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Review

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Changes in global trends in food waste composting: Research challenges and opportunities

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Abstract

Increasing food waste (FW) generation has put significant pressure on the environment and has increased the global financial costs of its appropriate management. Among the traditional organic waste recycling technologies (i.e., incineration, landfilling and anaerobic digestion), composting is an economically feasible and reliable technology for FW recycling regardless of its technical flaws and social issues. The global scenario of FW generation, technical advancement in FW composting and essential nutrient recovery from organic waste with waste recycling are discussed in this article. Recent research on various strategies to improve FW composting, including co-composting, the addition of organic/inorganic additives, the mitigation of gaseous emission, and microbiological variations are comprehensively explained. Subsequently, it is shown that the performing FW composting in an existing mechanical facility can improve organic waste degradation and produce value-added mature compost to save on costs and increase the technological feasibility and viability of FW composting to some extent.

Keywords: Food waste composting; gaseous emission; mitigation; maturity; microbes

1. Introduction

The increasing population and demand for food has put pressure on urban areas to manage FW, green waste and a number of other organic wastes in many countries (Chen et al., 2016; Maina et al., 2017). Composting could be the best solution for dealing with urban organic waste, through the use of nutrient amendments and urban farming reduces the environmental burden. Co-composting FW is a promising solution to tackle the FW situation (Dahiya et al., 2017). FW composting has shown its applicability in terms of economics and efficiency. Co-composting is the reserved aerobic decay of FW using a single feedstock. This approach may add sludge and organic waste in various forms similar to FW, forest waste and others. Fecal waste has high moisture and nitrogen (N) contents, and sometimes, FW is high in organic content and other properties, such as its ability to spread in the air (Dodick and Kauffman, 2017). The combination of more than one feedstock can provide a good chance to benefit from each component and to optimize the entire procedure. This approach is reflected in previous studies that considered the sustainability of treating FW throughout different countries, the findings of which addressed the preferences for using different treatment methods depending on the location. Composting is the least environmentally sustainable option according to broad economic principles (Slorach et al., 2019) (Figure 1).

Co-composting by composting FW with various organic substrates provides all the precursors required for natural activities, such as interactions with matter, microbial action and a method of biochar composting with many organic substances. This process supplies all the precursors necessary for natural maturation, such as a low-temperature environment, interaction with issue and enhanced microbial activity (Kammann et al., 2015). FW is the most abundant biowaste in the world (Waqas et al., 2018). FW is described as “the decrease in digestible food mass all over the component of the supply chain that particularly leads to edible food for human consumption" by the Food and Agriculture Organization (FAO) (Gustavsson et al., 2011).

Approximately1.3 billion tons of FW are generated every year, and its production is gradually increasing. FW primarily consists of organic components, such as carbohydrates, proteins, and lipids, which are digestible to different carbonic forms (Lin et al., 2013; Dahiya et al., 2015). Food waste is the primary part of municipal solid waste (MSW). Co-composting is a complex process that involves many chemical and biological events. Co-composting involves some challenges, such as a lack of synchronized maturity index system. Maturity can be defined as the degree of the digestion process that can be quantified as a humification process in the compost material. This process can be measured directly using respiration rates and other ways to measure the transformation of organic substances (Guo et al., 2012). The respiration index for the degradation of different material is correlated with the organic matter content of the compost and the chemical reactions performed by microbial activities.

The physical properties, such as the permeable space and pores can also affect the quality of compost and the speed of the composting process (Luo et al., 2014). 2) Odor and gas emissions are important challenges to control, and they have been addressed in many studies on co-composting because of their environmental impacts (Lou and Nair, 2009, Nasini et al., 2016). Three possible odorous by-products of composting can be CH_4, N_2O and NH_3, which can cause environmental pollution (Jiang et al., 2015). 3) Leachate generation with high microbial loads could be an emerging issue associated with co-composting procedures. Proper compost utilization and management can be significant issues (Chatterjee et al., 2013; Tyrrel et al., 2008). Components such as heavy metals, ammonia-nitrogen, and inorganic salt can be problems because of contaminated FW, and the concentrations of these components can be higher in the byproducts of co-composting (Eghball et al., 1995).Co-composting is a time-consuming and extensive process, but advances in technology have made it a little easier and more convenient, and the process duration and efficiency have been increased with better by-products than before. The use of additive and slurry in composting has enhanced the activities but at the same time the cost is also increased, and hence more research is required to lower the input cost to make composting profitable and economically feasible.

The aim of this paper is to provide a comprehensive review of the current state of the FW treatment and the co-composting facilities at a global level and also to identify future research directions clearly. This review covers FW policies and strategies, the volume of FW that is generated and its characteristics, and the gaseous mitigation research strategy used in compost facilities, in relation to their influencing factors and their priorities. Finally, the key bottlenecks for effective FW treatment and further suggestions about technical routes for improved FW management are analyzed in accordance with current changes and future perspectives.

2. Necessity for clean FW co-composting

One-third of all the food produced globally is wasted along the food chain, indicating the environmental burden that occurs if proper treatment is not provided; in addition, technology can make such a large quantity of FW valuable. Food waste is an important product of municipal corporations all over the world, and it was estimated to reach almost 45% of all community bio waste in Europe (IPCC 2006). Food waste reaches almost 55% of waste in emerging nations (Troschinetz and Mihelcic, 2009). The only treatment available for the majority of FW is incineration. The same conditions for food waste are observed in many countries, especially the developing nations. Sustainability in managing food loss is the primary emerging issue. The sustainable management of FW is a major concern by many countries, especially developed countries, which have some management strategies, but for developing countries, FW management is an alarming situation. Basically, the FW is disposed off in open landfills (Anjum et al., 2016), and FW mostly contains a large share of carbohydrates, proteins and lipids, which provide great opportunity to use it as a strong potential raw material (Awasthi et al., 2017). The increasing population is leading to more and more FW, and changing food habits, adaptation patterns, and food culture could be possible reasons for the increasing FW (Anjum et al., 2016).

Co-composting is a method that degrades compound organic matter into a useful organic product called compost (Sadef et al., 2016). However, the premature selection of FW and poor grading cause some challenges in breaking down its chemical and physical structures during composting (Wang et al., 2016). Selection and grading are important steps because some initial sequence of events can rapidly affect the entire process (Waqas et al., 2018). The composting method involves the aerobic decay of complex organic matter (OM) into simpler components that eventually becomes a mature organic compost through the action of different microorganisms. Various research studies have convincingly demonstrated the extra benefits of using various additives and bulking agents to overcome these limitations and change the physical structure of the composting form (Wang et al., 2016). Different organic materials, such as biochar, wood bark, and leaves, and inorganic materials, such as zeolites, lime and minerals were added to the compost as bulking agents.

3. Global scenario of FW co-composting

FW production could be viewed as the entire mass of FW produced every year (ton per year) and per capita. The regular per capita FW in North America and Europe is over 115 kg per year, and it is nearly 11 kg per year in southern and southeastern Asia (Gustavsson et al., 2011). Thi et al. (2014) stated that the FW per capita in technologically advanced nations and emerging nations are 107 kg per year and 56 kg per year, respectively. These figures show that FW production among advanced and emergent nations is fairly large, but the high production values result in widely scattered FW (Brian et al., 2013). FW management is described on the basis of advanced the existing standards to address the complex and appealing values of food related bioproducts among customers in industrialized nations. Hence, the consequences of managing large volumes of FW must be consistent with consumer expectations; for example, consumers who desire high-value food. Furthermore, customers could impact the amount of FW created by venders. FW or food related bio-products are not traded and they do not expire. It will be predisposed as a substitute of contributing it to food organizations (Commission European, 2014). The current emphasis on short-term gains will de-emphasize the demand for food production, and thus, the connected FW production at each capita is very low. However, through the impact of the rising population and cumulative experiences, it is expected that the total FW quantity created in emergent nations will not be lower than that of the developed nations. The FAO has stated that the yearly overall quantities of comprehensive FW production are nearly 1.3 billion tons/year, with no noticeable differences among those in developed (nearly 670 million tons) and emergent (nearly 630 million tons) nations (Table 1).

4. Technical advancement in FW management practices

4.1. Advancement and effectiveness of composting

The separation process has become easier with technological development. Advances in the separation process have made primary changes to drive the methods and materials used for co-composting. The primary precise separation of FW is an initial procedure that enables the synchronization of co-digestion. Many primary separation tools have evolved in European countries for better FW selection. The composition process is improved by co-composting urban biochar with FW by reducing the composting time, and many researchers suggest that there is improved seed germination when seeds are directly placed in finishing compost. The clogging of the pores is one of the limiting factors that reduces the surface area of biochar. The addition of biochar to composting base material brings many changes to the process and affects the microbial activities. Biochar is a standard material because of properties such as its high stability and high nutrient sorption. The porosity and good water holding capacity of biocharalong with its low bulk density make it an efficient and useful product for co-composting (Steiner et al., 2011). Biochar has been found to be effective in ammonia emission reduction (Steiner et al., 2010). Some additive effects were demonstrated in experiments with ammonia emissions in co-composting when biochar was added along with sewage sludge and woodchips (Malinska et al., 2014). Biochar helps to adjust the pH balance and works as a catalyst to increase composting (Sanchez-Garcia et al., 2015, Vandecasteele et al., 2016).

4.2. Innovation in compound microbial inoculum

The research on microbial community establishment has suggested that many compounds used for microbial inoculation help to improve the temperature, extension of high temperature periods, kinase activity, chemical composition and enzymes produced by microbial communities. Microbes such as *Ralstonia* sp., *Penicillium* sp., *Penicillium aurantiogriseum*, and *Acremoniumal ternatum*were used extensively by researchers alone and in combination to study the microbial inoculation effects on different FWs. Some new species have been found to provide better results, and more studies are required on the combined effects of different materials and conditions. The microbial community is an important factor in co-composting, to boost the procedure.

5. Microbiology of FW composting

The entire composting process is regulated by the microbial action directed at biodegrading the FW. Controlling the microorganisms at different steps to regulate and boost the process is a good strategy for controlling the desire products. The microbiology of FW co-composting can help us to modulate the rate of biodegradation, co-compost quality, time and efficacy (Jurado et al., 2014). Co-composting is the controlled aerobic degradation of organics using more than one feedstock (fecal sludge and organic solid waste). Fecal sludge has elevated moisture and N contents, even though biodegradable solid waste is elevated in organic carbon as well as having high-quality bulking properties (i.e., it allows air to flow and circulate). In combining the two components, the benefits of each can be used to optimize the procedure and the results. With the development of biological tools, new research is providing a complete series of the microbial action that occurs during specific points in digestion. Generally, microbiological recognition is directed, with the intention of understanding the microbial community interactions. Some interactions are positive and some are not beneficial for the co-composting procedure. The kinetics of co-composting can be measured by finding the activity with relation to the microbial activity (Franke-Whittle et al., 2014; López-González et al., 2015); however, a more precise analysis is needed to understand the relationship in FW, and other parameters are proposed by different researchers. Wang et al. (2017) demonstrated the diverse community structure of a composting procedure for *Firmicutes, Bacteroidetes, Proteobacteria* and *Actinobacteria*via advance Illumina sequencing methods. In the same investigation, the author concluded that there was diversity during the maturation phase, and a comparison was performed at different biodegradation stages.

5.1. New analytical tool and feasibility

Many different techniques were used to check the microbial diversity in composting and co-composting treatments. However, culture-based and culture-independent methods were used for decades. Culture-based methods include many similar techniques that were to measure the adenosine triphosphate (ATP) content (Horiuchi et al., 2003), and microorganism activities (Ryckeboer et al., 2003) and metabolites measurements, which makes easy to monitor the activities. The quantification of the data makes it easy to analyze and draw conclusions about these factors (Horiuchi et al. 2003). However, many of the aforementioned methods use isolated strains that grown on solid matrices. These methods can only provide a selective view of the composting process. Microorganisms have multiple growth systems, and many microorganisms are not cultivable, which makes the process biased. Cultivable organisms can represent any novel group of organisms or a community. Because of this limitation, culture-independent methods were used to make the process simpler and easier, to understand the action and activities of the microorganisms. However, this method was limited, with a small number of functions about the community evaluation, and secondary metabolites were not easy to measure. A molecular method such as those employing deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) made these analyses easier and more affordable (Jurado et al.,2014). The monitoring of bacteria (BA) via both cultural and molecular methods directed researchers to dissimilar and occasionally inconsistent outcomes, which leads to questions about the authenticity of the methods (Ishii and Takii, 2003).

The application of new procedures is believed to facilitate the recognition of exclusive organisms, but the accuracy can be improved and time can be saved using the modern approach. Sequencing can help to obtain the best results and is economical. Tiquia (2010) performed a grouping with terminal restriction fragments length polymorphism (T-RFLP) study to examine the variations in a microbial population during the period of digestion, and they combined several advanced genomic methods. Furthermore, each method has its limitations and benefits. Perhaps a factor could be measured to determine the substances require to construct a definite set of microorganisms (Carpenter-Boggs et al., 1998). Investigating genomic data via 16S (BA) or 18S (fungi) analyses has reproduced variety of qualitative and quantifiable data on ecological trials (Jurado et al., 2014). In addition, a microarray consisting of oligonucleotide probes targeted the changeable region of 16-strand ribosomal ribonucleic acid (rRNA) genes, which permitted the recognition of dissimilar organisms as developed by Franke-Whittle (2005).

This molecular technique is simple and requires little skills to perform, but at the same time, it requires the complete body of microorganisms. Consequently, this technique is appropriate only for confirming normally identified strains, and this technique is constrained for use in finding novel species. Therefore, all the methods can be considered as complimentary to one another, and every method has its importance. Antunes et al. (2016) has recognized new approaches for microorganisms during the high-temperature phase of composting using a mixture of diverse methods via shotgun DNA and metatranscriptome advanced sequencing. These are important methods in modern biotechnology that enable researchers to predict functionality and identity. The non-culture-based method is good, but the rich diversity of the microbial community is beyond the boundaries of this method. Additionally, multiple guides can be projected using sensible facts over the study of a reference library other than fingerprint records (Bent and Forney, 2008).

5.2. *Microbial community abundance and diversity*

Co-composting is a controlled aerobic digestion process with major influencing factors on the available microbial communities, including those in the mesophilic, thermophilic and mature stages (de Gannes et al., 2013), The microbial composition is greatly affected by nutrient access, oxygen availability, temperature fluctuations, overall pH balance and many other minor factors such as the type of raw material and bulking agents (Awasthi et al., 2017). Culture-dependent and independent techniques were the most frequently used tool for analyzing the microbial diversity, but these methods have many limitations, and modern biotechnological tools have replaced these traditional methods (de Gannes et al., 2013). Understanding the microbial community is important because having a greater understanding can help us to design an efficient co-composting method to obtain the desired products and manage the composting process (Vargas-Garcia et al., 2015). This better understanding is possible with high- throughput pyro-sequencing (Wei et al., 2017). The metabolism of BA communities in composting systems is complex and hard to understand because many factors govern the availability and diversity of microbial communities (Metcalf et al., 2016). Phylogenetic analysis of communities by compared to the original state can be developed to make predications regarding the useful composition and activities of microbial communities via high-throughput sequencing. The data generated by 16S rRNAHiSeq sequencing helps to determine the microbial communities associated with different degradation systems involved in co-composting (López-González et al., 2015). High microbial diversity can drive the degradation phase to a high degree, and it is directly correlated to the lignocellulose fractions (Franke-Whittle et al., 2014; López-González et al., 2015; Chandna et al., 2013; López-González et al., 2015). The data include information generated by *in-vitro* methods, which facilitates microbial classification. Antunes et al. (2016) analyzed the microorganism community sequence in FW composting, stating that rotating the piles for the duration of the biodegradation period greatly supports the variety in microbes. The population profile shows more diversity during highly aerobic processes (Table 2).

Using the advances in molecular biology and biological tools, many studies with multiple aims have been conducted to identify the full sequence and community diversity in microorganisms. The major objective in understanding the microbial community is to understand the functional processes of co-composting and composting. These methods can provide us with a complete and easy way to comprehend the whole procedure (Franke-Whittle et al., 2014; López-González et al., 2015). Progress in microbiology has made it easy to identify the microbial community in compost (Antunes et al., 2016; Franke-Whittle et al., 2014; Ishii and Takii, 2003; Kinet et al., 2015; López-González et al., 2015). The composting process involves many processes that are directly involved in digesting complex compounds into simpler forms (López- González et al., 2015). It is commonly believed that the high-rate degradation stage has maximum diversity (Chandna et al., 2013; López-González et al., 2015). Antunes et al. (2016) has observed the microbial arrangement in FW by using molecular methods for studying composting via molecular tools. Metagenomics along with meta-transcriptomic methods are valuable for the recognition of the composting process. The composting microorganisms act on an order of diverse microbes that are strongly reliant on biotic and abiotic influences López-González et al. (2015) stated that a huge number of acid-forming microbes controlled the pH and the consequential upsurge in odor creation. Shi et al. (2016) measured the changing aspects of the ammonia (NH_3) oxidizing bacterial (AOB) community in FW composting. These microbes have participated in the fundamental functions for N and NH_3 emissions. It was confirmed that together, nitrate and the pH are linked to the AOB population composition. It is assessed by adding psychrotrophic organisms to the compost to trigger the entire procedure at low temperatures (Hou et al., 2017). There is extensive recognition that the high productivity and variety of the characteristic microbiome in the composting procedure can be changed due to dissimilar ecological situations (Kinet et al., 2015).

5.3 Microbial inoculation-enhanced mineralization

Composting is measured by identifying the microbial inoculum used at different concentrations, but by adding some items to speed the entire process, these substances can enrich the process and the quality, and the final product can be more economical. Time can be saved by using these additives, which directly influence the rate of biodegradation (Karnchanawong and Nissaikla, 2014; Onwosi et al., 2017). The inoculants could be a precise strain (Hou et al., 2017; Nakasakiand Hirai, 2017; Tsai et al., 2007; Zhao et al., 2016), and sometimes, a commercial mixture at different concentrations can be used (Fan et al., 2017; Ke et al., 2010; Manu et al., 2017; Nair and Okamitsu, 2010), or for developed compost (Karnchanawong and Nissaikla, 2014; Kinet et al., 2015). Many studies suggest that reductions in the original time and higher temperatures can influence the microbial community. Furthermore, the accumulation of developed compost as a starter made improved enhancements in compost in assessments of the usage of marketable inoculants. Ke et al. (2010) demonstrated that the features of the different types of matter clarified the types of microbial inoculation, and thus, a good yield of co-composting final product was found. A new description by Nakasaki and Hirai (2017) revealed that they applied acid-utilizing yeast (*Pichiakudriavzevii*) as an inoculum for FW composting, which eliminated the lag phase and induced the microbiota. Acidification was efficiently evaded during the key phase of FW composting by injecting an anti-acidification microbial consortium. In view of the lignocellulosic portion of FW, many researchers have used lignocellulose-consuming microbes to mature the lignocellulose biodegradation (Jurado et al., 2014; Nair and Okamitsu, 2010; Wang et al., 2011; Zeng et al., 2010; Zhao et al., 2016). As stated previously, using a microbial consortium of specific species may improve the process routine along with the compost value. Manu et al. (2017) noted that some returns are attained through commercially accessible inoculums. A decrease in the procedure period, improvements in the lignocellulose biodegradation, and upgrading the compost value are accomplished with improved humic with fulvic acids.

6. Gaseous emissions and nutrient loss mitigation

The FW composting system is the most effective strategy for the fast valorization of FW matter into a steady and nutritionally improved biofertilizer. In gas emanations, such as those of the methane series (CH_4), N_2O, and ammonia (NH_3), composting applications for FW treatment are prevented. Gas emissions throughout composting do not exclusively cut back on the compost quality, in any case, but they can also cause environmental contamination (Yang et al., 2019). For this reason, few investigators have used evaluations of the microbial population as tools to relate the variations in operative constraints such as the pH through the microorganism numbers and their consequences in terms of odor emissions (Cerda et al., 2018; Sarsaiya et al., 2018). The N_2O and methane series generated throughout composting contribute considerably to heating. Their impacts are estimated to be 310 and twenty times more than that of other greenhouse gases such as CO_2 emissions. In most countries, FW makes up nearly half of all municipal wastes, and this share is also higher in developing countries (Sindhu et al., 2019). In alternative cases, the gas emissions of laughing gas following compost applications do not considerably differ from the application of ammonia nitrate; thus, neither a credit nor a control has been considered (Slorach et al., 2019). In spite of these negative properties, the combustion strategy includes consideration of the greenhouse outflow, CH_4, NH_3, CO_2, N_2O, CO and H_2 and is therefore related to serious natural dangers. Often, a critical issue is associated with the inability to apply the combustion strategy due to its difficult procedure (Nayak and Bhushan, 2019). Up to 342 kg of carbonic corrosive gas, a greenhouse gas (GHG), was made from producing 1 ton of waste material. It was found that 315 kg of greenhouse emissions were produced from 1 ton of FW by electricity, and the energy produced and the original materials had a calculated impact (Saqib et al., 2019). Ultimately, the consolidation of gas-handling parts in composting establishments should be important for mitigating emissions. Biofiltration may be a simple way of addressing composting components, which might help to decrease the gas mixtures and smells in a way that is ordinarily addressed throughout the process (Cerda et al., 2018).

Different solutions are projected to beat the inhibition impact of long chain (LC) fatty acids, together with the addition of active substance, decreasing the bioavailability of LC fatty acids through sorption, the addition of a co-substrate, and discontinuous feeding. In addition to LC fatty acids, volatile fatty acids (VFAs) are intermediates that may hinder biogas production at high concentrations. The co-digestion of wastes related to food materials with lignocelluloses will overcome VFA gathering and its inhibition (Mirmohamadsadeghi et al., 2019). As an example, the gas product yield was improved with the increasing reaction temperature, whereas the solid and liquid yields were reduced. At any duration, H_2 yield (1.1 mol/kg) accumulated considerably with the increase of the reaction temperature, and in particular, the best H_2 yield was obtained at 360 °C for ninety minutes (Su et al., 2019). Lime addition was used through the development of struvite over the accumulation of magnesium and phosphorus-related salts to provide a sensible pH range, and it should cut back on odor emissions. Reducing ammonia produced during struvite development considerably reduced most of the odor due to free ammonia, from 3.0 $\times 10^4$ to 1.8 $\times 10^4$ (Wang et al., 2018). In addition to being associated with a nursing binary compound containing dissolved organics, gaseous parts are obtained as by-products as well. This method, which is called the hydrothermal physical change, has shown exceptional results over different chemical processes or shifts (Nayak and Bhushan, 2019). In a field trial analysis, the observed batch was run under the best conditions (temperature, moisture, and light) for maximum plant N utilization, minimizing N losses (leaching and gas emissions) (Grigatti et al., 2020).

Yang et al. (2015) revealed that the blending of phosphogypsum and superphosphate dramatically mitigated CH_4 emissions (85.8% to 80.5%) and NH_3 releases (23.5% to 18.9%). The NH_3 emissions were reduced because the aeration rate was reduced. It is noteworthy that the aeration rate did not have a considerable effect on the compost quality. These results indicate that the aeration rate of 0.2 L (kg DM min)$^{-1}$ is also applied to regulate volatile sulphur compounds (VSCs) and NH_3 emissions throughout room waste composting (Zhang et al., 2016). Yuan et al. (2018) found that mixing phosphogypsum with dicyandiamide could reduce the methane and N_2O releases by 75.6% and 86.4%, whereas the NH_3 release is also accumulated to 22.0%. The mixture of superphosphate along with dicyandiamide could also reduce the CH_4, NH_3 and N_2O releases by 20.3%, 81.0% and 88.2%, respectively (Figure 2 and Table 3).

7. Policy and guidelines for FW management

Until recently, the remaining FW was either dumped in landfill sites or burned. This scenario continues in numerous nations regarding more sustainable techniques for biowaste management, and some have established new regulations concerning the continuing dumping of food-related waste residues, including organic matter valorization (Cerda et al., 2018). Different countries have adopted special techniques to tackle the mission of FW management. In particular, some information is accessible on evaluating the wide-ranging hydrologic influences of FW. Notably absent from prior study is an estimation of the resource impact incurred during post disposal phases. The hydrological consequences related to FW management therefore signify a massive gap in the literature, and one that precludes the comprehensive perception of the Food-Energy-Water (FEW) impact (Kibler et al., 2018). The requirements for electrical conductivity in composting digestate according to the regulation (ECN-QAS for Compost and Digestate legislation) is essential for accurate quality measurements of compost (Kucbel et al., 2019). Currently, the manufacture and use of compost/digestate are based on national environmental and fertilizer insurance policies (Lin et al., 2018). The Japanese FW material recycling regulation was established in 2001, modified in 2007 and 2015 to reprocess FW produced via food-associated trades and businesses. Furthermore, to a large extent, the producers of food-related waste (more than 100 tons annually) have been directed to post meal waste-associated information each year, which provides evidence on the quantity of meal waste produced and the volume recycled, among others (Joshi and Visvanathan, 2019). The most influential part of policy and law is that the policies and incentives could set off desired behavioral changes and that granting access to data on how to stop and manage meal waste should be an advantageous policy tool for attracting restauranteurs (Morone et al., 2019).

Since 2011, developing countries, such as Malaysia have imposed a solid waste and municipal cleaning management rule that penalizes the discarding of FW and orders the separation of wastes at the source. In Singapore, the National Environmental Agency (NEA) and the Agri Food and Veterinary Authority (AVA) are working to mitigate FW by directing educational programs to control shopping marketing for food bio-products. Concurrently, Filimonau and De Coteau (2019) suggested that no individual company coverage can remedy FW as an alternative, and there is a demand for alternatively customized flexible and temporary solutions that managers and personnel can use to transform consumer perceptions to varying degrees and follow up in communities, if and when required. In India, the MSW (Management and Handling) Rule was primary disseminated in 2000 and was revised in 2013 and 2015, and it emphasizes waste categorization. Thai authorities collaborated with the FAO to increase the focus on food loss and waste through a country-wide campaign known as the "The National Save Food". China has launched national-level campaigns and policies aimed at treating meal waste, including the 'Food Security Law' issued in 2009 that controls the difficulties of FW handling, and the Grain Law, which has divisions to reimburse for redeemable grain and combat food-related waste (Joshi and Visvanathan, 2019).

8. Compost quality

FW is managed and valorized on-site, which could enhance the cultivation quality regionally and help to extract it from landfills efficiently (Margaritis et al., 2018). A large quantity of documents is accessible on the controlled composting procedure, with the most important purpose of refining the product with high-quality bioproducts. In recent years, this issue has received further concentrated investigation (Cerda et al., 2018; Elkhalifa et al., 2019; Akarsu et al., 2019). Compost could be applied for soil modification, which sequesters carbon, improves soil moisture holds and mitigates irrigation supplies. Composting can also generate considerably fewer greenhouse gas releases and low leachate compared to landfilling (Kibler et al., 2018). The moisture content of a material is a necessary parameter during the FW composting process because water offers a medium for the dissolution and transport of nutrients that are vital for microbial growth and reproduction (Shen et al., 2015). To compare desirable composts for environmentally sustainability meal waste processing, the heavy metals and other carbon-based materials and maturity along with steadiness are the high-quality parameters for examining the compost quality. These factors are as follows:

8.1. Heavy metals and other OMs

FW includes not only food residues, such as rice, bread, and vegetables, but also some materials associated with serving food, such as toothpicks, paper towels, plastics, waste tableware, and many others. These substances might also include a small quantity of heavy metals (Chu et al., 2019). The FW metal contents can include powerful impurities from the existing feedstock. Additionally, the metals along with extra nutrients could pass through the soil and into the groundwater. Furthermore, FW is said to container higher amounts of salt-like matter, which can prevent plant development and undesirably disturb the soil assembly (Cerda et al., 2018). However, excessive concentrations of metals may additionally motivate the inhibition of AD (anaerobic digestion). Unlike carbon-based inhibitors, metallic factors do not change, and they should be accumulated in the fermenters to reduce their concentrations. The inhibition heavy metals is performed by hindering the shapes and characteristics of enzymes. Heavy metal inhibition is no longer generally a subject related to the anaerobic digestion (AD) of FW because the metal concentrations are continuously below the limit for FW (Mirmohamadsadeghi et al., 2019).

Research has shown that fulvic acids showed a broad range of properties, such as soluble microbial products, humic acid-like activities and tryptophan. Heavy metals (As, Cr, Cd, Cu, Ni, Hg, Pb and Zn) were redistributed among the distinct dissolved organic matter (DOM) sub-fractions in the thermophilic section of compost. Compost DOM and its associated sub-fraction had noticeable effects on the germination index (GI), biomass, shoot size, root length, and healthy index of cabbage seedlings (Shan et al., 2019). The AD originating from FW has been studied, and it was determined that the greatest lead elimination ability (355.3 mg g^{-1}) in a diverse range of biochars was from a 3% wt. sodium silicate binder, at six times higher than the corresponding activated carbon(Chen et al., 2019). However, the co-presence of FW composting and [S, S]-ethylenediaminedisuccinic acid (EDDS) improved the mobilization of Zn and Cu, while the co-presence of FW compost and ethylenediaminetetraacetic acid disodium salt (EDTA) decreased the available quantities of Cu and lead in solution (Beiyuan et al., 2018). Guo et al. (2018) found that after a 20-day successive period of post-maturity, the total P, N, and K in the FW compost were all in excessive of 11.66%.

8.2. Maturity and stability

Maturity and steadiness are vital constraints for compost quality evaluation. Maturity is a well-known term indicating the appropriateness of a compost property for a unique usage and is typically linked to plant progress and/or phytotoxicity (Sarsaiya et al., 2019a; Sarsaiya et al., 2019b). Stability is the step in the decompositions of carbon-based material that is confined in an environment and is circuitously allied to the biotic pattern (Cerda et al., 2018). Zhou et al. (2018) has observed that 67.2% natural decomposition was once completed with a 1:1:1 mixing ratio within 8 weeks. The GI (seeds) reached 157.2% using a 1:1:1 ratio, while different ratios confirmed that the value was greater than 130.0% and the remedy without lime was confirmed at 40.3%. Therefore, the use of natural Chinese medicinal residues as the bulking mediator to compost waste at the dehydrated weight proportion of 1:1:1 (FW: sawdust: Chinese medicinal natural residues) was once endorsed for meal waste- Chinese medicinal herbal residue composting (Zhou et al., 2018). The consequences for compost firmness parameters have remained at a 15% improved herbal zeolite content. The compost balance against moisture, electrical conductivity, organic substances, total carbon, mineral nitrogen, nitrification index (NI) and GI were accomplished after sixty days of food-related waste composting (Waqas et al., 2019). The maturity recognizes the degree of natural matter change at a few stages within the composting process as well as the phytotoxicity of the end product. To explore the ecotoxicity of normal substrates for their intended ultimate uses,Cesaro et al.

(2019) suggested a direct approach, depending on solid-phase tests, and a diagonal one, based on liquid-phase tests for evaluating the extracts of the tests. The NI is an imperative marker of compost maturity. It could be a proportion between $NH_4^+$and NO_3^-. a value for NI that is below 0.5 indicates incompletely developed compost, whereas up to three indicates developed compost and costs over three speaks to an immature compost (Waqas et al., 2018).. Amid concerns about composting FW, the development stages are characterized by measuring the quality of the substrate and the arrangement of lignin-humic complexes (Salgado et al., 2019) (Figure 3 and Table 4).

9. Compost application threat

For compost application, the bioremediation is likely to moderate the harmfulness as well as recuperate the agronomic value of food bio waste, permitting its application as an agrarian soil conditioner. Bioremediation is a broadly used strategy to decrease the damage of natural waste by using living beings that are able to metabolize, change or rot contaminants so that poisonous components are changed into less destructive items (Bamfoth and Sigleton, 2005; Makadia et al., 2011). One arrangement for bolstering this innovation is biostimulation, which incorporates the aggregation of an invigorating go-between to increase the characteristic microbiota development. The penetrability and agricultural land ventilation can be improved by physical assets or by collecting decompaction components, which allow for the appearance of the discussed properties in the FW compost framework, and the resulting oxygen-consuming circumstances within the method (Vasudevan and Rajaram, 2001), favoring the biostimulation approach (Sommaggio et al., 2018). At twelve months after compost application, a tendency towards decreased amounts of NH_4NO_3 and EDTA bioavailable copper and zinc were detected by Ventorino et al. (2019), which bioremediation is the suitable option for the mitigation of compost threat application in the agricultural areas.

10. Recommendation for future perspectives

In spite of the fact that FW bioresources are considered as top alternative raw materials for use as bioproducts and bioenergy in relation to added feedstock constituents, there are limitations. A chief investigation within the course of critical commercialized perspectives seems to expand the bioproducts and bioenergy generation viability that is noteworthy in a cost-effective process, which are as follows:

- According to the current suggestions, composts that yield a GI of 80% or more are considered mature, and those with a GI > 90% are considered exceptionally mature (Guidoni et al., 2018).
- Currently, there is no standard strategy suggested for generating the biochar used during manure composting (Akdeniz, 2019).
- A rising issue relating to the application of compost is the discharge of antibiotic-resistant microbes into the environment. A larger number of studies that address the impacts of biochar use on the disposal of antibiotic-resistant qualities, especially during manure composting, would be beneficial.
- Accordingly, examining the impacts of biochar alteration on temperature improvement and the disposal of pathogens during composting could help to constrain or anticipate the spread of animal infection outbreaks.
- The sorption of heavy metals from compost rich in particles (e.g., sewage slime) will influence the harm caused by macro elements (particles of calcium and magnesium, etc.) from FW compost. That is, whether a biochar is inclined towards the sorption of heavy metals or macro elements (Godlewska et al., 2017).
- Compared to solid waste composting, the high-impact treatment of digestates showed lower cumulative mass emissions of compounds and smell emanation components below 30.5 OUE g^{-1} OM_0 (Rincón et al., 2019).

- Advances in co-fermentation and the practice of recombinant/metabolically bioengineered microbial strains for the high-yield industrial generation of bioproducts and bioenergy should be developed (Sarsaiya et al., 2019c).

11. Conclusion

FW composting is an efficient, eco-friendly technology for transforming organic waste into stable/mature compost. Although odors are the major annoyance of improper composing principally due to the release of CH_4, NH_3, N_2O and volatile organic carbons (VOCs), numerous approaches with successful outcomes have been used to enhance FW composting, such as the pre-treatment of FW in combination with operational variations, different types of additives and bulking materials and/or microbial inoculums. Further research is also needed to understand the improvement mechanism and the exchanges of the supplemented additives with the prevailing microbes to enhance our improvisation abilities within the composting system.

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Highlights

- The challenges and opportunities for food waste (FW) composting were overviewed.
- FW composting microbiological variations are explained.

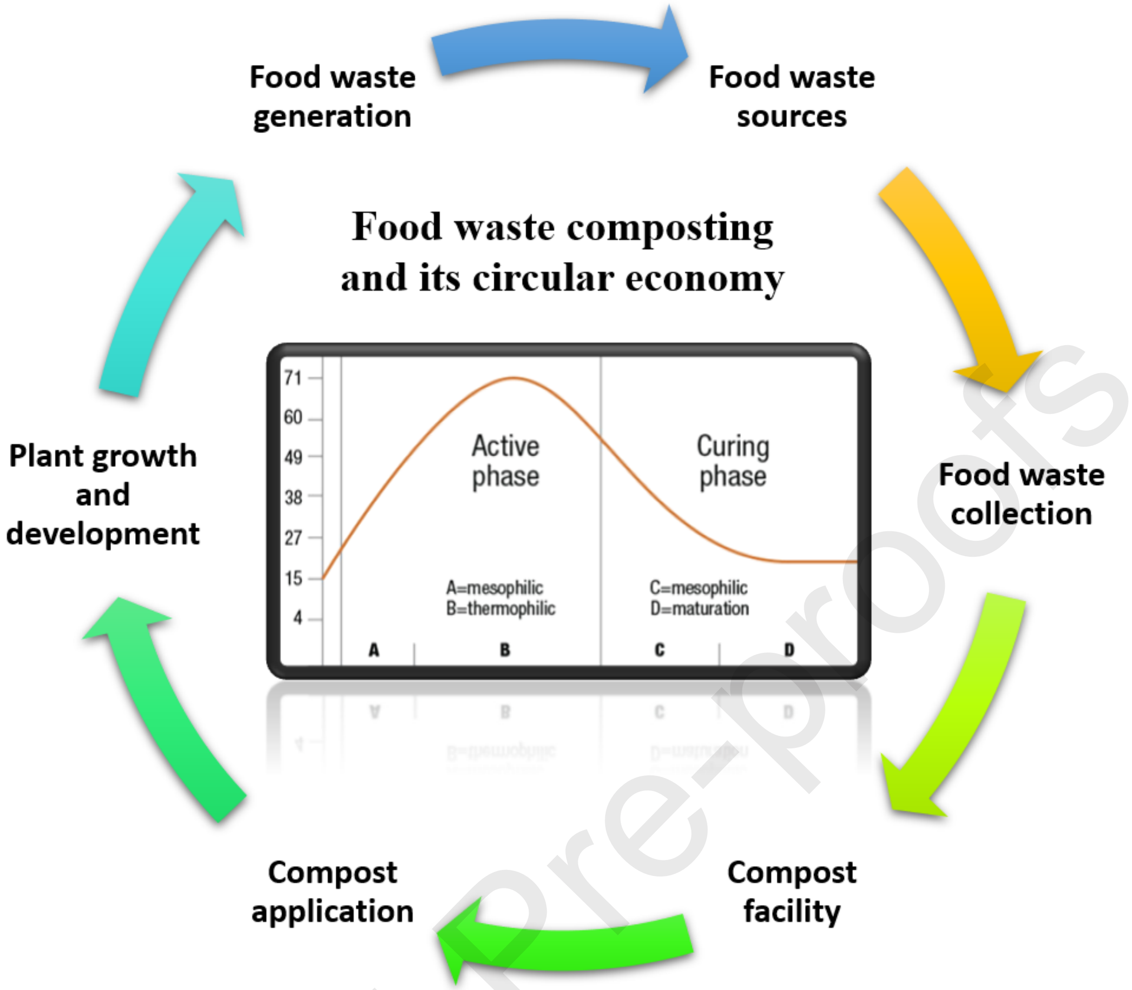
- Microbiology of FW composting has been studied with novel molecular tools.
- Gaseous emissions reduction during FW composting were evaluated.
- The global policy and legislation for food waste management were reviewed.

Figure Captions:

Fig. 1. Food waste composting life cycle for its circular economy concept.

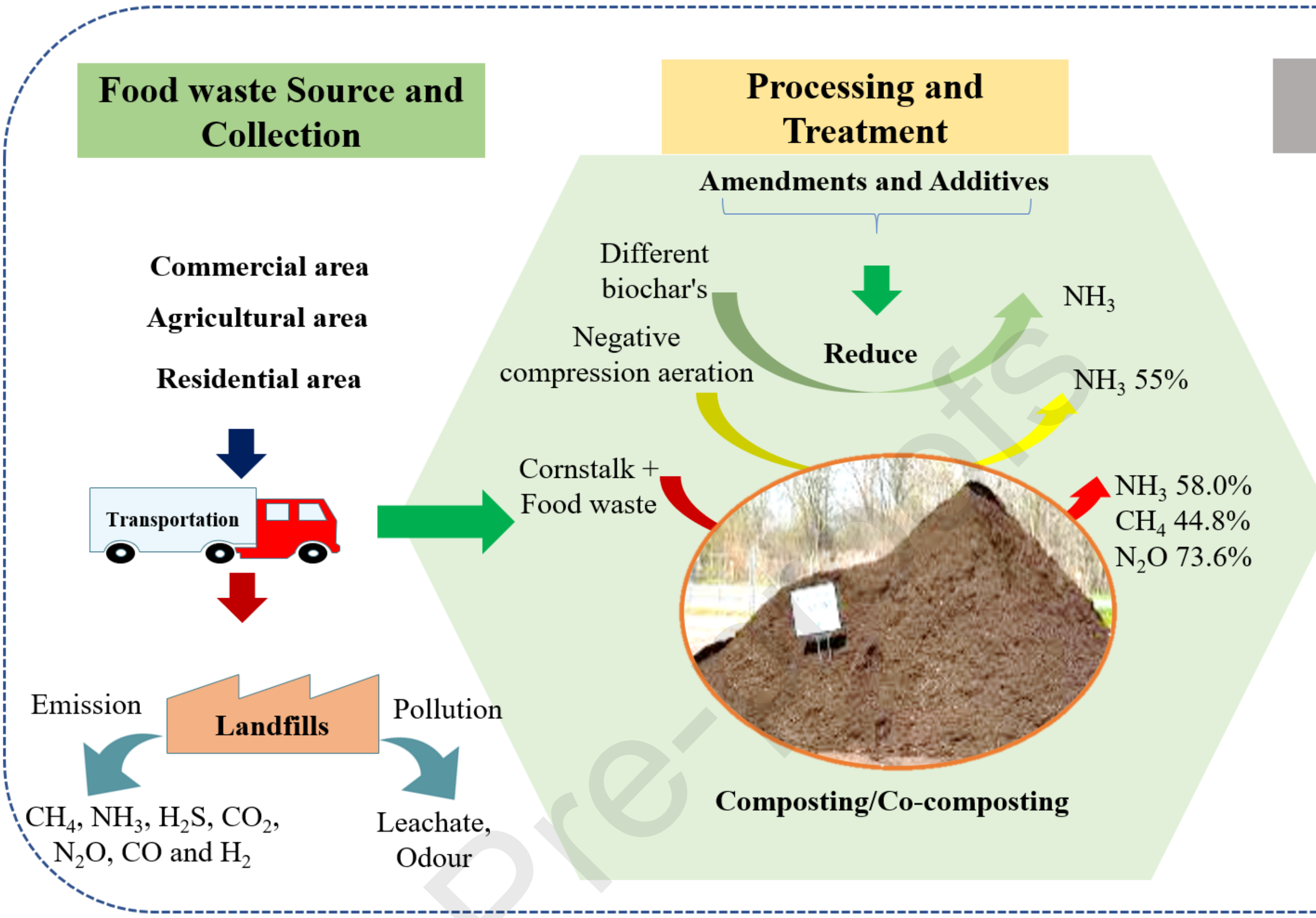
Fig. 2. Food waste sources and its composting for mitigation of gaseous emissions.

Fig. 3. Maturity and stability parameters and its research outcomes for the analysis of food waste compost.


Food waste generation
Food waste sources
Food waste composting and its circular economy
71
60
49
38
27
15
4
Active phase
Curing phase
A=mesophilic
B=thermophilic
C=mesophilic
D=maturation
A
B
C
D
Food waste collection
Compost facility
Compost application
Plant growth and development

949

950 Fig. 1.



Food waste Source and Collection
Commercial area
Agricultural area
Residential area
Transportation
Emission
Landfills
Pollution
CH4, NH3, H2S, CO2, N2O, CO and H2
Leachate, Odour
Processing and Treatment
Amendments and Additives
Different biochar's
Reduce
NH3
Negative compression aeration
NH3 55%
Cornstalk + Food waste
NH3 58.0%
CH4 44.8%
N2O 73.6%
Composting/Co-composting

Fig. 2.

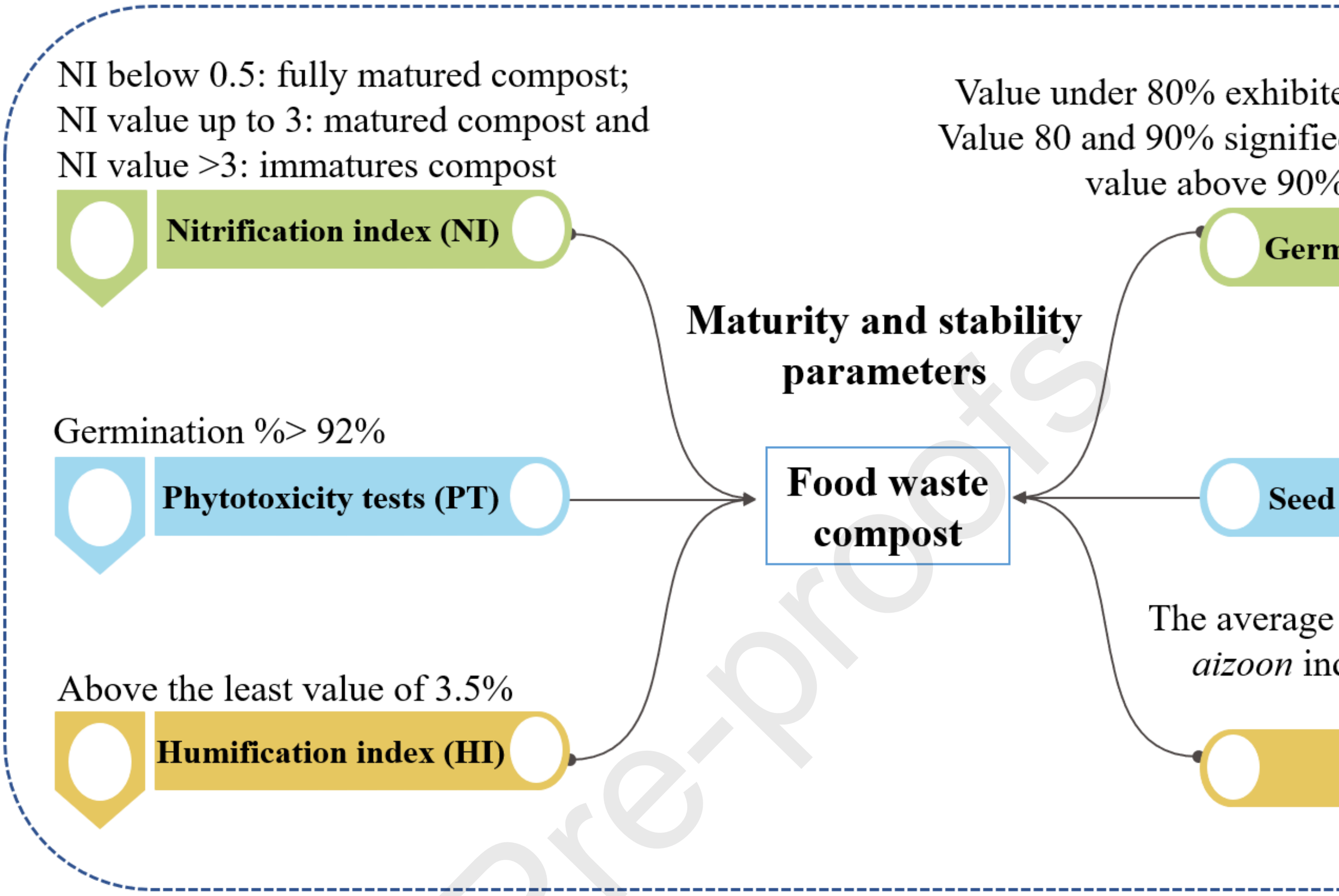


Fig. 3.

Table Captions:

Table 1: Scenarios of food waste generation in different countries.

Table 2: Summary of some microorganisms detected in different stages of the composting process.

Table 3: Gaseous emissions and its modern mitigation research approaches.

Table 4: Maturity parameters and its significant outcomes of food waste compost maturity.

Table 1.

Country	GNF (USS)	Population	Total FW (Ton/ year)		FW % in entire MSW	Reference e year
Developed countries						
Australia	65520	23130900	2261061	0.25	40.00	Liu (2013)
Denmark	61160	5613706	790502	0.32	NA	Veronique et al.(2010),Barbara et al. (2012)
Sweden	59240	9592552	1915460	0.27	67.00	Veronique et al.(2010).Naturvardsverket (2010)
Singapore	54040	5399200	796000	0.40	NA	NEA (2013)
The United States	53670	316128839	60849145	0.52	NA	Grocery Manufacturers Association(2012), Jean and Jefferey (2012)
Netherlands	47440	16804224	8841307	0.31	NA	Veronique et al.(2010), Barbara et al. (2012)
Germany	45170	80621788	12257998	0.34	61.00	Veronique et al.(2010), Barbara et al. (2012)
The United Kingdon	39140	64097085	14257000	0.37	50.00	WRAP (2012a), WRAP (2012b)
South Korea	25920	50219669	6241500	0.27	NA	Lisa (2013)
Developing countries						

Brazil	11690	200361925	33489000	0.17	54.90	Corsten et al (2012)
Turkey	10950	74932641	12375000	0.17	49.50	Kadir and Osman(2011), loannis et, at (2011)
Malaysia	10400	29716965	5477263	0.18	55.00	Zeeda and keng (2014)
Mexico	9940	122332399	19916000	0.16	52.00	Maria (2011)
Costa Rica	9550	4872166	903375	0.19	NA	Dhia et al. (2011)
Romania	9060	19963581	3573481	0.18	NA	Yan (2014)
South Africa	7190	59590000	9040000	0.15	NA	Margaret (2012)
Belarus	6720	9466000	903690	0.10	27.00	RECO Baltic Tech project (2012)
China	6560	1357380000	195000000	0.14	56.60	Yang et al. (2012)
Thailand	5370	65479453	9312788	0.14	44.43	Alice (2010)
Jamaica	5220	2715000	433333	0.16	53.70	Meghan (2014)
The Ukraine	3960	45489600	4440000	0.10	37.00	Sergiy and Vladimir (2012)
Nigeria	2760	173615345	25000000	0.14	60.00	Ogwueleka (2009)
India	1570	1252139596	71952838	0.06	51.00	Ranjith (2012). Manipadma. (2013)
Vietnam	1407	89708900	5743056	0.06	60.00	Ministry of natural resource of Vietnam (2011)

Table 2.

Microorganism		Identification technique	References
Type	**Identified microorganisms**		
Bacteria	*Streptococcus* spp., *Acinetobacterlwoffi, Clostridium tetani*	Oligonucleotide microarray and PCR	FrankeWhittle et al. (2005)
Fungi	19 and 11 species of Sordariomycetes and Eurotiomycetes class, respectively	Isolation in Petri dishes and identification through full sequencing of the ITS region.	Lopez Gonzalez et al. (2015)
Bacteria	*Acinetobacter* spp., *Actinomyces* sp., *Azotobacter* sp., *Brevindimonas* spp., *Clostridium* spp., *Lactobacilluspanis*, *Nitrobacter* spp., *Pseudomonas* spp., *Thermus* sp., *Xanthomonas* spp., among others	PCR-DGGE and COMPOCHIP microarray	Shemekite et al. (2014)
Bacteria	Many species related to *Firmicutes*, *Proteobacteria* and *Bacteroidetes* phyla. Main genera found were *Anoxybacillus* and Bacillus	PCR and high-throughput sequencing was performed using an Illumina MiSeq platform	Wang et al. (2017)

Bacteria	Actinobacteria and its function in a composting process under stress conditions	Culture based, transcriptomics and metaproteomics approach	Narihiro et al. (2016)
Bacteria	Most abundant species: *Symbiobacterium, thermophillum, Rhodothermus marinus, Thermobacillus compostii* and *Thermobispora bispora*. Microbial diversity associated to *Clostridiales*, *Bacillales* and *Actinomycetales* orders	Combined metagenomic and metatranscriptomics approach	Antunes et al. (2016)
Bacteria	*Proteobacteria* and *Actinobacteria*	Isolation in Petri dishes and identification by FISH method.	Haruta et al. (2003)
Fungi	The most abundant genera obtained were *Saccharomyces*, *Candida* and *Schizosaccharomyces*	Metaproteomics	Liu et al. (2015)
Bacteria	The most abundant microbial population obtained from the *Gammaproteobacteria* class: *Pseudomonadales* and Enterobacteriales orders. From the Bacilli class: Bacillales and Lactobacillales orders and from the Actinobacteria class: Corynebacterinae order	Metaproteomics	Liu et al. (2015)
Bacteria	*Proteobacteria*, *Firmicutes*, *Chloroflexi*, *Actinobacteria* and	Clone library from 16S rRNA	Tian et al. (2013)

	Bacteroidetes. Also, a minor presence of *Deinococcus*, *Thermus*, *Verrucomicrobia*, TM7, *Planctomycetes* and *Acidobacteria*.

Table3.

Year	Region	Feedstocks type	Analytical methods	Mitigation approach	Findings	Reference
2019	China	Kitchen waste (vegetables 41.5%, fruits 38.2%, staple food 7.6%, eggshells 7.2%, shells and bones, meat 2.3%, and others)	Syringe sampling method; titration for quantification method	Cornstalk mixed in a food waste at a proportion of 3:17 with 10% of raw composting constituents into the pile	Mitigate the emissions of ammonia 58.0%, methane 44.8%, and nitrous oxide 73.6%	Yang et al., 2019

2019	China, United Kingdom and Denmark	Livestock manure, food waste, sewage sludge and green waste	Meta-analysis; aerobic composting	Additives have been considered as a useful option to mitigate these environmental emissions	Additives reduced the total nitrogen (TN) loss 46.4%, NH_3 44.5%, N_2O 44.6% and CH_4 68.5% releases, and total GHG emissions 54.2%	Cao et al., 2019
2018	China, United Kingdom	Cattle manure + corn stalk	50 litre-scale reactors; flowmeter controllers; titrimetrically method;	Ammonia emissions significantly decrease through composting with negative compression aeration	NH_3 releases reduced by approximate 55%	Wang et al., 2018
2017	United Kingdom	Food related digestate, compost, green/food compost, solid farmyard manure, green compost, and livestock slurry	Ammonia and nitrous oxide emissions measurement; static chamber technique;	Precision application (i.e. bandspreading) can reduce NH_3 emissions	Emissions (NH_3, N_2O, NO_3^-) from green compost were all low	Nicholson et al., 2017

2018	Portugal	Broccoli, chestnut, white grape, red grape, olive. Broccoli wastes, chestnut wastes, grape marc	Photoacoustic Field Gas Monitor system	Diverse food waste used for lower gaseous emission	A lowest emission (34.6 g CO_2eC kg1 initial DM) observed on day 16 on the White Grape; chestnut compost associated with lower nitric oxide and ammonia emissions relative to the other waste materials	Santos et al., 2018
2017	Malaysia and China	Sawdust, and five different biochar, including cornstalk biochar, woody biochar, bamboo biochar, coir biochar, and layer manure biochar	Small-scale lab composters	10% biochars: bamboo biochar, cornstalk biochar, woody biochar, coir biochar and layer manure biochar for lesser releases	The cumulative NH_3 generation is expressively reduced by the biochar of cornstalk, woody, bamboo, layer manure and coir for treatments	Chen et al., 2017

2017	Portugal	Spent coffee, *Acacia dealbata* L. shoots and wheat straw	The measurements of CO_2, CH_4 and N_2O releases performed via a photo-acoustic analyzer	Carbon dioxide, methane and nitrous oxide emissions measured	Very low release of gases	Santos et al., 2017

Table 4.

Year	Region	Parameters	Key outcomes
2018	Spain	Nitrification index (NI)	Nitrification index < 0.5, fully m 0.5 < nitrification index < 3, mat
2019	Italy	Phytotoxicity tests (PT)	*Lepidum Sativum* GI values wer to be in the range 50–59%
2019	Italy	Humification index (HI)	Above the least value of 3.5%
2019	Chile and Germany	Phytotoxicity tests (PT)	Radish 41 germination %> 92%
2019	Pakistan, Saudi Arabia, Egypt	Nitrification index (NI)	NI below 0.5: fully matured com value up to 3: matured compost immatures compost
2019	Pakistan, Saudi Arabia, Egypt	Germination Index (GI)	Value under 80% exhibited an immatures compost while the ra between 80 and 90% signified a compost and value above 90% s highly mature
2018	Poland and Italy	Germination Index (GI)	GI values higher than 80%
2019	China	Plant growth	The average transformation in th dehydrated biomass of *Sedum ai* after three months indicated an application rate of 25% compost Application proportion of 50% had lower average change.
2019	Czech Republic	Humification index (HI)	HI increased after eight weeks f to 0.85

2018	China and India	Seed germination index (SGI)	157.2% SGI
2018	China	Germination Index (GI)	In treatment T2 127.88% and T3 139.18%
2019	China	Germination index (GI)	16.1 ± 2.2 in Kitchen waste; 96.3 in mature compost
2018	Pakistan, Saudi Arabia, Egypt	Nitrification index (NI)	more than 3
2018	China	Germination index (GI)	GI values of T and CK treatment 4.8% and 22%