Brewery spent grain</td>
<td>17.8 %</td>
<td>Czech et al. (2015)</td>
</tr>
<tr>
<td>Pseudobutyrivibrio xylanivorans Mz 5T+</td>
<td>Rumen bacteria, anaerobic</td>
<td>37; 35 °C</td>
<td>5 vol%; Once</td>
<td>Brewery spent grain</td>
<td>6.9 %</td>
<td>Czech et al. (2015)</td>
</tr>
<tr>
<td>Fibrobacter succinogenes S85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clostridium cellulosorans 743B</td>
<td>Anaerobic, mesophilic</td>
<td>37; 35 °C</td>
<td>5 vol%; Once</td>
<td>Brewery spent grain</td>
<td>3.9 %</td>
<td>Czech et al. (2015)</td>
</tr>
<tr>
<td>Consortium</td>
<td>Predominantly of the genus Clostridium</td>
<td>37 - 40 °C</td>
<td>10 wt%; Daily (routine)</td>
<td>Sweet corn processing residues</td>
<td>15 % (compare to one time), 56 % (compare to non-bioaugmentation)</td>
<td>Martin-Ryals et al. (2015)</td>
</tr>
<tr>
<td>Consortium</td>
<td>From compost</td>
<td>50; 35 °C</td>
<td>2 wt%; Once</td>
<td>Maize Straw</td>
<td>74.7 %</td>
<td>Hua et al. (2016)</td>
</tr>
<tr>
<td>Consortium</td>
<td>Thermophilic (from soil samples filled with rotten lignocellulosic materials)</td>
<td>55; 55 °C</td>
<td>2 vol%; Once</td>
<td>Cassava residues</td>
<td>96.63 %</td>
<td>Zhang et al. (2011)</td>
</tr>
<tr>
<td>Consortium</td>
<td>Yeast, cellulolytic bacteria, lactic acid bacteria</td>
<td>Not reported</td>
<td>0.01 wt%; Once</td>
<td>Corn straw</td>
<td>33.07 %</td>
<td>Zhang et al. (2011)</td>
</tr>
<tr>
<td>Isolated from compost (consortium, predominant by Clostridia class)</td>
<td>Anaerobic, thermophilic, cellulolytic,</td>
<td>55; 55 °C</td>
<td>0.1 vol%; Once</td>
<td>Cellulosic substrate (lab test-filter paper)</td>
<td>14.5 %</td>
<td>Kinet et al. (2015)</td>
</tr>
<tr>
<td>Isolated from sewage sludge cattle slurry and manure (consortium)</td>
<td>Cellulose degrading bacteria</td>
<td>30; 30 °C</td>
<td>10 % (v/v), pretreatment, different reactor</td>
<td>Maize silage</td>
<td>38 %</td>
<td>Poszytek et al. (2016)</td>
</tr>
</tbody>
</table>

Based on Table 2, a single bacteria strain and consortium are applied in the recent studies to increase the biogas yield. A consortium contributes to a higher yield of biogas production than the single strain. The use of the consortium allows for maintaining a high level of hydrolysis even at the mesophilic temperature. This demonstrated a great advantage in term of energy consumption. It also avoids the problems of feedback regulation and metabolite repression associated with the use of the single isolated strains. The microbial consortium is better adapted to pH and temperature changes and tends to show higher resistance to the presence of heavy metals, toxic organic compounds or contamination by other strains. The sterilisation of lignocellulosic feedstock is not necessary, which could lower costs and save time. The uses of single or mixed strains cultivation in the hydrolysis of lignocellulosic materials are not in accord with the degradation characteristics of lignocelluloses in nature (Zhang et al., 2011). Lignocellulosic materials are degraded under the cooperation of many microorganisms by producing a variety of cellulolytic and hemicellulolytic enzymes. This suggested that consortium is a better option than the isolated single or mixed strains. Martin-Ryals et al. (2015) suggest a routine bioaugmentation with the cellulolytic microorganism. Bioaugmentation is usually referred as a part of AD process (in the digester) where single or mixed strains are
added (Martin-Ryals et al., 2015) in contrast to the other biological pretreatment (an additional process before the substrate is fed into the reactors). Addition of mixed strains increased the biogas production by 15% during the AD of sweet corn processing residues as compared to that added with a single strain. The positive effect of the economic analysis and more in-depth calculation are needed to verify the practicality of routine bioaugmentation as the substrate treatment for the AD.

4. Conclusions

Microorganisms including bacteria and fungi have proven to enhance the degradation process based on the previous studies. The application of microorganism consortium in composting and AD provides an alternative solution to waste management as chemical and thermal methods are not favourable in term of cost and energy consumption. Co-composting aided by microorganisms offers the co-benefits of enhanced degradation and minimised valorisation of nutrients in the compost. An increment of biogas potential ranging from 3.9% to 96.63% is achievable with the application of microorganisms for crop residues in the AD system. Although the inclusion of microbial could enhance the performance of composting and AD, the economic feasibility of microbial culture cost remains the major concern in future studies.

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Reference


Čater M., Fanedi L., Malovrh Š., Logar R.M., 2015, Biogas production from brewery spent grain enhanced by bioaugmentation with hydrolytic anaerobic bacteria, Bioresource Technology, 186, 261-269.


Kumar A., Parihar S.S., Batra N., 2013, Enrichment, isolation and optimization of lipase-producing Staphylococcus sp. from oil mill waste (Oil cake), Journal of Experimental Sciences, 3 (8), 26-30.


Poszytek K., Ciezewska M., Sklodowska A., Drewniak L., 2016, Microbial Consortium with High Cellulolytic Activity (MCHCA) for enhanced biogas production, Frontiers in Microbiology, 7 (324), 1-11.


