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The Trade-Off Between Species Diversity and Functional Diversity in Anaerobic Digestion System

Mengjun Huang[1], Jianbin Lan[1], Qiang Lin[2*#], and Yusong Jiang[1*#]

[1]Research Institute for Special Plants, Chongqing University of Arts and Sciences, Chongqing, 402160, People's Republic of China

[2]Institute of Soil Biology, Czech Academy of Sciences, Na Sádkách 7, CZ37005, České Budějovice, Czech Republic

[#]These two authors contributed equally to this paper

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***For Correspondence**

Yusong Jiang, Research Institute for Special Plants, Chongqing University of Arts and Sciences, Chongqing, 402160, People's Republic of China.

E-mail: jysong@126.com

Qiang Lin, Institute of Soil Biology, Czech Academy of Sciences, Na Sádkách 7, CZ37005, České Budějovice, Czech Republic.

E-mail: lqkybs2009@126.com

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ABSTRACT

Anaerobic digestion (AD) has been comprehensively used in organic wastes treatment and energy production. The digestate can be used as a valuable fertilizer due to the increased availability of nutrients and the decreased survival of pathogens during the AD process. Methane as a renewable energy, can be applied into energy input concerning to living and industrial need. Thus, the improvement of the AD performance gradually becomes the target of many studies by regulating the physicochemical parameters. However, microbial ecologically, the AD process which is essentially driven and determined by microbial community can be regarded as an artificially microbial ecological system. The trade-off between the systemic stability and functional efficiency, regulated by microbial community, is crucial for the evaluation of AD performance but still remains vague. Although systemic stability have been focused on by many studies based on species diversity, microbial functional diversity referred to the systemic functional efficiency gets less attention. This paper dissects the trade-off between the systemic stability and functional efficiency in the AD process, from the perspectives of species diversity and functional diversity.

INTRODUCTION

Anaerobic digestion has been comprehensively considered as a valid solution for energy emergency and ecological pollution, by converting organic wastes, e.g. food waste and animal manure into renewable energy such as methane [1]. This conversion of complex substrates into methane depends on the microbiota mediated food web (hydrolysis, acidogenesis, acetogenesis and methanogenesis), and each step is conducted by various functional microbiota [2,3]. The food web and the thermodynamic boundaries connect the different microbiota into a microbial community. Thus, the AD system can be regarded as an artificially microbial ecological system. In an ecological system, bio-diversity plays a crucial role in the systemic stability and functional efficiency [4-6]. Especially in the AD system which tends to practical application, the trade-off between systemic stability and functional efficiency is crucial for the evaluation of the AD performance. Although some researches [7,8] have observed that high species diversity improved the anaerobic digestion efficiency, how the bio-diversity (species diversity and functional diversity), influences the trade-off between systemic stability and functional efficiency is still vague.

Systemic Stability and Species Diversity

The AD stability depends on the response of microbial community to disturbance. In general, the responses of microbial community to disturbance include four types: resistance, resilience, functional redundancy and differentiation [9]. The resistance of microbial community is unlikely to keep the AD stability because that the microbial community is generally influenced by disturbance [9], and that microbial community is sensitive to a fluctuation of NH_4^+ [10] and/or pH [11]. Although the microbial community has some resilience, due to the dynamicity of the AD process in which each step in food web should be balanced, a temporal fluctuation probably destroys the whole balanced system. The differentiation which changes both the species and function [9], impossibly sustains systemic stability. The functional redundancy makes microbial community whose composition has changed, still perform the similar function as the original community [9]. The microbial community with high diversity is considered to have high functional redundancy [7,12-14]. In the AD process, different microbiota perform various, complementary and even parallel metabolic pathways. The high functional redundancy provides more chance for the overlap of metabolic pathways performed by different micro-organisms such as the genus Clostridium, Syntrophomonas, Ruminofilibacter performing the hydrolysis of substrates [7]. This decreases disturbance impact on distinct pathways, by sharing the risks with more functional micro-organisms. The high functional redundancy provides community with more diverse and potential metabolic pathways [4, 8]. Once a specific pathway is inhibited, a parallel or complementary pathway would take place of it to keep the integrity of food web [8]. In consideration of the high availability of nutrient in the AD system, more parallel metabolic pathways performed by different microbiota improve the digestive efficiency. The various metabolic pathways also reduce thermodynamic difficulties by multiple syntrophic metabolisms. Consequently, the high species diversity provides a vast species pool which owns various metabolically functional potential, and hence improves the stability and efficiency of AD system. Based on such opinion, in the AD systems of fowl manure or vegetable/ fruit wastes, introduction of more species involved in substrate hydrolysis and methanogenesis to improve the species diversity, probably is an effective way to prevent system from breakdown caused by excessive NH_4^+ or acidification. In addition, the success of mixed fermentation is certainly based on high species diversity.

Systemic Functional Efficiency and Functional Diversity

Compared to the functional potential deduced from species, the metatranscriptomic analysis referring to active metabolic pathways, more immediately reflects metabolic profiles which are running [15]. Thus the metatranscriptomic analysis, in contrast to microbial community analysis, associates more tightly with systemic function [16,17]. The systemic function generally keeps conservative in a specific ecological system. In freshwater study, the functional differentiation among sites is not significant [12], which probably depended on the specific systemic feature. The same situation occurs in the AD system [18]. The functional expression range is highly conservative in reactors at different temperatures [18]. Thus, the functional diversity based on unweighted analysis, indicates the functional range, which is largely determined by the systemic feature, irrespective of different treatments/ sites. However, in functionally enriched systems such as AD, compared to the functional range, the functional efficiency gets more attention. The functional efficiency is mainly evaluated by the methane production yield and the conversion rates of substrates into methane. The differently relative abundances of metabolic pathways indicate various relative importances of metabolic functions. Thus, functional diversity based on weighted analysis could actually reflect the functional efficiency [18]. In the AD food web, there are many metabolic pathways concerning to various intermediates and final metabolites, so an even expression of various functional pathways may result in various intermediates and final metabolites, including not only CH_4 and CO_2, but also other compounds [1]. This is regarded as “wasting” of resources .In a previous study, the relationship between functional efficiency and functional diversity has been demonstrated by the viewpoint of “functional centralization” [18]. The high function centralization means more cellular activities focusing on specific functional pathways, so that these pathways are been strengthened [18]. Consequently, in AD systems, low functional diversity indicates the high functional efficiency of some specific metabolic functions. These metabolic functions which cause the low functional diversity are strengthened.

Species Diversity and Functional Diversity

In AD systems, high species diversity corresponds to high functional redundancy, and low functional diversity corresponds to high functional efficiency. However, the relationship between species diversity and functional diversity is still argued [5,7,12,19-21]. Here we discuss four major viewpoints to dissect this relationship.

1. The relationship between species diversity and functional diversity is restricted by the species pool [21]. When considering the limited number of species, the functional diversity significantly positively correlates with the species diversity. However, this correlation is reduced when more species are in consideration [22]. This conclusion is likely invalid in the microbial community, due to the complexity of microbial community.

2. The species diversity depends on the presence/absence and (relative) abundance of distinct species, and such traits of species influence the total gene pool in the system [12]. For example, if the relative abundance of methanogens decreases, the relative fraction of methanogenic genes in the gene pool is undoubtedly reduced. This finally affects the functional diversity.

3. The activities of micro-organisms affect the expression of distinct genes [23,24] and then the relative abundances of distinct metabolic pathways. If this viewpoint is amplified from a micro-organism to a microbial community, the activities of microbial community influence the microbial gene expression and then the functional diversity. Thus, compared to the present microbial community (based on 16S rRNA gene), the metabolically active microbial community (based on 16S rRNA) play more crucial role in the functional diversity [25-27]. Although the present species diversity provides potential gene pool, the active species diversity indicates which micro-organisms are “working”, more probably corresponding to the functional diversity.

4. The relationship between species diversity and functional diversity is largely regulated by the versatility of some species [18] and the functional redundancy [28]. For example, some distinct metabolic pathways are overlapped by various micro-organisms,

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but some species such as Clostridium are involved in multiple pathways [15]. Thus, the functional diversity is certainly misestimated based on species diversity. Due to the functional redundancy, the random species loss which influences the species diversity, unlikely affects the functional diversity [19,22]. Consequently, although there is a potential relationship between species diversity and functional diversity, this relationship is influenced by many complicated factors.

CONCLUSION

In the AD system, the species diversity regulates the systemic stability mainly through functional redundancy. Meanwhile, the species diversity provides the gene pool based on which different expressions of distinct genes regulate the functional diversity. The functional diversity indicating the different distributions of cellular activities into different metabolic pathways corresponds to the efficiencies of specific functions.

COMPETING INTEREST

All authors declare that they have no competing interests.

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