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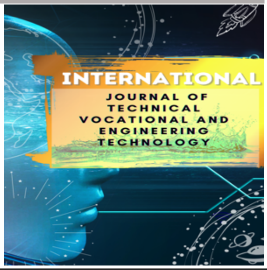

Recent Progresses and Challenges in Food Waste Composting Management at Higher Education Institutions

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ABSTRACT

Composting methods for food waste treatment can play an important role because of the biological stabilization of food waste into bio fertilizer and biogas by-products. Composting contributes to the reduction of CO_2 and CH_4 harmful emissions when food wastes are diverted from landfill. Higher education institutions (HEIs) have been pioneers in establishing composting programs on their campuses. However, there is scarce guidance on composting procedures. Therefore, this study aims to provide a critical assessment of the most recent research accomplishments and unique breakthroughs in composting management in HEIs. A review of 24 publications from related journals and conference proceedings was chosen and used in this investigation. The significant progress made in the composting of food waste in HEIs has been discussed, especially the modes of the composting operation, its strengths and limitations, the composition and capacity of composting, and finally, the fundamental strategies for the rational design of composting for effective transformations of food waste into organic fertilizer. The findings of the reviewed studies showed the primary problems of composting are gaseous emissions and non-biodegradable contaminants. Among the composting techniques, aerobic or anaerobic composting is found to be a suitable technique for the treatment of food waste. Comparatively, aerobic treatment is preferable in terms of scalability, handling, and maintenance, as reflected in the lower costs for large-scale operations. Food waste can be composted at HEIs through the use of co-substrates (i.e., bulking materials, amendments, and inoculation agents), an aeration system, a chemical or maturing compost as a cover substance, and other means. As a recommendation, the technological decisions related to technological readiness level and performance, safety, financial feasibility, also campus community involvement in the program must be made. The study potentially aids decision-making processes at the university alliance level by offering an accurate framework to promote actions to valorize food waste efficiently.

1. Introduction

Higher-education institutions (HEIs) are significant places of tertiary learning and research, and due to the large size, large population, and different complex activities available on campuses, they require proper facilities as well as solid-waste management services (Keng et al. 2020; Ghazvinei et al. 2017). Food waste and other biosolids are often the largest portions of a campus waste stream owing to the high cost of disposal, emitting the most greenhouse gases when deposited in a landfill (Brenes-Peralta et al. 2020; Ozcicek-Dolekoglu and Var 2019).

The inappropriate discard of organic wastes is especially relevant when looking at prospects for enhanced reduction and diversion of waste due to the significant financial and environmental implications (Ali et al. 2021). Diverting organics from the waste stream to composting has proven to be beneficial for HEIs as well as the municipalities and areas in which they are located.

Universities or other HEIs have been pioneers in establishing composting programs on their campuses, mostly in search of a long-term treatment for organic and food waste created by kitchen, dining and catering services (Torrijos et al. 2021). Seeing that a number of key issues have been reported on the university campuses that lack composting programs, several publication domains such as Scopus, Research Gate, Google Scholar, and others were investigated in order to identify different methodologies by different authors to handle food waste in the academic institutions to recommend better strategies for addressing food waste produced in Malaysian HEIs.

Many waste management researches at HEIs focus on waste characterizations and composting procedures (Alyaseri 2020; Ugwu et al. 2020; Aqeela et al. 2021). However, extensive explanations and comparisons of various composting procedures of food waste through either aerobic or anaerobic treatments, or a combination of the two, are frequently insufficient or omitted from the evaluations. As a consequence, inadequacies in the research imply that systematic approaches with a special emphasis on campuses, and a range of composting processes are required as a technique for managing the digestible waste.

Despite composting is commonly used at universities and other HEIs, there is yet scarce guidance on the composting procedures even though composting is involved in a variety of environmental, economic, and social settings (Shukor et al. 2018). Most of the researches focus only on the specifics of administered composting. This particular research, though very useful, is insufficient to make the right decisions on design, manufacturing or operational adjustments as suitability is based on judgements that vary between stakeholders and circumstances. As a result, there is no clear-cut solution that can be reached rationally. Thus, the purpose of this study is to present a critical assessment of the most recent research accomplishments and unique breakthroughs in food waste composting management in HEIs.

Table 1.1 provides a non-exhaustive list of the latest reviews on the aerobic and anaerobic composting processes at HEIs and more focused emphases on locally specific studies in Malaysia. The analyses therefore offer an understanding of the important characteristics of composting despite the challenges of food waste composting by presenting the conceptual efforts to minimize related uncertainties.

The ultimate goal is to assist decision-making processes at the university alliance level by providing an accurate framework and to facilitate activities to valorize food waste. The study possibly helps other relevant institutions, small communities, and perhaps even local municipalities plan for the management of degradable waste in local decentralized or semi-centralized organization, as well as prioritizing sustainable food waste management methods (Vázquez et al. 2020; Brenes-Peralta et al. 2020). Concurrently, further perspectives and future research requirements on this subject are also presented.

2. Review Methodology

This section discusses the method used to retrieve articles related to food waste composting management at higher education institutions. The purpose of this research was to review the various operational parameters and conceptual approaches for food waste composting. Thus, the research technique employed in this review included examining a range of composting that has been done in past research publications and papers on food waste at HEIs. The flowchart for the article selection and review procedure is shown in Figure 1.1. Three major databases were used in the research article selection process: Scopus, Google Scholar, and ResearchGate. Aside from that, manual searches were conducted to include related journals and conference proceedings.

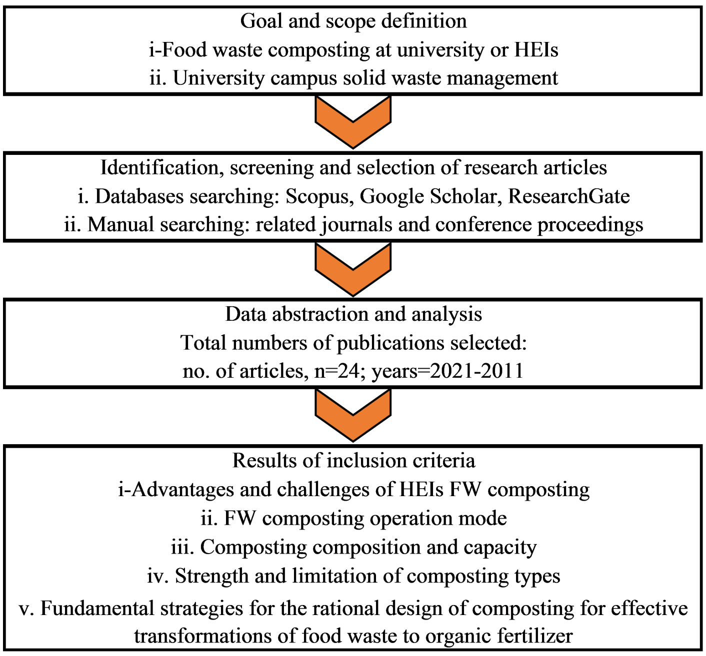

Figure 1.1: Flowchart for the article selection and review procedure

The following keywords were entered into Scopus, Google Scholar, and ResearchGate for the articles search: "food waste composting at universities", "higher education institutions composting", and "university campus solid waste management". A total of 24 publications were chosen and used in this investigation. During the selection step, the titles, abstracts, and content of these 24 articles were explored in depth to verify that they met the inclusion criteria and that they were relevant to the study's purpose.

The selected publications were extensively reviewed for the elements relevant to the study goals. The information was taken from the article, which focused on the benefits and challenges of HEIs FW composting; the mode of composting operations; the composition and capacity of composting; the strengths and limitations of each composting type; and finally, the fundamental strategies for the rational design of composting for the effective transformation of food waste into organic fertilizer.

3. Results

Table 1.1 presents a non-exhaustive list of the most recent revised aerobic and anaerobic composting process assessments at HEIs.

Table 1.1: A review of studies on food waste composting at HEIs in aerobic and anaerobic conditions.

Method of Composting	Country	Summary studies of composting			Ref.
		Sources	C/N	pH	
Dynamic and static composters	University of A Coruna, Spain	FW + GW	(Mean value of 14.0 ± 2.5)	7.85	Torrijos, Calvo Dopico, and Soto (2021)
Biolan Quick Composter 550-L	Turku University Campus Finland	FW	NA	NA	Erälinna and Szymoniuk (2021)
Passive aeration-static bioreactor	Universiti Malaysia Sabah (UMS) Malaysia	FW + DL	3:1	7.1	Aqeela et al. (2021)
Lab Scale compost 1 & 2	Middle East Technical University, Turkey	FW + YW	19:1 15:1	7	Bahçelioğlu et al. (2020)
(i) AD (ii) turned pile compost	Federal University of Pernambuco, Northeastern Brazil	FW + PW	20:80	6.8 ± 0.3	de Sousa et al. (2021)
Closed and dynamic composter (DC) 1st stage Static home composters 2nd stage	University of A Coruña, Spain	FW + GW	14:21	6.3	Vázquez et al. (2020)
AD centralized (continuous load digester), AD semi-centralized (continuous load digester, Centralized Takakura composting, Semi-centralized Takakura composting.	University Costa Rica, Latin America	FW	NA	NA	Brenes-Peralta et al. (2020)
Open Air Static Pile composting	Campus University of Nottingham Malaysia	FW+LW	20:31	6.2 ± 0.7	Keng et al. (2020)
Dry Anaerobic Digestion (Cowtech.)	UPM, Serdang Malaysia	FW+ dry leaves + manure	21	8	Lim et al. (2019)
In container composting	UTHM Pagoh, Malaysia	FW	30:1	7.85	Hamid et al. (2019)
Lab Scale (i) Batch Assays: FW with Mature Compost (ii) Semi Continuous Operation	University of Barcelona	FW: a university canteen	NA	6	Cheah, Dosta, and Mata-Álvarez (2019)

AD	Singapore	FW: a university canteen	17.33	7.25	Zhang et al. (2018)
AD	Korea	FW:a university cafeteria	NA	7.4	Park et al. (2018)
Pilot scale waste digester	University of Malaya	FW	NA	NA	UMZWC (2018)
AD	Colombia	FW:a University restaurant	33.6	5.6	Parra-Orobio et al. (2018)
AD	China	FW:a school canteen	7.01	7.34	Li et al. (2018)
AD	USA	FW: University	NA	6.8	Hobbs et al. (2018)
Windrow Composting, AD	Campus National University (UKM) Malaysia	SW of the campus	NA	NA	Ghazvinei et al. (2017)
In vessel	Kean University, New Jersey, USA	Fresh Matter in FW	4:1	NA	Mu et al. (2017)
In vessel, Turned Windrow	Campus National University Malaysia	FW	NA	NA	Zaini et al. (2015)
Vermicomposting	Puncak Alam Campus of Universiti Teknologi MARA (UiTM), Shah Alam Malaysia	FW (Bedding cow dung and sewage sludge)	2:6.0:5	NA	Baki et al. (2015)
Mini Biogas (AD)	Universiti Sains Malaysia	FW	NA	NA	Othuman et al. (2014)
Windrow composting	Campus National University (UKM) Malaysia	YW + FW	1 ton of FW will be mixed with 2.36 tons of yard waste	NA	Zarina et al. (2013)
Vermicomposting	Campus National University Malaysia	FW	7.51	NA	Tiew et al. (2011)

FW: Food Waste; KW: Kitchen Waste; YW: Yard Waste; SS: Sewage Sludge; NA: Not Applicable; LW: Leaves Waste; DL: Dry leaves; PW: Pruning Waste; C/N ratio: Carbon to Nitrogen ratio; pH: "potential of hydrogen" is a scale used to specify the acidity or basicity of an aqueous solution.

Based on the findings from Table 1.1, the increase in research in this field was visible after 2011, demonstrating the scientific community's interest in food waste composting, which has notably ascended over the previous ten years. Figure 1.2 shows the study trends in food waste composting. The number of publications was lowest in the beginning years of the study with 1 to 2 articles per year. There was an increase in the number of publications between 2018 and 2020 with 4 to 5 studies per year. From 2011 to 2021, the number of relevant publications in Malaysian HEIs increased to roughly 1 to 3 every year, with 2019 having the maximum number.

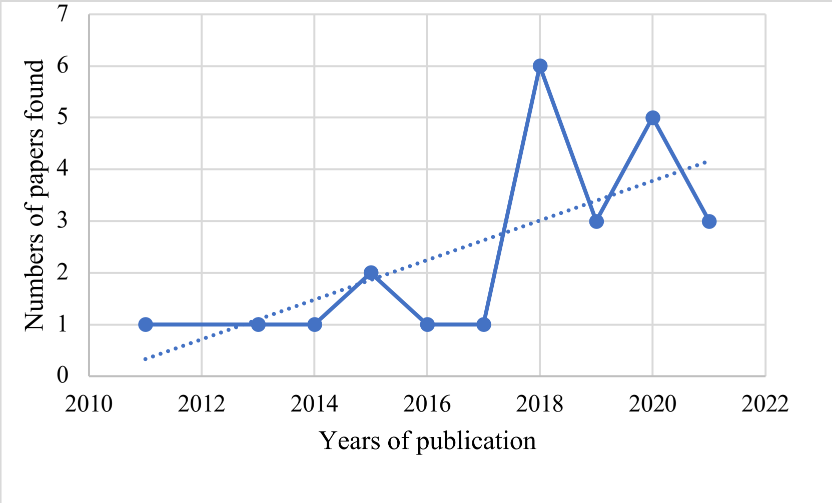

Figure 1.2: Distribution of the number of papers found (n = 24)

The dynamics of studying food waste composting could have been influenced by two factors: (i) the expanding shift in HEI food consumption patterns resulting from food preparation wastes and unconsumed food, leading to a high creation rate of these wastes, and (ii) the environmental and hygienic problems associated with landfill disposal, such as the emission of greenhouse gases and ammonia (Torrijos et al., 2021).

Figure 1.3 depicts the classification of articles depending on the nations studied and percentage of publications by country such as in China, Spain, the United States, Brazil, Korea, Singapore, and Turkey. Few researches were done in the Middle East, where it is a regular practice to collect and transport food waste to the composting sites at the solid waste treatment centers or to final disposal facilities such as landfills (Al-Rumaihi et al. 2020; Abduli et al. 2011).

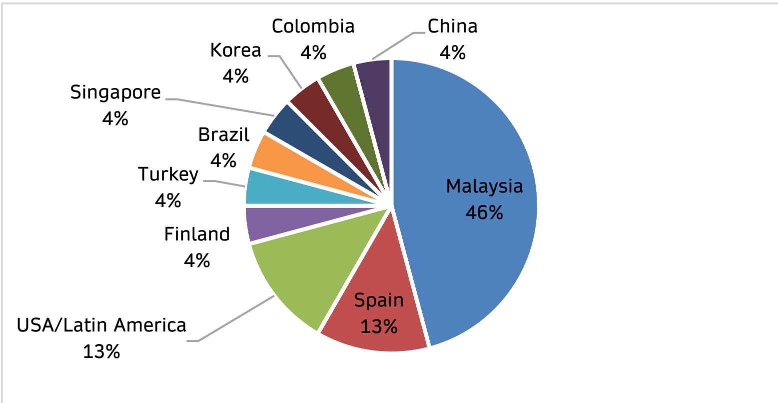

Figure 1.3: Categorization of papers reviewed (n = 24) according to the countries and percentages of studies

3.1 Advantages and Challenges of Composting Food Waste

Referring to Table 1.1, the biological process is predominantly conducted in two main popular biological processes used to valorize food waste materials: (i) composting and (ii) anaerobic digestion (Lim et al., 2019). Diverting food and organic waste from landfills to composting or AD has various environmental benefits, including a greener option to landfilling for organic waste, reducing landfill greenhouse gas (GHG) emissions and preventing groundwater pollution from leachate. Other benefits include reusing nutrients through composting and enhancing soil conditions through compost application. Furthermore, they have a minimal economic investment, a moderate operational cost, and a reduced complexity (Bong et al. 2017; Reyes-Torres et al. 2018).

The techniques for both applications have been well acknowledged and described in existing literature; nevertheless, several elements for the practicability of food waste composting in HEIs and identification of key problems happening in the process can be improved. Food waste may contain a significant number of inert materials, such as glass or plastic, depending on the collection mechanism. Particularly, food waste composting issues include (i) food waste composition, (ii) odors, and (iii) process monitoring challenges such as routine variables, mixture conditioning, with porosity as the key challenge, and process control parameters (Cerda et al. 2018). In addition, microbiology plays a vital part in food waste composting, such as microbial populations that require inoculation.

GHG releases from composting processes are highly influenced by the representational forms of the food waste. Gaseous emissions are typically ammonia (NH_3), hydrogen sulphide, and volatile organic compound (VOC) pollutants, which are mainly correlated with the breakdown of organic matter and are liable for unpleasant odors. Furthermore, nitrous oxide (N_2O) and methane (CH_4) are frequently used to calculate the process' contribution to GHG emissions. These contaminants, which are linked to the occurrence of anaerobic or anoxic zones within the solid matrix, have 296 and 25 times larger warming potential in the atmosphere than carbon dioxide (CO_2) (Sánchez et al. 2015). Finally, there are concerns about the compost quality and problems such as heavy metals and non-organic material, as well as maturity and stability (Cerda et al. 2018).

3.2 Operation Mode

Composting is divided into two types (Figure 1.4): the first is a natural aerobic process in the presence of oxygen (O_2). Secondly, the anaerobic composting of food waste is a biological phenomenon that permits the biodegradation of waste through the microbial decomposition of organic materials without the need for oxygen. It could be shown as a two-step process comparable to Bokashi's composting (Lim et al. 2019). Both processes, which actually occur in aerobic and anaerobic conditions, are defined as a biological degradation of organic materials. The composting process produces compost as a by-product, which is an organic amendment that is beneficial for soil improvement and plant growth. The anaerobic digestion process produces biogas, which is a combination of gases mostly composed of CH_4 and CO_2, as well as a non-stabilized digestate. Both procedures are effective and ecologically advantageous methods of controlling food waste, and they are widely used across the world.

According to Table 1.1, in terms of composting operation mode, the AD and aerobic biological stabilization processes are frequently used. Comparatively, in relation to scalability, handling, and maintenance, the aerobic biological stabilization outperforms anaerobic biological stabilization. Aerobic open-type composting systems such as windrow, aerated static pile, or aerobic close-type such as vermicomposting and in vessels can be the better choices, with lower costs for large-scale operations (Lim et al. 2017). While AD encourages and enhances the use of renewable energy sources such as biogas, significant research on the manufacture of biogas from organic waste for the creation of renewable energy have resulted in continued growth of biogas performance over the last few decades (Brenes-Peralta et al. 2020). In particular, methane yield and volatile solids reduction were used to assess experimental effectiveness. Various features of AD were studied in order to improve methane-generating performance. Researchers have considered additive supplementation, operational variations, parameter optimization, and microbiological effects (Zhu et al. 2018).

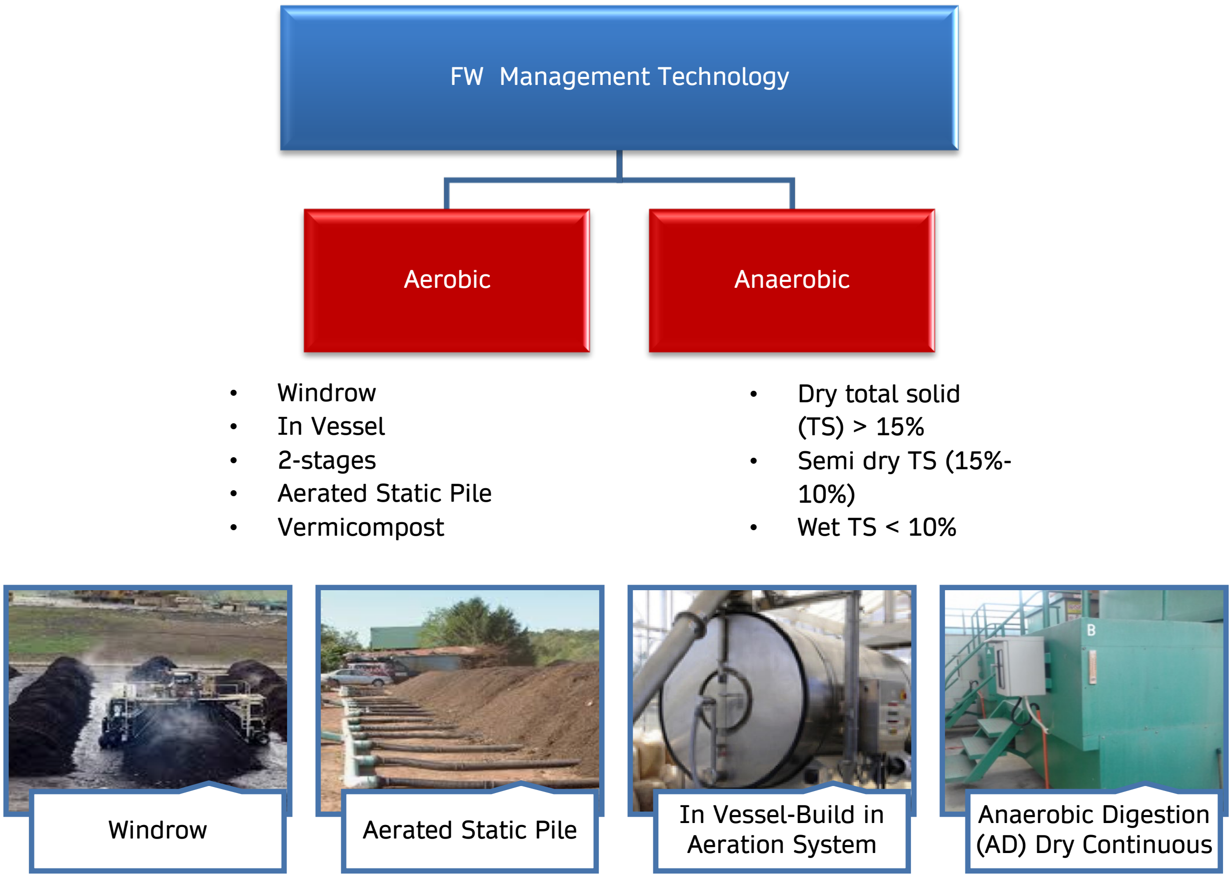

Figure 1.4: Classification of food waste composting conducted at HEIs

3.2 Composting Composition and Capacity

Food waste varies greatly based on its source and it is heavily influenced by consumer eating habits. Food waste is a heterogeneous material with a high moisture content, a considerable organic-to-ash proportion, and an ambiguous structural feature. According to Thi et al. (2015), food waste can include 74–90% moisture, a volatile solid to total solids ratio (VS/TS) of 80–97%, and a carbon to nitrogen (C/N) ratio of 14.7–36.4. As per Table 1.1 and Table 1.2, the majority of the researchers employed food waste and other organic components (i.e., yard or pruning waste, dry leaves, cow manure, etc.) produced from campus solid waste with a capacity of composting ranging between 1 kg and 1 ton of food waste treated per day or per batch.

The feedstock composition and characteristics are the most significant variables for the design and operation of the composting facility, as well as the ultimate homogeneity of the compost. The primary contributors to inventories are input and output emissions from the feedstock. Composting systems have a high potential for GHG contamination both during the process and during storage, resulting in low C/N waste and high moisture content.

HEI waste is a substantial form of organic waste that is perfect for composting. This category includes not only mixed solid waste, but also additional materials such as organic components from source-separated garbage, garden and yard waste, food waste, and others. This type of composting substrate differs from manure in that it has less organic matter, nitrogen, and humidity. The effect on GHG emissions is expected to be different for this component since lower amounts of organic C and N in the feedstock will lead to a decrease in GHG emissions (Sánchez et al. 2015).

As shown by Baki et al. (2015)'s laboratory scale research on vermicomposting, the most efficient ratio was shown to be 2:6:5. (food waste, earthworms, bedding). Mu et al. (2017) found that the ratio of food wastes to wood chips used in vessel composting was approximately 4:1 by weight. Wood chips were put into the composter to increase the C/N ratio since the compost produces an offensive smell if the C/N ratio was not in the right range.

Table 1.2: Various composting capacity at HEIs

Type of composting	**Capacity**	**Ref.**
Biolan Quick Composter 550-L	550L	Erälinna and Szymoniuk (2021)
Passive aeration-static bioreactor	Not stated, but 10 kg of compost seed was placed at the bottom of the reactor	Aqeela et al. (2021)
Dynamic and static composters	360.5 kg of biowaste per batch	Torrijos et al. (2021)
Lab Scale compost 1 & 2	Not stated	Bahçelioğlu et al. (2020)
Open Air Static Pile composting	200 kg/day	Keng et al. (2020)
Dry Anaerobic Digestion (Cowtech.)	100 kg/day but a daily input of 40 kg substrates	Lim et al. (2019)
In vessel	1000 lbs (450 kg) of food scraps and an additional 250 lbs (125 kg) of wood chips per day	Mu et al. (2017)
Wet AD	1000 kg of organic waste	Othuman et al. (2014)
Windrow	1 ton of FW will be mixed with 2.36 tons of yard waste	Zarina et al. (2013)
Vermicomposting	1kg organic waste	Tiew et al. (2011)

Hamid et al. (2019) researched container composting and observed that container composting comprised of green materials (rich in nitrogen—N), such as wasted vegetables or vegetable peels, fruit peels, coffee and tea grounds; and of brown materials (rich in carbon—C) such as dried leaves, soil, shredded paper, and newspaper. In this study, the C/N ratio was set at 30:1.

Meanwhile, Universiti Sains Malaysia has developed a Mini Biogas that can generate 600 kilowatts of power per day from 1000 kg of organic waste. Organic waste, such as food waste and cow manure, is anaerobically digested in this plant to produce methane gas (biogas), which is used to generate heat and power. Universiti Malaya Zero Waste Campaign has diverted approximately 700 tons of waste from landfills with its recycling and on-site treatment since 2011. Universiti Malaya has also established a pilot-scale food waste digester capable of converting food waste into liquefied fertilizer and biogas with an amount of 100 kg/day.

A dry anaerobic digestion research by Lim et al. (2019) proposed a high proportion of dry leaves, 86.9%, with a low food waste composition of 13.1%, made up of vegetable waste (1.1%), fruit waste (4.9%), and meat waste (7.1%). Only 6% of cow dung was suggested for the formulation, with the remaining 94.0% of food waste coming from a healthy mix of vegetable waste (23.2%), fruit waste (34.3%), and meat waste (36.5%). The constructed regression models were experimentally tested, and the anticipated responses for C/N ratio (21.2–21.8), pH (7.92–7.99), and electrical conductivity (0.97–1.03 dS/m) were all within acceptable limits.

Vazquez et al. (2020) found that composting organic waste generated by university canteens with C/N ratios of 14–21 required a carbon-rich additive to equalize the C/N ratio and, most importantly, a structural element that promoted the matrix aeration during the process. The utilized bulking agent supplied both the C/N ratio and structural correction. After 3.5 months of processing 360.5 kg of biowaste per batch in 340 L static composters at thermophilic (51.5 °C) conditions for roughly 80 days, a stable compost (Rottegrade class IV-V) was obtained. This feeding rate corresponded to a volumetric feeding rate of 1060 kg of biowaste per m^3 of composter volume every batch. The optimum treatment capacity for static composters was determined at 10,903 kg biowaste/year for the reference composting site with 3 m^3 of installed composter volume, considering the ideal tenure of 3.5 months for each batch.

Torrijos et al. (2021) stated that the relative humidity of bulking materials varied (20–60%) and the C/N ratio was about a mean value of 14.0 ± 2.5. Aqeela et al. (2021) investigated a passive aeration-static bioreactor, and it was discovered that the maximum temperature was achieved at 47.8 °C on day 12. The moisture content was recorded at 15.4% while pH and electrical conductivity values were 7.1 and 7.5 mS/cm on day 40, respectively. The organic carbon showed a rapid loss in the beginning and slowly degraded after day 30.

3.4 Strengths and Limitations

The similarities across the composting studies, as indicated in Table 1.1, are primarily in the types and sources of feedstock used. Similarly, emissions created, particularly those related to biological treatments, such as composting treatment facilities, are connected to the range of technology used, the waste content being treated, and the operating conditions of the facility (Sanchez et al. 2015).

In terms of AD solutions for organic waste management, the operational steps of closed-type systems include pre-treatment, non-digestible material separation, shredding, digestion, assimilation, biogas recovery, and residual treatments (Rocamora et al. 2020). Dry AD reduces waste, generates energy, and produces compost fertilizer. Its small-sized mesophilic conducting reactor uses less energy for heating, produces no or little effluent, and requires a small working area (Lim et al. 2019). However, in wet AD, diluting of the waste stream prior to internal mixing activities necessitates not only a higher water cost, but also a high-volume reactor, a large working area, and an expensive installation, as well as creating leachate, air, and water emissions (Van et al. 2020).

Meanwhile, an aerobic windrow system is an open-type composting system in which the operating processes include shredding of biodegradable waste, appropriate moisture and air circulation, and frequent turning and mixing for a period of 4 weeks to about 6 months. Windrow offers low capital costs, eliminates a significant volume of biodegradable waste (> 10 tons) and provides compost fertilizer (Lim et al., 2017). On the other hand, windrow practice is associated with significantly higher levels of human health risks (Al-Rumaihi et al. 2020).

Passive file composting usually involves little labor and technological inputs, and it is typically turned once a year. The downsides include the time-consuming process, the establishment of anaerobic conditions (odor problem) as a result of occasional rotation, and the possibility of overheating and burning (Tiew et al. 2011). The majority of open composting techniques, such as windrows, passive piles, and aerated static piles, have drawbacks, the majority of which are linked to unpleasant odors and discomforts created throughout the process and insect problems caused by opening the aerobic treatment area (al-Rumaihi et al., 2020).

Regardless of the organic materials utilized or the process parameters, odors are inevitable by-products of the composting process (Figure 1.5). Odors led to environmental impacts by the composting facilities and raise societal concern, often causing plant closure or the development of preventative measures (Colon et al., 2012).

Figure 1.5: Aerobic food waste composting process and emission (Cerda et al. 2018)

Using open static aerated pile composting has shown that substituting food waste for compost from landfills and replacing chemical fertilizers for organic composting will substantially reduce environmental effects, particularly global warming, ecotoxicity, eutrophication, and depletion of natural resources (Keng et al. 2020). Finally, while an open-type composting system conducted on-site is the best option in terms of the categories evaluated in this study, it can perform poorly if not well maintained. Its attraction is dwindling due to the large GHG emissions caused by anaerobic methanogenesis (Lundie and Peters, 2005).

In research done by Baki et al. (2015), vermicomposting was proven to be beneficial in reducing food waste. After 7 days, practically all of the food waste from the laboratory scale testing was composted. However, earthworm growth was hindered owing to food shortages, high moisture content, and anaerobic conditions. The most efficient ratio for laboratory scale testing was shown to be 2:6:5. (food waste, earthworms, bedding).

There are fewer two-stage composting (TSC) researches. Thus, the efficiency and usefulness of TSC must still be explored. The TSC system combines two independent composting methods into a single composting procedure to increase the final product quality and procedure effectiveness, and to reduce the biological impact of conventional composting. TSC alternates between in-vessel composting, also known as primary composting (PC), and the windrow method, also known as secondary composting (SC).

The TSC research by Vazquez et al. (2020) found that when the bulking agent was of a proper and homogenous particle size, as utilized in these trials, the operation of the static composters was highly easy and reliable. The system was capable of treating up to 20 kg/day of organic food waste, with each individual contributing 1 hour of labor every week. For larger volumes of waste, a dynamic composter that favored mechanical and automated mixing of waste and bulking ingredients was preferable. The thermophilic fermentation stage was also accelerated by this dynamic composter. Stable compost of Rottegrade IV-V was created in 5-8 weeks when a dynamic digester was utilized as a first stage, and in 3–4 months when only static home composters were used. The resulting compost had a high nitrogen content of 2.5–3.6% and a C/N ratio of 11–15, depending on the bulking material to waste ratio used (Vazquez et al., 2020).

In-vessel composting refers to the confinement of the composting activity to a variety of holders or containers. It is available in a variety of systems that use a variety of strategies to enable the greatest degree of temperature control and to speed up the composting process. In-vessel composting is normally completed within a few days. Although more expensive than other techniques, it requires less space and is more convenient than other methods.

Furthermore, the vessel is designed to compost a smaller volume of waste, treating 1–5 tons of waste throughout the course of the composting process. It is suitable for on-site composting of household waste in a small populated area, but there is room for improvement in the technology, notably on the high-power utilization in operating the composter. GHG pollutants are more likely to be emitted towards the completion of the process when the compost is discharged and fossil fuels are utilized for power as in-vessels in the enclosed system (Lim et al., 2017).

Whether the composting system is opened or closed, an educational institution should inform and transform the society to become more concerned about environmental issues. The significance of minimizing solid waste in our society should be communicated to students and staff so that they are motivated to practice waste reduction (Ali et al. 2021).

3.5 Fundamental strategies for the rational design of composting to effectively transform food waste to organic fertilizer

Certain components of the composting process will be influenced by certain traits. The pH, C/N, moisture content, aeration rate, particle size, and porosity should all be vigilantly altered to account for the food waste characteristics (Cerda et al., 2018). Mistakes in the early preparation and modification of the combination with conventional bulking agents, or in the process control will result in odor emissions, increased environmental impact, and low-quality compost (Figure 1.6). Evaluating the quality of the compost is also difficult since many approaches may be employed to analyze its maturity and stability, especially in the case of food waste, where impurities components in the compost must be taken into account. Furthermore, the compost's quality impacts its viability for subsequent use in soil bioremediation or other applications.

Figure 1.6: Hotspots of research regarding food waste composting (Cerda et al. 2018)

The relative quantity of odorous chemicals is determined by the starting material, the composting process design (open or closed), and process parameters such as moisture and aeration, as well as the composting stage (active composting phase or curing phase) and composting activities (e.g., shredding, screening, or turning). To reduce the emission of these pollutants, the composting process must be optimized by: (i) maintaining the right aeration rate and therefore avoiding anaerobic conditions in the solid composting matrix; and (ii) choosing various bulking agents in a sufficient ratio to give the requisite free air space. The development and evaluation of a novel strategy for optimizing biological activity using the oxygen uptake rate (OUR) result in a modest decrease in VOC emission (Cerda et al. 2018).

Emissions from waste treatment plants, particularly those using biological treatments, are affected by the technology used, the kind of waste being treated, and the working condition of the facilities. As a result, it is critical to link emissions to the performance of biological treatment facilities as well as the wastes being treated because each treatment technique and waste will result in varying levels of end product quality and organic matter stabilization. In recent years, one of the primary concerns has been the use of respirometry indices to evaluate the stability of organic matter (Cerda et al. 2018; Sanchez et al. 2015).

The placement of waste in piles of an optimum size and porosity to favor the homogenous distribution of O_2 is a critical factor for the efficacy of the composting process, especially in open systems such as windrows with minimal gaseous pollution (Shahudin et al., 2013). It is recommended to change forced aeration in order to maintain aerobic conditions without adding more O_2. High air flows exceeding O_2 needs might be acceptable in order to avoid an increase in pollution caused by heat. To address these challenges, a novel, sophisticated controller based on the oxygen absorption rate recorded on-line was presented. In addition to the physical composition of the matrix, the biodegradable mixture should have appropriate moisture content and a compostable C/N ratio. Table 1.3 summarizes an in-depth discussion of the food waste biotreatment procedures, which include windrow, aerated static pile (ASP), in the vessel, two-stage composting, and AD single stage (wet and dry system). This content is used here to assist in evaluating the preferences of each FW biotreatment method that involves composting or AD to minimize landfilling. The features of each composting system were gathered from numerous studies, with base data, in-vessel, windrow, and TSC derived from Lim et al. (2017), Mu et al. (2017) and Wei et al. (2001); and AD derived from Chen (2012) and Karmperis et al. (2013). Besides that, various evaluations and discussions were obtained from several composting plant managers.

In addition, there are four approaches that can be employed for the composting optimization methods, including using co-substrates (such as bulking materials, additives, and inoculants), an aeration system, a chemical, or mature compost as a cover substance.

However, employing co-substrates such as bulking materials (i.e., fly ash, bio-char, and woodchips) reduces pollution the most since bulking materials induce more air circulation to the compost, regulate moisture, enhance porosity, and offer structural support (Bong et al. 2017). Sawdust use, for example, would result in the lowest GHG emissions (33 kg CO_2 eq. t^{-1} DM) while the aeration system that uses forced continuous aeration with less aeration results in the greatest reduction in CH_4 emissions (Yang et al. 2013; Jiang et al. 2015).

Table 1.3: The comprehensive assessment of current different FW biotreatment techniques

Biotechnology treatment types		**Aerobic**				**Anaerobic**	
		Windrow[a]	**ASP**[a]	**In Vessel**[a,b]	**Two Stages**[s] **Compost**	**Anaerobic Digestion**[s]	
Criterion of Assessment						**Dry**[b]	**Wet**
Economy	**Capital Cost**	Low	Medium	High (Based on 40T the capital cost analysis) Medium (Based on 1T the capital cost analysis)	High	High	High
	Management Cost	Medium	Low	High (maintenance)	High	High	High
	Labor	High	Medium	Low	High	Medium	Medium

	Land Requirement	Large	Medium	Small	Large	Small	Small
	Site Selection	Away from populated area	Away from populated area	Anywhere that can accommodate the composter	Away from populated area	Anywhere that can accommodate the digester	Away from populated area
	Transportation of Waste	Low (No transportation if conducted on-site)	Low (No transportation if conducted on-site)	Low (No transportation if conducted on-site)	Low (No transportation if conducted on-site)	Low (No transportation if conducted on-site)	High
	Waste Water	Little leachate	Little leachate	No leachate	Little leachate	No leachate (As leachate is collected and sold as liquify fertilizers- based on Petaling Jaya AD dry single-stage continuous type (Cowtech technology)	Heavy leachate
	Soil	Heavy Metal Contamination	Heavy Metal Contamination	Less on Heavy Metal Contamination	Heavy Metal Contamination	Heavy Metal Contamination	Heavy Metal Contamination
Technology	**Preferable waste input**	All type of waste. Preferable with less emission of odor e.g., plant-based wastes	Homogeneity/consistency waste + bulking agent	All type of waste. Preferable easily degraded e.g., FW + speedo enzyme	All type of waste. Preferable FW/Green waste/ Dewatered sewage sludge + amendment	High solid content (20%-40%) Preferable easily degraded waste e.g., FW and organic waste e.g., agricultural and animal waste	All type of waste.
	Loading capacity	>10ton	>10ton	1ton-5ton	1ton-5ton	1ton-2ton	>10t
	Composting period	Long (120days-240days)	Long	Short (24hours-on MAEKO only)	Long 217days (10days-Organic matter degradation) (207days-compost maturation in the windrow)	Short 30days (Based on Cowtech technology)	Long

	Type of amendment can be considered	Increase aeration + bulking agent or chemical additive or microbial additive	Increase airflow in active ASP + bulking agent or chemical additive or microbial additive	Usually in mechanical aspect, increase the system temperature, pressure and turning frequency + enzyme	Usually in mechanical aspect, increase the system temperature, pressure and turning frequency. Increase aeration + bulking agent or chemical additive or microbial additive	Bio-Enzyme	Additive supplementation (Biochar, activated carbon). Microbial action based on different inoculum or sludge sources (i.e., protieniphilum spp. and concurrent propionic acid accumulation in deterioration period of AD); Or continuous feeding mode of diluted FW; Or mixing velocities (i.e., mild 50rpm mixing speed and a stable operation)
	Composting period with amendment)	Can be reduced by more than 30% if amendment successfully applied	Beside increase airflow which might give a similar efficiency than windrow, effect of the rest of the amendments will be lower than windrow system	>80% of the time in composting can be reduced, but the curing phase will take around 4-8weeks while MAEKO composter (taken 2 weeks for curing)	>50% of the time in composting can be reduced, but the curing phase will take around 4-8weeks	>50% of the time in composting can be reduced	>50% of the time in composting can be reduced
	Compost Quality	Medium to good	Medium to Good	Good	Good	Good	Good
Community	**Convenience**	Significant	Significant	Significant	Significant	Significant	Significant
	Resource	Medium	Medium	Medium	Medium	Large	Large
	Reduction	20% reduction	20% reduction	80% reduction	50% reduction	70% reduction	70% reduction

4. Recommendations

Attempting to divert food waste or other organic waste from the waste stream have been challenging at HEIs. The utmost difficulty for HEI campuses in terms of practicing sustainable solid waste management is the lack of knowledge within the campus population. Furthermore, there are no clear standards or procedures regarding solid waste management on campus. Other obstacles that contribute to inappropriate solid waste management practices include a shortage of solid waste management professionals and insufficient waste segregation facilities (Ali et al. 2021).

The ISO 14001 recommendations, which evaluate the aspects of each of the environmental programs, are to be supplemented by the following recommendations to apply effective composting waste management systems: (i) the presence of an environmental management plan, facility improvement, and level of financial and human resources available; (ii) the control processes in place (e.g., systematic environmental management, audits, management reports); and (iii) the level of campus community involvement in the program (Carpenter and Meehan, 2002).

Biological technology solutions can be difficult to select; therefore, clear choices must be made based on numerous factors, including waste burden, available land area, waste transportation distance, total operation expenses, and environmental and social implications (Lundie et al. 2005; Menna et al. 2018; and Shukor et al. 2018). "Is this composting optimal for food waste reduction and appropriate for the generation of biofertilizers?" or, to put it another way, "the sustainability question," is multifaceted since composting solutions are involved in a variety of social, economic, and environmental settings. Because suitability depends on judgments that differ between stakeholders and situations, there is no clear-cut solution that can be achieved logically and without controversies. With this in mind, the incorporation of specific issues such as environmental sustainability, financial viability, and social acceptance into the diverse practices of current FW composting and AD plants must be further explored.

Adopting a collaborative strategy is one approach to cope with this difficulty (Fiez, 2017). This method is founded on the premise that united and aligned parties may accomplish more collectively by establishing a win–win approach to solve issue. It makes it easier for diverse stakeholders to share their information. The decision-makers at the university management level must assess the necessary measures to reach the best conclusion and recognize the specific strengths and limitations of that judgement. Proper project's planning and execution phases can reduce the likelihood of a mistake and the risk of a technique. In this regard, the evaluation activities assist the decision-maker in analyzing each recommended technology so that an optimized solution may be produced (Shukor et al., 2018).

5. Future research

Various strategic concerns, technological techniques, and particular research areas have been given in the composting of food waste. The predominant view of the aerobic and anaerobic processes is the synergy between the primary food waste composition and the four approaches that can be used for composting optimization methods, including using co-substrates (such as bulking materials, additives, and inoculants), a ventilation system, a chemical, or matured compost as a cover material.

Composting for food waste is sensitive to the structure of the composition C/N; therefore, the preparation technique, preparation settings, and component all have a substantial impact on its performance. In summary, the following future research directions on composting for food waste would be proposed:

(1) The two-stages aerobic composting system merits further investigation in order to maximize its benefits over single-stage system's synthesis settings in order to obtain high active and stable processes with quicker degradation reactions and fewer offensive odors.

(2) To discover additional information on how a dry anaerobic digester, such as the dry anaerobic digestion Cowtech. system, may be utilized to create consistent compost from food waste. Dry digestion is an appropriate approach for handling organic wastes with diverse compositions, including the organic part of municipal solid waste.

More study is needed to address some of the difficulties involved with the process' significant total solids content. Some of the characteristics that need to be investigated further in batch dry anaerobic digestion to reduce localized inhibitory effects and to avoid process destabilization are inoculum to substrate ratio, feedstock content and size, liquid recirculation, bed compaction, and use of bulking agents. Furthermore, for continuous dry anaerobic digestion systems, more research must be paid to the interaction involving feedstock content, organic loading rate, and mixing routines. The vegetable and fruit wastes significantly reduce the pH value and electrical conductivity. With fruit waste, the C/N ratio increases considerably. Meat waste, on the other hand, results in a considerable rise in pH and electrical conductivity, both of which are beneficial for making high-quality compost. Table 1.4 and Figure 1.7 and show the diagram of the dry digester and the general specification of the dry anaerobic digestion system.

(3) Individual waste behaviors of residents must be analyzed to improve civic FW prevention and give recommendations to the university solid waste management alliance, the governments, and related companies.

(4) Appropriate FW sorting and collection must be well designed with sufficient and well-managed facilities.

Table 1.4: General specifications of Dry AD

Specs:	Descriptions
AD type	Cowtec hi-dry batch continuous anaerobic digester
HRT	Hydraulic Retention Time is 30 days
Temperature	Mesophilic 30 – 35 degrees Celsius
Feedstock material	Food waste
TS	Total solid < 25%
C: N Ratio	Carbon to Nitrogen ratio 10-35:1
Feedstock dimension	Maximum dimension of feedstock materials is best between 5 cm long and 1 cm wide

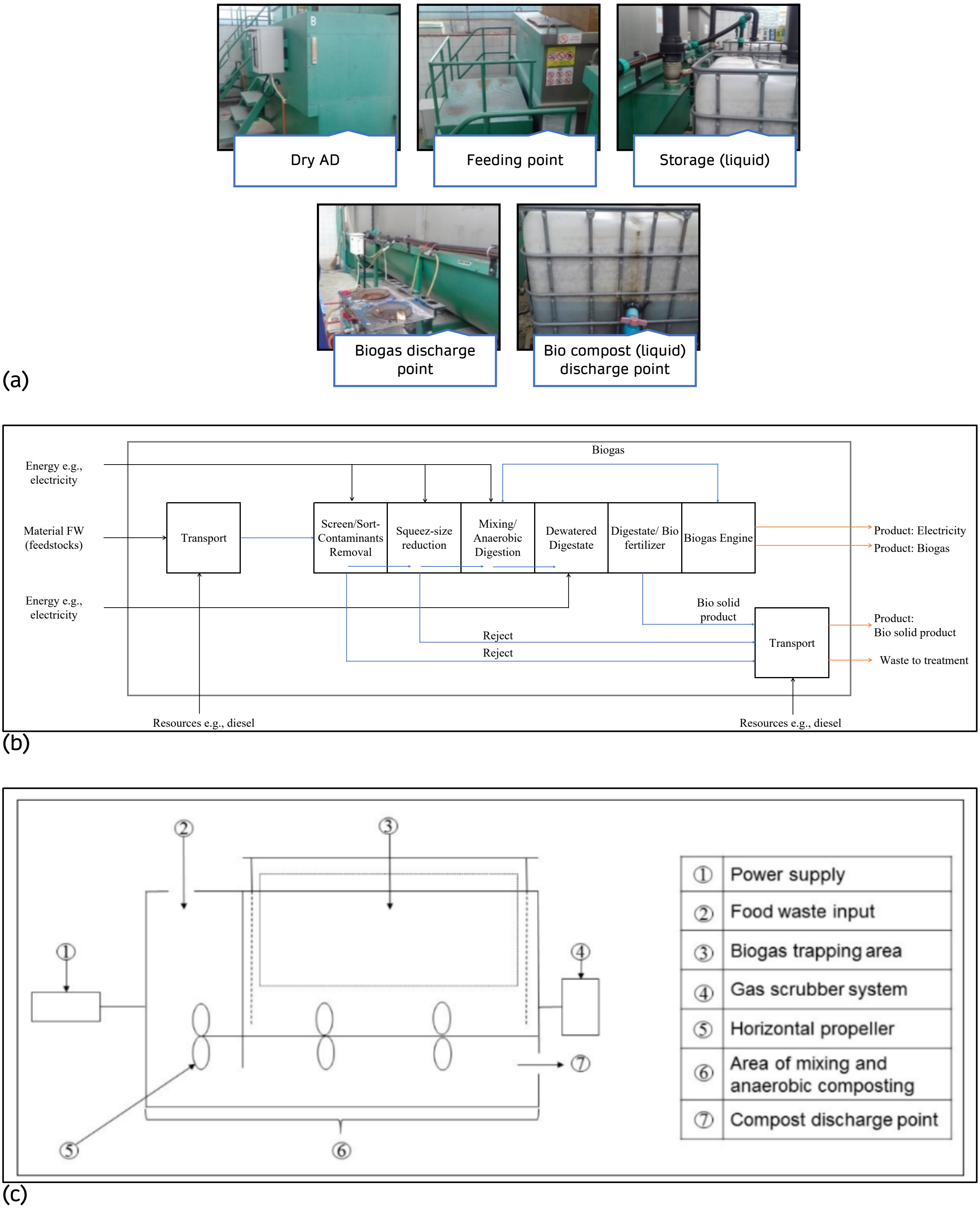

Figure 1.7: (a) Pictures of dry anaerobic composter (adapted from Majlis Bandaraya Petaling Jaya, Selangor Malaysia); (b) Flow process of dry anaerobic digestion (adapted from Majlis Bandaraya Petaling Jaya, Selangor Malaysia) and (c) Schematic diagram of dry anaerobic composter (Cowtec. system) (adapted from Lim et al. 2019).

6. Conclusion

Composting is a well-regarded waste management method due to its resilience and the prospect of getting a profitable product with a soil amendment potential. Composting operational parameters and raw material conditioning have been extensively researched as evidenced by the scientific literature.

The primary problems of composting are gaseous emissions and non-biodegradable contaminants. Apart from these composting studies, which include criteria and indicators related to environmental performance, the financial viability and social acceptability of the various practices of contemporary food waste composting and AD plants must be investigated further. Technological choices related to technological readiness level and performance, safety, and many others aspects are also necessary to consider in the implementation of the studied solutions. It is essential for HEIs to implement campus recycling and waste reduction initiatives inside campuses. This includes policy formulation, facility improvements, 3R initiatives, environmental awareness, and education. As an educational institution, the community should be taught and formed to become more ecologically responsible. Likewise, the institution can broaden its community assistances in solid waste management via collaborations with tertiary interest groups and the establishment of a technology transfer center.

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