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REVIEW: Potential of Thermophile Inoculation and Substrate Amendment for Rapidly Shorten the Maturation Period on Composting of Bio–Fertilizer

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Abstract

There is no fixed time to determine the period of finished compost. Generally, duration of composting depends on both combination of substrate and compost management. Simultaneously, either by amendment of substrate or manipulating the process will sustain the quality of finished compost. Overview of all phases in composting process shows the dependency on microbial activity of microorganisms exists on the foremost phases (mesophilic and thermophilic). Concomitantly, up to date there were a lot of significant studies on microbial inoculation by several groups of microorganisms on to substrate compost. Due to that reason, this review inquires the possibility of thermophile inoculation on reducing the maturation period for composting is governed by many elements. The selection of thermophile attributable to the maximum microbial metabolism occurs at bio-oxidative phase of composting. Therefore, inoculation of thermophiles dominate the thermophilic phase hence activate composting process.

Keywords: Composting, maturity, microbial inoculation, substrate, thermophile.

1. Introduction

Aerobic composting is defined as an aerobic microbiological process which is converts organic waste into more valuable products for soil and plant nutrients [1, 2]. It is control biological oxidation process that converts complex organic mixture to a more simple, stable and homogenous compounds. In general, composting process is initially by a mesophilic stage and then a rapid transition of increasing high temperature to the thermophilic stage. After subsequent decreased in temperature, the curing stage starts for maturing the compost. Decomposition undergoes four phases in the composting; mesophilic, thermophilic that degraded most rapidly (>40^{o}C), temperature falling (end of bio-oxidative phase) and maturation [3, 4]. Conversely, it is difficult to maintain an optimum temperature during composting and at the same time to sustain the microorganisms on their growth and reproduction [5]. In any event, selected substrate stimulates high adaptability of microorganism that turns toward enrich bio-fertilizer [6]. Subsequently, potential for both combination of microorganisms and substrate could be an effective compost management in study the maturity of compost. Less time for maturity would be achieved if these two parameters that govern an aerobic biodegradation were thoroughly optimized.

Creating optimum composting is necessary to achieve rapid maturity by three approaches; controlling on composting environment [7-9], amendment on composting materials [10-12] and time for nutrient application [13]. Definably preparation of compost substrate determines the succession of microbial inoculation [14-16] and vice versa [14]. The vital aspect to produce good quality inoculation is associated with the effective quality control system [17] during pre and post inoculation. The starting compost materials can be inoculated with the selected microorganisms to enhance the composting process by increase the higher level of available energy for putrefied organic materials incorporated in the mixture. This review will discuss the potential of thermophile inoculant for evaluating the quality of final product and possibility of reducing the composting maturity period. The composting substrate materials that have been reported to improve the microbial inoculation are also presented.

2. Inoculation of Thermophile

Inoculation significantly affects the degradation indices, and differences due to both raw materials and microbial inoculants could be observed [18]. Microbial inoculation in substrate composting rapidly enhance the acceleration of the composting process, increase cellulose activity and promoted biodegradation of organic matter [19, 20, 21]. The fundamental roles of microorganisms such as bacteria, actinomycetes and fungi are consuming organic waste directly. There are known as the first level decomposers. Inoculation of thermo-tolerant microbes including bacteria, fungi and actinomycetes were studied from different substrate composting is show in Table 1. The microbial community naturally presents in organic waste habitually proceeds the composting satisfactorily [1] since some indigenous microorganisms are better adapted to solid substrate than are inoculated microorganisms [22] even though matured compost prepared without microbial inoculation it still valuable [23]. However, inoculation of foreign microbial community is an alternative that potentially enhance more effective strategy of the composting system [24]. Some modifications of microbial inoculation have been tested in such a way to study the possibility of reducing the time needed to complete composting while sustain the quality of the final product [25]. The efficacy of microbial inoculant achieve when it is prepared in sterile rather than non-sterile substrate [26] in order to minimize any contamination. Nevertheless, high temperature gradient during thermophilic phase also inhibits harmful microorganisms, impurity and contamination occurs in compost heap.

The selection of microorganisms for inoculation have to bear with this vital principle of composting which are narrowing down C/N ratio, destruction of harmful pathogen and stabilization [27]. Studies show that inoculation with bacteria and fungi successfully breakdown ligno-cellulolytic material that has been reported to be effective in composting [28, 29]. Previous report by Wei et al [30] stated that inoculation could accelerate the compost maturation phase and mixed co-inoculation with

Table 1: Several Group of Thermophile Applied in Composting

Substrate	Type of Microorganism	Reference
Agricultural and animal wastes	Thermo-tolerant phosphate solubilizing microbes	[33]
Vegetable waste	Amylolytic and cellulolytic thermophilic bacteria	[37]
Grape pulps and fresh sheep manure	Mesophilic and thermophilic cellulolytic strains	[25]
Feather waste	Mesophilic-thermophilic bacteria and fungi	[77]
Food waste	Thermophilic lipolytic microbes	[42], [78]

lingo-cellulolytic microorganisms and complex microorganism shows clear advantages over a single inoculant. In other words, development of ultimate inoculant involves in appropriate compost substrate sustain the growth of microorganisms and enhance the rate of decomposition and optimize the maturity period of composting.

2.1 Advantages of Thermophiles

Microbes involved in composting reaction do not have similar nutrient, oxygen, temperature, moisture and pH requirements. They are very diverse in their growth requirements but still work in coordination and balance to initiate and further undergo complete composting process in symbiosis environment. These microorganisms have certain chemical requirements, primarily carbon for energy, nitrogen to build proteins, and oxygen for respiration. An understanding of the dynamics of the microbial community would therefore be useful as part of an attempting to improve the efficiency of composting [31]. Thermophilic bacteria could be applied in composting due to some reasons:

1) Bio-oxidative phase occurs at high temperature more than 40°C.

2) Degradation of recalcitrant compounds required higher temperature.

3) Thermophiles are very active in high solid environment.

4) Production of beneficial themophilic enzyme enhanced by thermophilic bacteria.

Thermophiles are growth at optimum temperature above 45°C [24]. Thermophilic microbial communities are very active in high solid environment [32] capable to accelerate the decomposition of agricultural and animal waste [1, 33, 34]. It is shows a strong relationship exists between microbial activity and temperature during the composting. The amount of heat produced temperature above 65°C [35]. Previous study on composting degradation bacteria developed by Austria ORGANICA Company stated that thermophile could metabolize and breed rapidly in a large scale production under enough oxygen supply and humidity [1]. This study was in line with Madigan [24] reported thermophile shown high growth rates and generation time could shorten composting period. Consequently, Xiao et al [36] claimed that mesophilic, cooling and maturity might not necessary phases of composting since thermophile could metabolize most of the organic substrates.

2.2 Significant Using Thermophiles

Inoculation beyond the thermophilic stage was proven to be more effective than at the earlier stage of composting and also results in rapidly drop of C/N ratio in composting [37]. Exothermal biological oxidation of organic compound which is performed by active aerobic microorganism populations in composting is a controlled bio-oxidative process that involves heterogeneous organic substrate in solid state [38]. The unique properties of thermophiles optimally survive at high temperature is the most reliable influence to maintain longer bio-oxidative phase and activate the process [14]. Modification on composting condition probably will sustain these parameters; biological, chemical and physical. Temperature gradient directly reflects microbiological activities during composting [39] and degradation of substrate which exhibit as a good indicator of maturity. Thermophilic inoculation produces thermophilic enzymes in compost. Enzymatic activity of thermophilic enzymes has potential to elevate the degradation rate of compost substrate compare to control conditions [40, 41]. Thus, thermophilic inoculation is possible to decrease the maturation period of the compost when compared with the control [42].

Several bacteria and fungi have been successfully used in practical process for rapid composting [43] as the decomposer on plants residue and evaluated for their biodegradable activity on waste materials [44]. Since lignin and cellulose in compost are the most recalcitrant compounds to decompose by microbial therefore, thermophilic and lignolcellulolytic microorganism had shown advantages to be and efficient degrader [45], hence accelerates composting. In fact, thermophilic microbial communities are very active in a high solid environment [32] capable to accelerate the decomposition of agricultural and animal waste [1, 33].

3. Substrate Compost Components

Proper chemical and physical requirements need for optimal microbial growth so that successful composting will occur. Both are needs to work together. Overview of substrate shows the capability on the activation of microbial metabolism during composting. Plus, well-prepared of correct compost mixture sustains the quality, stability and maturity of compost. Composting begins from mineralization of readily biodegradable compounds, which is the process and rate depending on the type of composted waste. During composting, the degradation of complex compounds by microorganisms such as proteins, hemicellulose, cellulose and lignin are transform into more simple carbohydrates, amino acids, peptides and phenols. Quality of substrate is one of the crucial factors to promote valuable final compost, activate microbial activity and healthy plant growth. Compost can be set from a variety of organic waste which governs by appropriate processing treatment. Composting has many applications beyond making the fundamental of compost only. Information of final product represents how well the upstream process. The key factor for a good substrate enhancement related to the higher composting rate which based on the replacement of more natural and abundant locally of substrate at lower cost [46, 47]. Composition of raw materials affect the quality and stability of compost prepared [48]. However, substrates originated from organic waste are more consistent as since they are highly biodegradable for microbial community.

Amendment of substrates compost affects energy released by heap due to distinction of thermal values of single heterogeneous material. Vargas-Garcia [14] observed the different of highest temperature point during thermophilic phase on four differences raw materials. The combination of raw materials with high content of N and density with straw, saw-dust and other materials containing more C improves consistency C/N ratio of the substrates and the conditions for composting. However, the discrepancy of this difficulty is closely related to the initial substrates as a control of composting. A good substrate will grant the microbial inoculant and so expected to maintain the reactivation for a longer thermophilic phase. Chouchene et al [49] listed three assortments of substrates compost (1) absorption of substrate on low-cost renewable absorbents, (2) natural evaporation of the water and (3) energy recovery by combustion of the impregnated absorbents.

3.1 Characteristic of Substrate

Substrates for preparing composting are classified by three components which are primary substrates, amendment and bulking agent [50]. The primary substrate is the main waste material involves in the composting. The selected primary substrates are the important materials that determine the characteristic of the compost mixture. Vargas-Garcia et al [14] stated that relationship between thermal value and compost heap could be determined both on substrate and microbial inoculant in the system. The fertility of compost depends on the amount of nutrient fixed by the substrate. Some substrates have many nutrients but it is difficult to absorb as mean of does not allow water/carrier to penetrate into it. Therefore, by using organic matter as the main substrate will drive the chemical properties by improves the plant nutrients uptake and bacterial survival. Several alternative carriers have been proposed for example different types of clays, animal manures, plant waste and complex organic matrices such as sludge and municipal solid waste [51].

Amendment substrate is material which is mixed with the primary substrate to balance the C/N ratio, modify the pH, improve stability and optimize the water holding capacity [52, 53]. Amendment of substrate compost also indicates the raw organic material follows the modification by control the properties via a wide variety of biological and biochemical process or addition some compost bulking agent. In many cases, there is more than one amendment substrates may be added to the compost mixture. The selection of amendments used also is readily available and least cost. Organic and inorganic compost amendments such as addition of farmyard manure and NPK fertilizer potentially to increase enzyme activity [54] thus indirectly, increase the decomposition rate of organic matter. Some amendments of substrate and selection of microbial inoculant should be applied to develop good upstream (pre-composting) and downstream (post-composting) processes. Amount of soil organic carbon and the concentration of macro and micronutrients are also increases by substrate amendment [55, 56]. It was recommended to conduct of lower C/N ratio for the composting of recalcitrant compounds such as high lignin content, cellulose and hemicellulose in plant waste. In fact, addition of organic amendment at a low rate potential to increase bacterial biomass but contrary on fungal biomass [57].

A bulking agent is a decay-resistant and stable material to provide better structure and porosity to the compost. In other word, bulking agents react as a catalyst for the composting process due to no decomposition and can be screened from the finished compost and re-used for the next composting cycle. Some amendment can also be a bulking agent. Application of substrate using bulking agent were poor on consistency [58]. Bulking agent is very unique because it will degrade within selective raw substrate compost only. Sawdust has been proven to be a good amendment substrate as a bulking agent for sludge composting [49, 58]. Nakasaki et al [59] also found that greater thermophile community in raw sewage by applied rice husk as a bulking agent. Separately, Tang and Katayama [60] reported that several type of bulking agent such as rice straw, sawdust, waster paper and vermiculite are not suitable as they were not degraded in the composting of cattle manure within 14 days after begin the process. However, Hay et al [61] claimed that straw and sawdust have been confirmed to degrade in sludge composting by prepared with appropriate ratios between sludge and bulking agent. Vuorinen [62] examined the effect of bulking agent; barley straw and Sphagnum peat for cattle and pig manure composting on enzymatic activity on acid and alkaline phosphomonoesterase and ฿-D-glucosidase by degradation of bulking agents. Huet et al [63] tested recycled and fresh wooden pallets on urban sludge composting from wastewater treatment plant. Kato and Miura [64] proposed the matured compost used as a bulking and inoculating agent for evaluating the maturity of cattle manure compost. Solid and liquid waste organic from varies sources can be composted because large amount carbon mineral content. However, liquid wastes are not easily degrade because a large amount of complex carbon and bulking agent is required to absorb excess moisture to allow penetration of oxygen and heat transfer.

3.2 Physical and Chemical Characteristics of Substrate

Quality of substrate is one of the crucial factors to promote valuable final compost, activate microbial activity and healthy plant growth. The key role played by physical properties of substrate compost includes water holding capacity, void fraction, diffusion, total porosity, texture, bulk density and thermal value have been brought by several studies. Physically, the initial substrates have to be preliminary fragmented into small pieces. This provides larger surface area for faster decomposition by the microorganisms. The smaller size of substrates particles decreases also the surface area per volume. It is need also to eliminate mechanical admixtures. All these parameters are interconnected and affect the reaction rate, degradation kinetic and heat and mass balances in the composting. Difficulties often occur during composting because the effects of degradation on physical properties are not sufficiently study and the fact is lacking.

Vargas-Garcia et al [14] stated that relationship between thermal value and compost heap could be determined both on substrate and microbial inoculant in the system. The study of compaction effect in the composting was insufficient, thus the information of energy generation and dissipation through compost are always lacking [63]. The characterization of composting system is very challenging because the wide range of physico-chemical properties of starting raw materials and chemical-biological interaction during composting. An enhancement of substrates to achieve rapidly composting should allow the replacement of more natural by-products such as peat and manure. The compost produced from the organic waste processing is more reliable considered as clean biowaste since there are originated after pre-screening of initial organic raw materials for matrix composed [65]. Therefore, this substitutions and manipulating of initial substrate are able to ensure higher compost quality for a stimulating carrier for solid bed inoculant use in composting system. Co-composting techniques is an efficient way contributing to the resolution of manure composting [66]. This technique is expected to be a suitable environmental friendly treatment for both main and amendment substrates detoxification and stabilisation. An application of both manure and amendment enable to prolong a thermophilic phase handle up to stand for several weeks [67].

The fertility of compost depends on the amount of nutrient fixed by the substrate. Some substrates have many nutrients but it is difficult to absorb as mean of does not allow water/carrier to penetrate into it. Therefore, by using organic matter as a main substrate will drive the chemical properties by improve the plant nutrients uptake. Combination of materials with high content of nitrogen and density with straw, saw-dust and other materials containing more carbon improves consistency of the substrates and the conditions for composting. Benefits of compost amendment affect chemical characteristics such as cation exchange capacity (CEC), atmosphere or soil pH [68] and microbial growth [69]. Eventually, during composting C/N ratio insignificantly affects pH changes [70] because of the wide range of microorganisms involved. Thermophiles tolerate with different pH ranges which is depends on their groups. Bacteria survive with compost pH range between 6 and 7.5; fungi 5.5–8.0 and actinomycetes 5.0–9.0 [71].

4. Evaluation of Stability and Maturity Compost

The quality of final compost is associates with the stability and maturity degree while performed the composting process. Stability and maturity are described the degree of degradation and transformation of organic waste into compost. Stability specifies the completion of microbial activity rate in compost which is evaluated by different biological measurements. While, maturity related to the degree of decomposition of phytotoxicity organic waste during composting. Unstable or immature compost possess high level of phytotoxicity on plant and soil [71, 72] by inhibit seed germination [71, 73], struggle for oxygen between microbial biomass and plant [74], nitrogen starvation [75] and negative influences on crop production.

Determination of compost maturity is crucial for agricultural amendment which initiated from substrate selection, management of composting process and determination of microbial activity. There are few reports on compost maturity analyses but no standard procedures for evaluating compost maturity with single method due to less accuracy and variation of uncertainty variables. Stability and maturity evaluation can be done using different methods; physical, chemical or biological test. Itavaara et al [76] reported that the compost stability and maturity parameters assessment are based on the specific starting raw materials and the process selection; the highest optimized operating condition and substrate mixture are highly recommended.

Evaluation of maturity by using physical assessments is much easier compare to biological and chemical assessments due to simple measurement of evaluating parameter such as pH, temperature, moisture, odor and compost texture. Chemical measurement such as C/N ratio, cation exchange capacity (CEC), carbon utilization, phosphate solubilisation, nitrification, humification index, and mineralization and oxidation of complex organic matter into stable compound are most frequently used to determine maturity of compost. These tests are more complicates and finicky usually proposed indirect method for many measurements. Biological maturity analysis for example germination index, respiration index, microbial biomass and enzymatic analysis are mostly studied. Both chemical and biological maturity evaluations are performed in laboratory analysis which is quite complex methods.

This review highlights the role of thermophiles and substrate for inoculating agent in optimizing the maturity period of compost. During the composting process, possibility of thermophiles inoculant to decompose organic substrate will investigate through the assessment of compost maturity period. Despite all the proposed methods to establish the degree of maturity, the accepted practice in evaluating maturity are very broad because composting system is associates with a lot of undefined physical, chemical and biological parameters; difficult to control.

5. Conclusion

Degradation of organic waste is very efficient during bio-oxidative phase where the temperature of compost heap achieves the highest peak. Thermophile is the top group of microorganisms to drive the composting at this phase, thus sustain to prolong the duration for microbial activity and sanitization of any contamination. Utilization of the microbial inoculation over conventional composting improved the degradation of organic substrate materials. The novelty on application of thermophilic microbial inoculation for composting pronounced the researcher to enhance the process for others significant using difference strains of microorganisms. Selection of thermophile type also depends on the substrate to be composted such as liable or recalcitrant organic compound. Some modifications have been working on substrate by pre-treatment to ensure the survival of thermophile inoculant in composting process.

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