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Evaluation of Microbial Inoculation Technology for Composting

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Utilisation of microbial inoculant (MI) in composting is a bioremediation technology aiming to enhance the degradation rate and the compost quality. There is a diverse opinion about the effectiveness of MI in composting. The reproducibility of the results is a great challenge notably for an open composting system compared to a closed in-vessel system. Its efficiency is expected to be affected by the starting materials and the operating conditions. Optimising the physicochemical parameters during composting, i.e. the initial C:N, pH values, moisture content and aeration during composting was reported to be more crucial than the role of MI. This study aims to review the effectiveness of MI for the composting of two types of starting materials, i.e. the organic portion of municipal solid waste (OP-MSW) and lignocellulosic waste (LW). The potential effects of MI to enhance the composting parameters are presented. It is found that the effectiveness of MI to facilitate the composting process is depending on the type of wastes to be managed and the aims to improve the targeted quality of composting. The use of MI tends to exert a more significant positive effect on the composting of LW than the OP-MSW. There is no absolute consensus on the efficiency of MI for composting as it varies on a case-by-case basis. A decision framework is needed for the application of MI for different composting scenarios.

1. Introduction

The decomposition process takes place in nature, as the naturally occurring microbes break down the complex organic materials into simpler constituents; it is a relatively lengthy process. Human intervention is attempted to improve the efficiency of this natural process through composting. Composting is a relatively low-cost and environmentally friendly method for solid waste disposal (Kamyab et al., 2015). The utilisation of microbial inoculant (MI) in composting aims to increase the microbial population to enhance the degradation rate. The population of the naturally occurring microbial has been compromised due to chemical pollution in the modern life. MI is sometimes referred as activators (Awopetu et al., 2015) and accelerator (Marousek et al., 2016). A wide range of commercial MI is available to enhance soil fertility and composting. The scientific evidence to quantify the effectiveness of MIs on composting is still lacking.

Commercial MI consists of a single or mixed culture or the matured compost. The use of matured compost as MI poses less argument on the compatibility with the indigenous microorganism in the compost (Karnchanawong and Nissaikla, 2014). The use of specific microorganisms, such as the white rot fungus *phaberachaete chrysosporium* (Huang et al., 2015) and the thermoactinomyces vulgaris (Ke et al., 2010), have posted more argument on its effectiveness. Marousek et al. (2016) analysed the quality of the compost inoculated with six commercial MIs and revealed the low quality of the MIs. The issue was caused by the weak

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legislation and resulted in the unethical market for MI. It is remarkable to evaluate the effectiveness of MI for composting.

Numerous studies have reported the insignificant effect of MI as compared to the control (Hubbe et al., 2010). The possible explanations could be that: (a) the composting materials have readily attracted the diverse community of indigenous microorganisms hence the addition of MI becomes insignificant; (b) the mixed inoculums is not compatible with the properties of the composting materials (e.g. inappropriate C:N); (c) the sub-optimal operating condition for composting. Controlling the key parameters such as C: N ratio, aeration and moisture content is widely deemed important to provide an optimum condition for composting. The C: N ratio has been reported as the limited factor for bioremediation process (Lemos et al., 2013). Wang et al. (2015) highlighted that composting can be enhanced most significantly by controlling the initial C:N ratio and moisture content. The utilisation of MI can be a relatively low-cost approach to improve the composting quality. Wang et al. (2015) highlighted the dependence of microbial communities by the input materials. They suggested that there is no universal MI compatible for all type of composting materials. Zhou et al. (2015) introduced a three-stages inoculation strategy of composting by inoculating the proper microorganisms for the specific stage. Monitoring the effectiveness of MI for composting can be complicated, notably under an open system where the ambient temperature and moisture level might affect the microbial population. This paper reviews the effectiveness of MI for the composting of two common input materials, i.e. the organic portion of the municipal solid waste (OP-MSW) and the lignocellulosic waste (LW). The potential role of MI to affect on a range of composting parameters is analysed. The long-term goal is to establish a decision framework for the application of MI based on different composting materials.

2. Materials and Methods

The keywords used for this study included microbial inoculants (MI), composting, food waste, kitchen waste, lignocellulosic waste and municipal solid waste. It aims to compare the effectiveness of MI for the composting of OP-MSW versus that of LW. The effect of MI on the composting parameters (temperature, odour, enzymatic activities, organic matter content, microbial population, volume reduction, humification) and compost quality (pH, germination index, nitrogen content, phosphorus content, potassium content, C:N ratio) was evaluated. The main component in the OP-MSW and LW for each study is listed in Figure 1. The overall effectiveness of MI for the composting of OP-MSW and LW is illustrated by the forest plot for comparison (RevMan Version 5.2).

Organic Portion of Municipal Solid Waste (OP-MSW)	
Reference	Main component
Ke et al. (2010)	76.9 % Food waste
Payel et al. (2011)	100 % Kitchen waste
Abdullah et al. (2013)	80 % Vegetable waste and onion peels
Xi et al. (2005)	Municipal solid waste[1]
Raut et al. (2008)	100 % Municipal solid waste
Nair and Okamitsu (2010)	51.5 % Kitchen waste and paper
Karnchanawong and Nissaikla (2014)	71.4 % Food scraps
Chen et al. (2013)	Vegetable and fruit waste[1]
Wei et al. (2007)	100 % Municipal solid waste
Nakasaki et al. (2015)	52.6 % Food waste
Xi et al. (2015)	55.6 % Municipal solid waste
Lignocellulosic waste (LW)	
Reference	Main component
Huang et al. (2015)	45.8 % Rice straw
Rashad et al. (2010)	80 % Rice straw
Del Carmen Vargas-Garcia et al. (2006)	75 % Pepper plant waste
Rovshandeh et al. (2005)	100 % Hardwood barks
Xu et al. (2016)	60 % Rice straw
Kostov et al. (1991)	100 % Sawdust
Formowitz et al. (2007)	92.3 % Banana residue
Jusoh et al. (2013)	50 % Rice straw
Wang et al. (2016)	76.2 % Sophora flavescens residue

Figure 1: The main component in organic portion of municipal solid waste (OP-MSW) and lignocellulosic waste (LW).[1]Bulking agents were used but the ratio was not reported by the authors.

3. Results and Discussion

The positive (+) effect or no significant different (NSD) of MI on the composting of OP-MSW or LW is shown in Figure 2. Not all analyses have been conducted in each study, hence the analysis was left as blank.

Organic Portion of Municipal Solid Waste (OP-MSW)													
Reference	Temp	pH	TOC	Odour	C:N	Volume	N	K	P	EA	MP	GI	HM
Ke et al. (2010)	NSD	NSD	NSD		NSD					NSD		NSD	
Payel et al. (2011)				+		+							
Abdullah et al. (2013)	NSD		NSD		NSD		NSD						
Xi et al. (2005) two-stages	+			+							+		
Raut et al. (2008)					NSD					NSD	+		
Nair and Okamitsu (2010)	NSD	NSD					NSD						
Karnchanawong and Nissaikla (2014)		NSD			NSD		NSD	NSD	NSD			NSD	
Chen et al. (2013)				+		+							
Wei et al. (2007)											+		+
Nakasaki et al. (2015)	+		+								+		
Xi et al. (2015) three-stages	+	NSD			+	+							
Lignocellulosic Waste (LW)													
Reference	Temp	pH	TOC	Odour	C:N	Volume	N	K	P	EA	MP	GI	HM
Huang et al. (2015)													+
Rashad et al. (2010)	+	NSD			+		+		+		+	NSD	
Del Carmen Vargas-Garcia et al. (2006)	+												+
Rovshandeh et al. (2005)					+								
Xu et al. (2016)	+												
Kostov et al. (1991)											+		
Formowitz et al. (2007)	+				+		NSD	NSD	NSD				
Jusoh et al. (2013)	+	NSD	+		+		+	+	+				
Wang et al. (2016)	+	NSD	+		+					+		+	

Figure 2: The effect of microbial inoculants (MI) on each parameter for the composting of OP-MSW and LW. NSD= No significant different, += Significant positive different, Temp= Temperature, TOC= Total organic carbon, C: N= Carbon to nitrogen ratio, N=Nitrogen, K=Potassium, P=Phosphorus, EA= Enzymatic analysis, MP=Microbial population, GI=Germination index and HM= Humification.

3.1 Effect of MI for the composting of organic portion of municipal solid waste (OP-MSW)

The significant positive or insignificant effects (%) of MI on the composting and quality parameters for OP-MSW are tabulated in Table 1. All studies have reported an increased microbial population for the compost with the addition of MI. However, all studies have reported an insignificant effect (0 %) of MI on the composting in terms of the pH values, germination index, nitrogen content, potassium content, phosphorus content and enzymatic activity.

MI offers less demonstrable value for the composting of OP-MSW. It is likely that the organic waste contained a high level of labile organic content that is readily degradable. This allows the naturally occurring microbial to proliferate in the favourable environment. The composting performance with or without the addition of MI becomes comparable.

Based on Table 1, it was reported consistently (100 %) that MI was able to suppress the foul odour, enhancing humification and contributed to volume reduction for the composting of OP-MSW. If MI can be produced at a good economy scale, the application of MI could be a viable solution to control odour for composting.

50 % of the significantly positive and insignificant effects have been reported on the temperature profile during composting. Increased temperature is caused by heat generation from the microbial metabolism. The temperature profile may be significantly affected by the MI if the input material did not have sufficient of microbial population for the degradation process. A few studies have reported the positive effect of MI on OM (33.33 %) and C: N (20 %).

3.2 Effect of MI for the composting of Lignocellulosic waste (LW)

A more profound effect of MI was reported for the composting of LW as compared to that for OP-MSW. All studies (100 %) reported the significant positive effect of MI on temperature profile, C: N ratio, humification, microbial population and enzymatic activity during the composting of LW as shown in Table 2. At least half of the study (≥50 %) reported the positive effect of MI on the enhancement of organic matter content, nutrient content (NPK) and germination index for the composting of LW. The effect of MI on pH was consistently reported as insignificant by all studies reviewed (0 %). Its effect on volume reduction and odour performance were not analysed in all cases. It was likely that the volume reduction was less significant compared to the OP-MSW as LW takes a much longer time (2-3 months) to degrade; LW has less issue on the odour.

3.3 Overall discussion on the effectiveness of MI

Based on Table 1 and 2, a significant positive effect of MI was consistently reported (100 %) for the composting of LW and OP-MSW in terms of humification in the end compost. Humification was greatly affected by the lignocellulosic fraction of the composting material and occurred during the thermophilic phase. This condition required the addition of specific microbes hence 100 % positive significant effect was reported for humification.

MI did not show a significant effect on the pH profile for both of the composting studies. The pH profile can be altered by the composition of the starting materials (e.g. the C: N ratio), pre-treatment, post-treatment or by increasing the composting duration.

The forest plot in Figure 3 suggests that LW (toward the right-hand side) is more affected by MI than the OP-MSW (toward the left-hand side). Song et al. (2016) stated that MI is needed for the composting of the materials that are rich in the refractory lignocelluloses. The effect of MI is more evidenced for the composting of LW, especially by introducing the strains capable of producing high enzymatic activity of lignocellulase and cellulase. For the composting of OP-MSW, controlling the operating parameters such as C: N, moisture, and aeration will be a better approach to enhance the performance of composting.

Table 1: The significant positive or insignificant effect of MI on the respective parameters for the composting of organic portion municipal solid waste (OP-MSW) or food waste (FW).

No.	Parameter	Significant Positive Effect (%) on OP-MSW
1	Temperature	50
2	Odour	100
3	Enzymatic activity	0
4	Organic matter content (OM)	33.33
5	Microbial population	100
6	Volume reduction	100
7	pH	0
8	Germination index (GI)	0
9	Nitrogen content (N)	0
10	Phosphorus content (P)	0
11	Potassium content (K)	0
12	C:N	20
13	Humification	100

Table 2: Significant effect of MI on the parameters for the composting of LW

No.	Parameter	Significant Positive Effect (%) on LW
1	Temperature	100
2	Odour	Not reported
3	Enzymatic activity	100
4	Organic matter content (OM)	66.66
5	Microbial population	100
6	Volume reduction	Not reported
7	pH	0
8	Germination index (GI)	50
9	Nitrogen content (N)	66.66
10	Phosphorus content (P)	66.66
11	Potassium content (K)	50
12	C:N	100
13	Humification	100

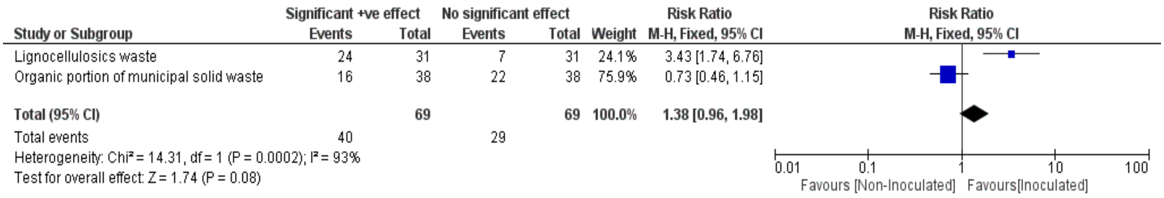

Figure 3: The forest plot comparing the effectiveness of MI for the composting of lignocellulosic waste (LW) against the organic portion of municipal waste (OP-MSW) as input material.

4. Conclusions

This study elucidates the effects of microbial inoculant (MI) on the composting parameters for the composting of OP-MSW and LW. MI is likely to significantly enhance the composting of LW than OP-MSW. It seems that MI is less capable of enhancing the composting of OP-MSW as compared to the control (without MI). It is likely that the existing microbial could readily degrade the labile portion within the OP-MSW. MI is found to be effective for the odour control during the composting of OP-MSW. The effectiveness of MI varies based on the characteristics of the inputs materials and the operating condition. Evaluation of MI on composting is complicated, future study should consider a more detailed composition of the input materials (e.g. % of carbohydrates, lipids, fibre), the composting system (open vs. closed), sizes, and inoculant concentration. A decision framework is required for the effective application of MI for different composting scenarios.

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