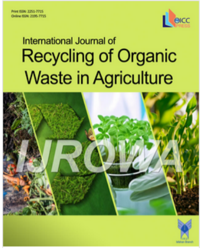

Volume 13, Issue 3, 132427 (1-12)

International Journal of Recycling Organic Waste in Agriculture (IJROWA)

https://dx.doi.org/10.57647/j.ijrowa.2024.1303.27

Feasibility study of pilot scale vegetable waste composting project for Kundasang community's waste management program

Noorafizah Murshid[1], Abu Zahrim Yaser [1*], Mariani Rajin[1], Sariah Saalah[1], Junidah Lamaming[1], Mariana Taliban[2]

[1]*Chemical Engineering Programme, Faculty of Engineering, University Malaysia Sabah, Malaysia.*
[2]*Persatuan Pemborong dan Peruncit Sayur Bumiputera Kundasang, Sabah, Malaysia.*

*Corresponding author: zahrim@ums.edu.my

Original Research

Received:
12 April 2023
Revised:
8 July 2023
Accepted:
29 October 2023
Published online:
15 January 2024

Abstract:

Purpose: Vegetable waste (VW) composting was assessed using a passive aerated pilot-scale composter at Kundasang, Sabah. The passive aerated composting system proposed at Kundasang Community Composting Site (KCCS) was analyzed for its techno-economic impact.
Method: The composting performance (temperature, organic matter loss, moisture content, pH value, electrical conductivity, and nutrient value) of 500 ± 2 kg of VW, 250 ± 2 kg of RH, and 19 ± 1 kg of CM feedstock mixture was analyzed. The benefit-to-cost ratio was used to assess the impact of the techno-economic analysis on the designed and piloted KCCS.
Results: In the pilot scale composting condition, temperature reached its highest at 59 ± 7 °C (day 5) and for five consecutive days (day 2 until day 6) in the thermophilic phase. Results of the final compost (on a dry matter basis) showed that the moisture content is 62 ± 0.2% WM, the pH level is 7.6 ± 0.1, the electrical conductivity is 1.8 ± 0.4 mS/cm, and the N, P, and K values are 0.58 ± 0.10% DM, 0.04 ± 0.02% DM, and 0.17 ± 0.04% DM, respectively. The techno-economic analysis shows that with the capital cost normalized on a 20-year basis, the KCCS composter system can generate approximately MYR 25, 000 (USD 5, 600) per year in revenue.
Conclusion: The results show that these composting methods are suitable for VW and Kundasang community conditions, and this study will benefit the community in dealing with VW waste and generating a circular economy while establishing a self-sustaining community.

Keywords: Vegetable waste; Composting; Passive aerated composter; Community composting; Techno-economic analysis; Sustainable development

1. Introduction

Kundasang, Sabah, is a rural area about 100 km from the urbanized capital of Kota Kinabalu. It has a complex landscape that is affected by many social, tourism, and economic activities. As one of the biggest vegetable distributors in Sabah, Kundasang generates approximately 1 ton of vegetable waste daily. Vegetable waste is generated in huge volumes, and since landfilling and incineration are the two most common ways of disposing of it, handling this waste has become a significant issue. The current method is environmentally harmful and resource-wasting, so the recommendation to replace it with more environmentally sustainable and recycling-efficient approaches, namely composting, arises.

Composting is a biochemical process described by Bernal et al. (1998) that relies on the conversion of organic matter through microorganisms and occurs in a water-soluble phase to stabilize organic matter. The Food and Agriculture Organization (FAO) stated that composting may be divided into two categories by the nature of the decomposition process: anaerobic digestion (decomposition occurs where oxygen is absent or in limited supply) and aerobic degradation (in the presence of oxygen). In low-temperature digestion, anaerobic microorganisms dominate and develop intermediate compounds (including methane, organic acids, hydrogen sulfide, and other substances) that may accumulate and are not metabolized further. In composting, aerobic microorganisms break down organic matter and produce carbon dioxide (CO_2), ammonia, water, heat, and compost, the relatively stable organic end product. Eq. 1 displays a simple conversion of the composting process into CO_2, H_2O, NH_3, and a significant amount of energy is released (Díaz et al., 2002; Finore et al., 2023; Yaser et al., 2022). The heat generated accelerates the breakdown of proteins, fats, and complex carbohydrates such as cellulose and hemicellulose; hence, the rotting duration is shorter.

$$\text{Biogenous waste} + O_2 + \text{microorganism} = CO_2 + H_2O + NH_3 + \text{compost} + \text{heat} \tag{1}$$

Malaysia, as a significant producer of rice, has an abundance of rice husk (RH), with an annual production of over 0.48 million tons (Eizlan et al., 2022). This provides an excellent opportunity for utilizing RH in composting, as it offers advantages such as high capillarity, increased ventilation, enhanced water-holding capacity, and control over moisture content (Bian et al., 2019; Li et al., 2021). In comparison, rice straw, despite higher production (3.18 million tons/year), presents logistical challenges, including handling and collection from the field, making it less favorable in terms of cost-effectiveness (JS Lim et al., 2012).

Bulking agents are important for the composting of vegetable waste (VW) to reduce its moisture content (Murshid et al., 2022b) and to increase its C/N ratio and porosity (Dayananda and Shilpa, 2020). The addition of long-term, structurally stable material is important to increase the air void volume of the rotting material during the whole rotting process. Only a sufficient number of air-filled pores (FAS, free air space) allows a uniform oxygen supply to the microorganisms by means of passive aeration (by convective airflow). Additionally, the addition of woody structural material allows for optimization of the C/N ratio.

Composting can be carried out by adjusting the substrate C/N ratio and moisture content as well as using chemical and biological additives to achieve reduction and recycling for sustainable waste management (Zhang et al., 2022). Therefore, it is crucial to optimize the conditions of composting to ensure the high quality of the final product (Sokač et al., 2022). Chicken manure contains a diverse microbial population, including beneficial bacteria and fungi, which contribute to the decomposition process and enhance nutrient cycling while balancing the C/N ratio. According to estimates for the year 2020, Malaysia's livestock will excrete 17.76 million tons of manure, primarily from poultry and cattle (Zayadi, 2021), which, after composting, can then be used as a nutrient-rich soil amendment. By leveraging the availability of rice husks and chicken manure, Malaysia has the potential to develop sustainable and cost-effective composting practices, benefiting both waste management and agricultural productivity (Sokač et al., 2022).

Currently, different communities have varied approaches to waste management, and it depends on their geographic location, distance from the disposal facility, frequency of garbage collection, budget availability, pre-existing solutions for their waste treatment, and the attitudes of their residents toward waste management and subsequent disposal (Jamaludin et al., 2022). In the Kundasang community, they discard VW through landfills and are now searching for innovative, low-cost, and effective methods to manage this waste. Thus, this study proposes composting as a substitute technology to reduce waste entering landfills.

To promote self-sustaining and sustainable development, the concept of community farming is combined with a pilot-scale composting facility (Nadhirah et al., 2021). The economic analysis was estimated in a Microsoft Excel© spreadsheet, and the costs of essentials were based on local vendor or manufacturer quotations. The economic analysis provided information about the capacity, cost, and benefit estimate of the process, which is essential to estimating the cost-benefit ratio during composting (Boni et al., 2022).

Therefore, composting of vegetable waste was conducted using rice husk and chicken manure as bulking agents and compost activators, respectively. The pilot-scale composting process was conducted in a passive aerated composter located at the Kundasang Community Composting Site (KCCS)(Fig. 1). One of the contributions of this study is that it is a pioneering study that explores the competence of a pilot-scale composter in Kundasang, Sabah, along with its feasibility as a profitable composting site and a technology

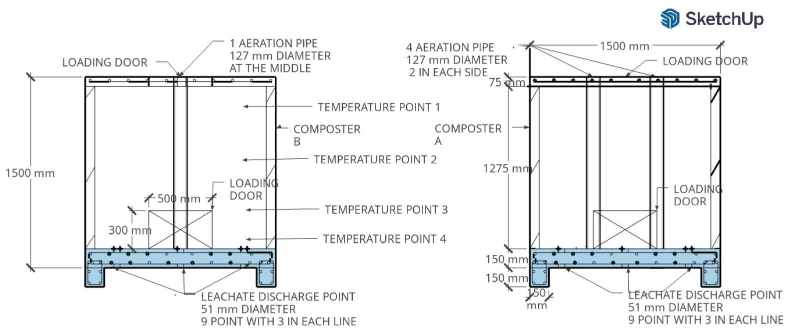

Figure 1. Dimension and detailing from the front view of proposed composters (A on the right and B on the left figure) at Kundasang Community Composting Site.

for rural development. As in Oviedo-Ocana et al. (2015) and Torrijos et al. (2021), they evaluated the performance of pilot-scale composting consisting of 300 kg or more of initial feedstock.

Compost quality was investigated by monitoring processing and analyzing quality parameters like moisture content (MC), loss on ignition (LOI), total organic carbon (TOC, estimated by multiplying LOI with factor 0.58), nutrient concentrations (N, P, and K), pH value, and electrical conductivity (EC).

2. Materials and methods

Feedstock

Vegetable waste (VW), rice husk (RH), and chicken manure (CM) from Kundasang, Sabah, were used as raw materials for composting. While the VW was obtained from vegetable vendors at Kundasang Vegetable Fresh Market, the RH was gathered locally from Kundasang paddy farmers. The CM was supplied by a local chicken farm near Kundasang town. To ensure that the feedstock mixture in the current study was exposed to an equal amount of microbial surface area for activities during the composting process, the VW was shredded by a shredder chipper (B&S XR) into uniform particles (0.5–2.0 cm in diameter), as shown in the (Resmi and Vinod, 2022) study.

Experimental set-up

The pilot-scale composting was conducted using passive aerated composters available at the Kundasang Community Composting Site (KCCS) (composters detailed in Fig 1). This study used the optimized ratios of biogenous wastes in the feedstock mixture as determined by preliminary studies by Murshid et al. (2022a) for rice husk (RH) and Murshid et al. (2021) for chicken manure (CM). The total feedstock mixture had a wet basis weight of 769 ± 2 kg, comprising 500 ± 2 kg of VW, 250 ± 2 kg of RH, and 19 ± 1 kg of CM. Initially, the VW was shredded, and then the weighed feedstock mixture was mixed using a mini concrete mixer (MPM 3 T).

Both composter designs (Composter A and B) are similar, with 1.5 m in height, 1.5 m in width, 1.5 m in depth, and 9 holes located at the bottom of the composter acting as leachate discharge and ventilation points. At the beginning of the composting process, the homogenously mixed feedstock is poured into composter A (with 4 aeration pipes high), and after 5 days, the rotting material is manually transferred to composter B (with 1 aeration pipe low), causing the aeration intensity to alternate, as in the Bari and Koenig (2001) and Then et al. (2021) studies. After a further 5 days, the rotting material in composter B was transferred back to composter A, and this alternating transfer between composters A and B continued every 5 days until day 30.

Based on promising results reported by Ma et al. (2022) a turning frequency of 5 days was employed to improve the composting process. Rasapoor et al. (2016) stated that the combination of turning and aeration could solve the problem of long degradation time and concurrently guarantee the acceptable quality of finished compost for agricultural purposes. Shimizu et al. (2018) stated that aeration mode in an alternate (on or off) sequencing process and full turning are optimal composting conditions for organic matter degradation. Thus, by utilizing the optimized feedstock mixture and implementing specific design features, the composting trials were carried out to maximize the composting process's efficiency and generate valuable outcomes for the local community (Lin et al., 2008).

Analytical methods

The study aimed to understand the overall efficiency of converting biogenous waste into compost. Initial results provide insights into the starting conditions of the rotting process, and the final compost output is essential to assessing the quality of the finished product; thus, samples are collected on days 0 (initial) and 30 (final), similar to the Ajaweed et al. (2022) and Arbab and Mubarak (2016) studies. Samples were taken for physio-chemical analysis similar to Oviedo-Ocana et al. (2015) and Arbab and Mubarak (2016) studies including MC, pH level, EC, and LOI, while temperature was measured by inserting a digital thermometer (Hanna-HI98501) daily in 4 different points of the composter. All the samples were processed at the Chemical Environmental Engineering Lab for physio-chemical analysis. A total of 500 ± 5 gram samples were taken from six different places in the composter and blended homogeneously to form an integrated sample. Afterward, three different samples were analyzed to be averaged.

In a drying oven (Binder), the samples were dried for 24 h at 105 ºC to determine their MC (Ghinea and Leahu, 2020). Eq. 2 was used to determine the MC percentage (%, on a WM basis). For the pH and EC, 10 g of the dried and milled sample were mixed with 100 mL of distilled water and agitated for 20 min with a magnetic stirrer before being left for 24 h. After sedimentation, filtration using 5 μm filter paper was used to obtain 10 mL of the extract. Then, the pH and EC indicator meters (Eutech PC 450) were immersed in the extract for each pH and EC value determination.

The total organic matter (OM) loss was determined (using Eq. 3) by weight loss on ignition (LOI) on a dry mass basis (Dias et al., 2010). OM loss can be calculated from LOI at the beginning and LOI at the end of the experiment under the assumption that inorganic matter (kg DM) will remain constant during the rotting process. Dried and milled samples were weighted for 30 g on a DM basis in each crucible before being burned in a high-temperature furnace at 550 ºC for 4 h. Then the weight of ash is calculated using Eq. 4, and total organic carbon (TOC) can be estimated using Eq. 5. Nitrogen (N) was assessed utilizing a protein analytical method in accordance with the Malaysian Standard (MS417; Part 3:1994). Phosphorus (P) and potassium (K) concentrations were measured using inductively coupled plasma-optical emission spectrometry (ICP-OES) and hydrochloric acid as the digestion solvent in accordance with Environmental Protection Agency (Method 200.2). For N, P, and K tests, samples were sent to Chemsain Konsultant Sdn Bhd.

$$\text{MC (\%WM)} = \frac{\text{weight of wet sample-weight of dry sample}}{\text{weight of wet sample}} \times 100\% \quad (2)$$

$$\text{OM Loss } (\%) = \frac{100}{A} \times (1 - \frac{100 - A}{100 - B}) \times 100\% \quad (3)$$

$$A = \text{Initial LOI}$$
$$B = \text{Final LOI}$$

$$\text{Ash } (\%\text{DM}) = \frac{\text{Weight}_{\text{crucible+sample (after burning}} - \text{Weight}_{\text{crucible}}}{\text{Weight}_{\text{sample}}} \times 100\% \quad (4)$$

$$\text{TOC } (\%\text{DM}) = \frac{\text{organic matter } (\%\text{DM})}{1.8} = \frac{100 - \text{ash}}{1.8} \quad (5)$$

Techno-economic analysis

Based on data collected on the site and a review of the literature, the economic analysis of the composting facility was evaluated. With the capital cost normalized on a 20-year basis, the annual total cost and revenue of the composting plant project were determined, and the economic analysis was carried out. By analyzing the fixed capital, capital investment, operational cost, overheads, product sales, and cost-benefit ratio, the payback duration and profits of the composting plant project were determined. Using Eq. 6, the results obtained were derived for the net direct expenses of composting:

$$\text{Net cost of composting} = \text{Investment cost} + \text{Operational cost - Revenue of compost} \quad (6)$$

Employing a plant manager and general laborers and paying them a wage based on days included in operational expenditures. Electricity supply for the composting site is generated by solar energy, where photovoltaic panels (PV) with power storage were installed on each composter building and office to save on the cost of electricity. Water consumption was estimated to be around 3,000 gallons per year and might be reduced by utilizing a rainwater harvesting tank. The water rate for industrial activities is MYR 1.60/m^3, with a minimum payment of MYR 70.00, according to the Sabah State Water Department.

The produced compost is sold for MYR 2.50 per kilogram to generate income. Site preparation, paths, fences, pipes, wiring, drainage, machinery units, and other start-up necessities are all included in the original cost calculation. According to an area-based cost estimate for site preparation, which is MYR 3, 250/m^2 for buildings with a roof, gutter, and full or half wall, and MYR 950/m^2 for a composter with a full wall and cover, reading point, and aeration pipe. Solar panels, a shredder, a mixer, a weighing scale, a bagging station, and a storage box for compost and rainwater collection, along with some of the other tools needed for setting up the composting system, are purchased.

The cost per year comprised wages for management and laborers, servicing of equipment, fuel used by shredders, nutrient analysis of compost, utilities, and compost bagging. The facility will operate daily. Using the projected full amount of vegetable waste generated in the vicinity of Kundasang Community Composting Site (KCCS), which is situated at 5.982168 ° latitude and 116.580272 ° longitude, the plant's production capacity was determined.

3. Results and discussion

Pilot-scale study

In this study, the MC of VW reached 93 ± 2% WM, as shown in Table 1, and according to (Bernal et al., 2009), the optimum MC should be 50 – 60% WM. Thus, to reduce the high MC from VW, rice husk (RH) has been added to balance the MC in the feedstock mixture, according to Tiquia and Tam (1998) and Gao et al. (2010) studies (Bernal et al., 2009). The RH mixed into VW and chicken manure (CM) reduces the MC from 92% WM to 72% WM and provides sufficient porosity. Although RH assists in decreasing the MC, it will increase the C/N ratio in the mixture. The feedstock mixture in Table 1 shows that the C/N feedstock mixture is ± 4, and, in such cases, microorganisms require additional nitrogen. In many studies, manure was adapted (Ogunwande et al., 2008; Sarika et al., 2014; Tiquia and Tam, 2000); however, using a lot of CM will increase the cost of composting. Thus, in this study, the composting will be carried out at a high C/N ratio (Hackett et al., 1999; Murimi and Gbedemah, 2018). The main purpose of CM addition is as a compost activator, and our previous optimization study (Murshid et al., 2021) showed that 2.5% CM enhanced faster degradation. The key properties of raw materials, feedstock mixtures, and compost for this study are shown in Table 1.

Temperature is an essential factor in composting that facilitates the process by eliminating pathogens that are harmful to soil organisms and weeds (Amrit et al., 2021). The graph in Fig. 2 shows the trend of temperatures for 30 days of composting. After day 1 of mesophilic temperatures (< 45°C), the conditions change to thermophilic (day 2 – day 6) and last for 5 days. A maximum temperature of 59 ± 7 °C was attained on day 5, which is 4 days after entering the thermophilic phase. The degradation of organic matter was faster at the early stage of composting in the treatment due to the high temperature of the compost mixture (Peng et al., 2023). Manually turned compost piles, causing the temperatures to fluctuate as the available C compounds were relocated for microorganisms (Li et al., 2022) .

After day 6, temperatures gradually decreased, re-entering the mesophilic phase and approaching the ambient temperature. The temperature in the compost was reduced because a large amount of easily degradable organics had been decomposed in the early stages. In the composting process, the moisture not only supports metabolic processes but also creates an environment for the transport of micromolecules formed by organic matter decomposition (Saalah et al., 2019). Table 1 shows MC during composting decreases from 72 ± 5% (initial) to 62 ± 1% (final) due to evaporation and leaching (Mishra and Yadav, 2022).The final pH value increased by 15% from 6.6 to 7.6 ± 1, signifying the biodegradation process. In the composting of sun-dried green bean, pepper, and cucumber plants. López et al. (2002) also observed the same range of initial (pH 6.6) and final (pH 8.5 ± 0.3) pH values, which supports the current findings.

Table 1. Physicochemical properties of raw materials, initial feedstock mixture, and final compost.

Parameters	Vegetable waste	Rice husk	Chicken manure	Feedstock mixture	Compost
MC, % WM	93 ± 2	12 ± 1	8 ± 2	72 ± 8	62 ± 1
pH	5.1 ± 0.1	6.7 ± 0.1	8.2 ± 0.2	6.6 ± 0.1	7.6 ± 0.1
EC, mS/cm	9.23 ± 0.50	0.41±0.50	2.27 ± 0.52	1.65 ± 0.50	0.18 ± 0.40
TOC, % DM	48 ± 1	53 ± 2	48 ± 1	53 ± 1	45 ± 2
LOI, % DM	26 ± 1	29 ± 2	26 ± 1	29 ± 1	25 ± 2
N, % DM	1.60 ± 0.05	0.54± 0.05	2.15 ± 0.05	0.45±0.02	0.58 ± 0.02
P, % DM	0.10 ± 0.05	0.15 ± 0.05	2.99 ± 0.05	0.18±0.01	0.04 ± 0.02
K, % DM	0.17 ± 0.05	0.14 ± 0.05	1.10 ± 0.05	0.15±0.04	0.17 ± 0.04
C/N, DM	30 ± 1	99 ± 1	22 ± 2	117±4	77 ± 28
WD, % WM	2.75 ± 0.07	0.76 ± 0.50	.75 ± 1.05	1.06±1.00	2.23 ± 0.23
DD,% DM	.41 ± 0.10	0.71 ± 0.12	1.65 ± 0.34	0.50±0.10	1.32 ± 0.33
OM loss, %	NA	NA	NA	NA	12 ± 2

Abbreviation: Mean value, ±=Standard deviation from replicate measurements; MC=Moisture content, DM=Dry matter; EC=Electrical conductivity: TOC=Total organic matter: OM=Organic matter; N=Nitrogen: P=Phosphorus; K=Potassium: C/N=Carbon-to-nitrogen ratio: WD=Wet density: WM=Wet matter: DD=Dry density: NA=Not available.

After composting for 30 days, the EC profiles exhibit an increased trend, from 1.7 mS/cm to 1.8 mS/cm. It was reported by Li et al. (2023) that < 3.0 mS/cm indicates compost is non-toxic to crops. Organic matter (OM) loss findings demonstrate trends for the organic matter reduction value, as shown in Table 1. In this study, the initial C/N ratio was 117 ± 4 and decreased to 94 ± 28, showing a similar trend to Murimi and Gbedemah (2018) study, where they started composting with a C/N of 115 and decreased to 107 after 84 days of composting. The CM used at 2.5% might contribute to a lower nitrogen percentage at the end of composting. The lower nitrogen content in this study might

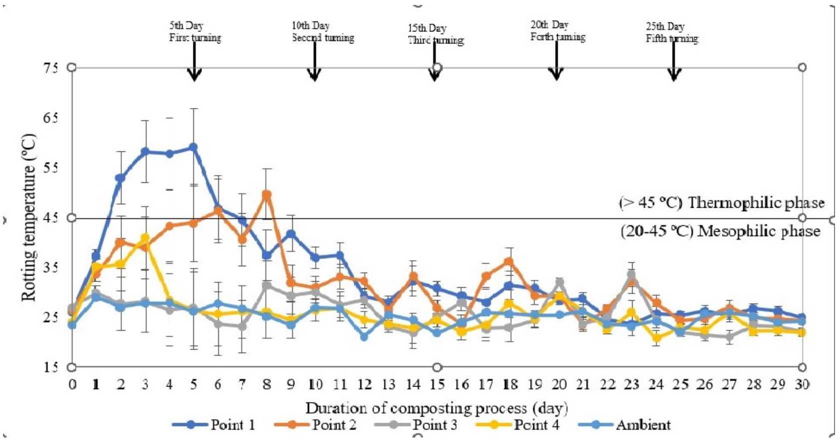

Figure 2. Temperature profile during pilot-scale composting for 30 days.

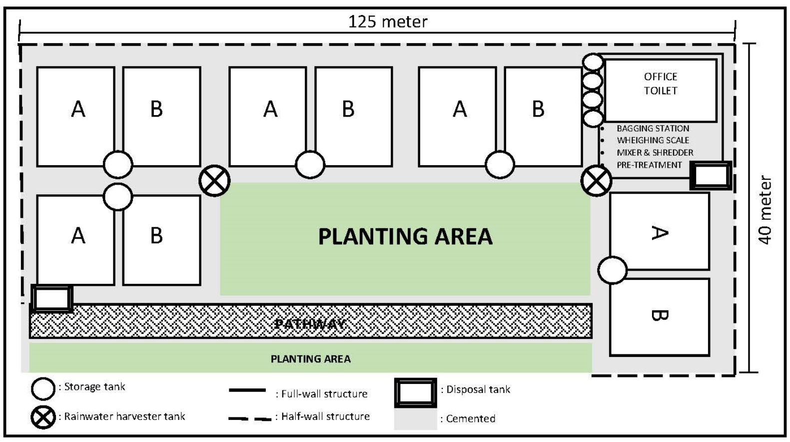

Figure 3. Plant layout for the composting system on KCCS.

Table 2. Comparison of physiochemical characteristics for vegetable waste composting.

Feedstock (%)			Type of composter	Volume (m^3)	Mode of aeration	Turning frequency	Composting duration	OM loss (%)[a]	Max temp(° C)	MC (%)[b]	Nutrient (%)[a] N	P	K	WD (g/cm^3)[b]	DD (g/cm^3)[a]	Ref
VW (65)	Rice husk (32.5)	Chicken (2.5)	C	1.5	Passive	Every 5 days	30 Days	12	Day 2 (59°)	62	0.6	0.1	0.2	2.2	1.3	**This study**
VW (76.9)	Leaves (15.4)	Horse dung (7.7)	C	0.3	Active	Daily	21 Days	30	Day 2 (40°)	81	2	1	2	NA	NA	(Dayananda and Shilpa, 2020)
VW (35)	Rice straw(1)	Chicken manure(55)	C	2.2	Active	NA	22 Hour	NA	Hour (66°)	46	NA	NA	NA	NA	NA	(Ajmal et al., 2020)
VW (33.4)	Rice husk(33.3)	Chicken manure(33.3)	NC	3.0	Passive	Every 3 days	95 Days	24	Day27 (70°)	58	1.7	0.4	3	NA	NA	(Tratsch et al., 2019)
VW (30)	Rice husk(10)	Chicken manure(60)	C	2.2	Active	NA	22 Hour	NA	18Hour (75°)	44	NA	NA	NA	NA	NA	(Bian et al., 2019)
VW (75.2)	Leaves (17.3)	Carton (7.5)	C	0.1	Passive	Every 14 days	50 Days	28	Day 3 (60°)	63	NA	NA	NA	NA	NA	(Rawoteea et al., 2017)
VW (47)	Sawdust (26.5)	Sludge (26.5)	C	0.2	Active	Every 2 days	20 Days	NA	NA (60°)	50	NA	NA	NA	NA	NA	(Arslan et al., 2016)
VW (12.5)	Rice straw and hull(54.2)	Soil (33.3)	C	2.8	Active	Every 3 days	50 Days	28	Day 3 (70°)	65	NA	NA	NA	NA	NA	(Zhang et al., 2014)
VW (66.7)	Sawdust (13.3)	Chicken manure(20)	C	2.3	Passive	Daily	20 Days	28	Day 2 (60°)	45	2.4	1.3	1.4	NA	NA	(Bhatia et al., 2012)
VW	Rice	Enzyme	C	0.1	Active	Daily	9 Days	47	Day 3	18	1.1	NA	NA	NA	NA	(Murugesan and Amarnath, 2020)

Abbreviation: OM=Organic matter; Max temp=Maximum temperature; C=Composter; NC=Non-composter; In=Initial; Fin=Final; EC=Electrical conductivity; MC=Moisture content, a=Dry matter (DM) weight basis; b=Wet matter (WM) weight basis; WD=Wet density; DD=Dry density; VW=Vegetable waste; Ref=Reference; NA= Not available be due to the low CM application in the initial compost formulation.

Total phosphorus (on a DM basis) was observed in the study at 0.04 ± 0.02 %, a decrease from the initial (Table 2) value of 0.18 ± 0.01%. The final compost potassium concentration was 0.17 ± 0.04% (on a DM basis). Low phosphorus and potassium levels in the final compost might be due to leaching (Mengqi et al., 2021), and leaching happens during the first 5 days with 40 (± 5) liters of leachate per 850 kg of waste on a wet matter basis. The concentration of NPK in this research is summarized as 0.58% (± 0.1), 0.04% (± 0.02), and 0.17% (± 0.04) (on a DM basis). It is generally desirable to have nutrient-rich compost; however, supplementary nutrients such as CM can be added at the final stage in order to enhance nutrient availability (Kumari et al., 2022). Although compost produced has a low nutrient content, it can be resourceful as the seed starter used for composting also reduces synthetic fertilizer usage, aligning with Kundasang's sustainable waste management and agricultural goals.

Assessment on techno-economic

This section presents valuable information on the feasibility of the composting plant for processing vegetable waste as feedstock at the Kundasang Community Composting Site (KCCS). The findings from the pilot-scale study on the composting process offer understanding and facilitate the ability to take actions for the construction of the composting facility based on actual circumstances. The effectiveness of the composting process at KCCS must be investigated. Depending on the location, output volume, and technology employed, the economic viability of the composting system varies greatly.

The composter designed for KCCS includes two distinct types of composter designs. Each composter type has a volume of 3.4 m^3 with a dimension of 1.5 m × 1.5 m × 1.5 m and costs MYR 3, 250 per composter. The composting system will use the optimum mixture ratio determined from our previous study (Murshid et al., 2022a; Murshid et al., 2021) and operational techniques adopted in other studies (Ma et al., 2022), where there will be turning every five days.

The feedstocks mixed with a vegetable waste-to-rice husk-to-chicken manure weight ratio of 2:1:0.03 resulted in an initial moisture level of 72% WM. Each cycle of the composting process has a 30-day detention time. 1,000 kg of feedstock total are used by each composter. The vegetable waste will be collected from the Kundasang Fresh Market. Locals paddy farmers in Kundasang will collect and transport the rice husk to KCCS. VW is provided without charge, excluding collection and delivery to the composting facility. For rice husk, it costs around MYR 1.50, and chicken manure costs around MYR 0.50 for 1 kg, respectively, including transportation to KCCS. According to the results, it was estimated that 40% of the initial feedstock weight was made up of the biodegraded compost (¡ 15 mm) produced, in which around 53,800 kg of compost per year are expected, with 160 kg for usage at a planting site of $9m^2$ as an eco-tourism attraction.

The proposed design for the composting system is shown in Fig. 1, and the plant layout is shown in Fig. 3. The composting plant includes a station to separate waste from foreign objects, a machine to shred vegetables, a mixer, a measuring station, a packing station to package the compost, a storage facility to keep the compost produced, an office, and a planting site. As the VW will be delivered daily and processed directly, other materials (RH or CM) can be stored in a storage tank located near the pre-treatment area. With a total area of 125 m × 40 m that is all cemented (except the planting area), it is convenient to have pathways for internal transport for the whole process. 10 sets of composters can accommodate vegetable waste processing in the KKCS area. This composting facility needs an estimated total area of 5,000 m^2.

The economic analysis for the composting system at Kundasang Community Composting Site (KCCS) is shown in Table 3. For a 5,000 m^2 area of the composting plant, a total plant investment of MYR 180,000 is required for site preparation, which includes the construction of all composters, offices, and planting areas. The total initial investment, including 10% contingencies, is MYR 16,000. The annual operational cost of the composting system at KCCS will be around MYR 74,000 which includes wages, maintenance, raw materials, compost analysis, utilities, and other expenses. 10% of overall maintenance costs are expected to be spent on other expenses.

The compost produced will be used for fertilizing, replacing costly chemical fertilizer to be utilized around the planting area, and extra compost can be sold for MYR 2.50 per kilogram. Notably, the compost manufacturer may sell the product at a higher price to make a profit. In this case, the use of compost is the main focus in order to improve sustainable waste management at KCCS and the surrounding area and lessen the reliance on chemical fertilizers.

However, the leachate produced by composting can be environmentally hazardous because it contains a high organic load and cannot be stored in the composting plant. Due to the high concentration of dissolved nutrients in leachate, which makes the treatment procedure expensive for a low-value technology like composting, leachate is often released into the nearby wastewater treatment facility. The leachate can be repurposed as a moistener for rotting material during the intensive degradation phase, where huge losses of water occur, or as a bio-fertilizer for planting.

With the capital cost normalized on a 20-year basis, the annual total cost and revenue were determined (Bong et al., 2017). The KCCS composting system is economically viable, as shown by the benefit-to-cost ratio of 1.82. Also, the benefit-to-cost ratio value is better than 1, which suggests that executing the composting process has more advantages than disadvantages (Rahman et al., 2020). The minimum payback period for the suggested composting system is 5 years. The composting system generates an estimated annual revenue of MYR 25,000. To produce 1 kilogram of compost, the cost is around MYR 1.05. In order to account for differences from the cost estimate, additional expenses known as contingency charges are added to the project budget. All cost projections are speculative, and

Table 3. Costing estimation analysis for the composting system in KCCS.

Item	Unit	Unit price(MYR)	Total price(MYR)
(A) Capital cost			
Site construction	5	19,500.00	97,500.00
Office & toilet construction	2	2,500.00	5,000.00
Fencing & pathway	1	7,000.00	7,000.00
Piping & wiring	1	2,000.00	2,000.00
Photovoltaic panels with power storage	4	1,500.00	6,000.00
Composter - 10 set	10	3,250.00	32,500.00
Shredder & mixer	2	1,950.00	3,900.00
Storage box	7	1,040.00	7,280.00
Weighing scale	1	500.00	500.00
Planting stand & shedding	1	1,500.00	1,500.00
Auxiliary	1	300.00	300.00
Contingencies (10%)		10%	16,348.00
Total (A)			*MYR 179,828.00*
(B) Operational Cost (Yearly)			
1. Labor			
General worker	12	1,500.00	18,000.00
Labor (2 laborer/cycle)	9	1,000.00	9,000.00
Machinery maintenance and fuel consumption	9	50.00	450.00
Compost analysis	32	150.00	4,800.00
2. Raw material			
Rice husk (MYR 1.50/kg)	14, 040	1.50	21,060.00
Chicken manure (MYR 0.50/KG)	1, 728	0.50	864.00
Vegetable waste transportation	9	100.00	900.00
Bagging	12	1,000.00	12,000.00
3. Miscellaneous cost			
Miscellaneous cost (10% of maintenance cost)		10%	45.00
Contingencies (10%)		10%	6,711.90
Total (B)			*MYR 73,830.90*
(C) Cash inflow per year			
Sell excess compost (MYR 2.50/kg)	53, 800	2.50	134,500.00
Total ©			*MYR 134,500.00*
Production cost	**MYR/kg**		**1.02**
Final costing and minimal return year			
Total investment (Normalized for 20 years)			*MYR 35,965.60*
Total cost per year			*MYR 73,830.90*
Total cost per year			*MYR 134,500.00*
Annual total profit			*MYR 24,703.50*

unless installation is properly completed, it is impossible to determine the total installed cost of any component.

Vegetable waste in Kundasang might be effectively diverted from landfills with the proper composting system in place as part of the management of biogenous waste. The use of compost in the KKCS could save the annual allocation budget used to purchase compost for landscaping purposes in the surrounding area. Furthermore, biofertilizers manufactured from vegetable waste can be utilized as soil remediation to lessen the consumption of artificial fertilizers, enhance soil quality, and clean up contaminated soils, which will raise agricultural output (Shafique et al., 2021).

The proposed plan for the KKCS design plant (Fig. 3) to be sustainable starts with the selection of location, which is beneficial for transportation distance, local ecosystems, and energy use. KKCS optimized on-site electrical energy by integrating solar energy with photovoltaic panels (PV) on the roof to harvest solar power and supply it throughout the facility. The surrounding walls for the building structure (except the composters and office) themselves help in reducing annual energy consumption by having half-open walls that favor the composting process as it demands natural ventilation throughout the process. Besides, having a budget allocated yearly (Table 3) to do maintenance on the machines enables employees to work faster and reduces manual and repetitive tasks that increase both efficiency and overall productivity. Furthermore, the planting area lowers the ambient temperature, which increases the efficiency of PV on the roof while also increasing employee productivity and profitability. Thus, sustainable buildings, such as KCCS, not only reduce pollution that may occur by composting, but they can also result in significant economic savings by increasing employee productivity and lowering energy, maintenance, and operational costs. In the future, the investigation of optimization of composting conditioners, development of all kinds of microorganisms, rational management of the composting process, and improvement of solid waste life cycle assessment Xu et al. (2021) should be assessed.

4. Conclusion

The vegetable waste composting process was demonstrated using a pilot-scale composter at KCCS using a total feedstock mixture of 769 ± 2 kg (weight on a wet basis), comprising 500 ± 2 kg of VW, 250 ± 2 kg of RH, and 19 ± 1 kg of CM. The final compost N, P, and K were 0.58% DM (± 0.10), 0.04% DM (± 0.02), and 0.17% DM (± 0.04), respectively. This pioneering pilot-scale study suggests a feasible and environmentally friendly approach to managing vegetable waste generated in Kundasang, Sabah. This study also proposed rural management of vegetable waste generated by agriculture activities in Kundasang. In the community, composting is proposed as a waste management method because it has a lower carbon footprint than alternative waste disposal options like landfills or incinerators, ensures economic sustainability, and considers the possibility of producing compost that will be valued by the market. Meanwhile, a community's amount of information and understanding has a significant impact on social acceptance. Based on the economic analysis, the composting system using passive aerated composters symbolizes technology for rural development that is economically feasible to build at Kundasang Community Composting Site (KCCS) and could possibly generate a profit of MYR 25,000 (USD 6,000) per year.

Acknowledgment
This study was supported by grant numbers SDK0102-2019; and DLV2302 from Universiti Malaysia Sabah, Malaysia.

Author contribution
The authors confirm the study conception and design: AZ Yaser, M Taliban, and N Murshid; data collection: N Murshid; analysis and interpretation of results: N Murshid, AZ Yaser, and J Lamaming; draft manuscript preparation: N Murshid, J Lamaming, S Saalah, M Rajin, and AZ Yaser. All authors evaluated the results and approved the final version of the manuscript.

Conflict of interest statement
The authors declare that they are no conflict of interest associated with this study.

References

Ajaweed AN, Hassan FM, Hyder NH (2022) Evaluation of physio-chemical characteristics of bio fertilizer produced from organic solid waste using composting bins. *Sustainability* 14(8):4–15. https://doi.org/10.3390/su14084738

Ajmal M, Aiping S, Awais M, Ullah MS, Saeed R, Uddin S, Ahmad I, Zhou B, Zihao X (2020) Optimization of pilot-scale in-vessel composting process for various agricultural wastes on elevated temperature by using Taguchi technique and compost quality assessment. *Process Saf Environ Protection* 140:34–45. https://doi.org/10.1016/j.psep.2020.05.001

Amrit LM, Minakshi K, Debashis D (2021) Composting: Phases and factors responsible for efficient and improved composting. *J Agri Food* 3(1):85–90. https://doi.org/10.13140/RG.2.2.13546.95689

Arbab KMA, Mubarak AR (2016) Characterization of compost as affected by manipulation of C/N ratio. *Agric Sci Digest* 35 (1): 44–47. https://doi.org/10.18805/asd.v35i1.9309

Arslan TEI, Ünlü A, Topal M (2016) Determination of the effect of C/N ratio on composting of vegetable-fruit wastes. *Int J Environ Waste Manage* 18(2):181–194. https://doi.org/10.1504/IJEWM.2016.080405

Bari QH, Koenig A (2001) Effect of air recirculation and reuse on composting of organic solid waste. *Resour Conserv Recycl* 33 (2): 93–111. https://doi.org/10.1016/S0921-3449(01)00076-3

Bernal MP, Alburquerque JA, Moral R (2009) Composting of animal manures and chemical criteria for compost maturity assessment. A review. *Bioresour Technol* 100 (22): 5444–5453. https://doi.org/10.1016/j.biortech.2008.11.027

Bernal MP, Paredes C, Sánchez-Monedero MA, Cegarra J (1998) Maturity and stability parameters of composts prepared with a wide range of organic wastes. *Bioresour Techno* 63 (1): 91–99. https://doi.org/10.1016/S0960-8524(97)00084-9

Bhatia A, Ali M, Sahoo J, Madan S, Pathania R, Ahmed N, Kazmi AA (2012) Microbial diversity during rotary drum and windrow pile composting. *J Basic Microbiol* 52(1):5–15. https://doi.org/10.1002/jobm.201100077

Bian B, Hu X, Zhang S, Lv C, Yang Z, Yang W, Zhang L (2019) Pilot-scale composting of typical multiple agricultural wastes:Parameter optimization and mechanisms. *Bioresour Technol* 287:121482. https://doi.org/10.1016/j.biortech.2019.121482

Bong CPC, Goh RKY, Lim JS, Ho WS, Lee CT, Hashim H, Mansor NN Abu, Ho CS, Ramli AR, Takeshi F (2017) Towards low carbon society in Iskandar Malaysia: Implementation and feasibility of community organic waste composting. *J Environ Manage* 203:679–687. https://doi.org/10.1016/j.jenvman.2016.05.033

Boni A De, Melucci FM, Acciani C, Roma R (2022) Community composting:A multidisciplinary evaluation of an inclusive, participative, and eco-friendly approach to biowaste management. *Clean Environ Syst* 6:100092. https://doi.org/10.1016/J.CESYS.2022.100092

Dayananda S, Shilpa S (2020) Vertical in-vessel composter for stabilization of market vegetable waste. *Int J Eng Adv Technol* 9(3):2249–8958. https://doi.org/10.35940/ijeat.C4906.029320

Dias BO, Silva CA, Higashikawa FS, Roig A, Sánchez-Monedero MA (2010) Use of biochar as bulking agent for the composting of poultry manure: Effect on organic matter degradation and humification. *Bioresour Technol* 101(4):1239–1246. https://doi.org/10.1016/j.biortech.2009.09.024

Díaz MJ, Madejón E, López F, López R, Cabrera F (2002) Composting of vinasse and cotton gin waste by using two different systems. *Resour Conserv Recycl* 34(4):235–248. https://doi.org/10.1016/S0921-3449(01)00109-4

Eizlan A, Aziz Abd H, Ahmad S (2022) Characterization of silica from Pasir Puteh, Kelantan rice husk for water filter application. *Mecha Manuf Eng* 3(1):915–920.

Finore I, Feola A, Russo L, Cattaneo A, Donato DP, Nicolaus B, Poli A, Romano I (2023) Thermophilic bacteria and their thermozymes in composting processes: a review. *Chem Biol Technol Agric* 10(1):1–22. https://doi.org/10.1186/S40538-023-00381-Z/TABLES/7

Gao M, Li B, Yu A, Liang F, Yang L, Sun Y (2010) The effect of aeration rate on forced-aeration composting of chicken manure and sawdust. *Bioresour Technol* 101(6):1899–1903. https://doi.org/10.1016/j.biortech.2009.10.027

Ghinea C, Leahu A (2020) Monitoring of fruit and vegetable waste composting process: Relationship between microorganisms and physico-chemical parameters. *Processes* 8(3):302. https://doi.org/10.3390/pr8030302

Hackett GAR, Easton CA, Duff SJB (1999) Composting of pulp and paper mill fly ash with wastewater treatment sludge. *Bioresour Technol* 70 (3): 217–224. https://doi.org/10.1016/S0960-8524(99)00048-6

Jamaludin H, Elmaky HSE, Sulaiman S (2022) The future of food waste: Application of circular economy. *Energy Nexus* 7:100098. https://doi.org/10.1016/J.NEXUS.2022.100098

JS Lim Z Abdul Manan, Alwi SR Wan, Hashim H (2012) A review on utilisation of biomass from rice industry as a source of renewable energy. *Renew Sustain Energy Rev* 16(5):3084–3094. https://doi.org/10.1016/j.rser.2012.02.051

Kumari S, Manyapu V, Kumar R (2022) Recent advances in composting and vermicomposting techniques in the cold region: resource recovery, challenges, and way forward. *Advanced Organic Waste Management: Sustainable Practices and Approaches,* 131–154. https://doi.org/10.1016/B978-0-323-85792-5.00005-8

Li D, Yuan J, Ding J, Wang H, Shen Y, Li G (2022) Effects of carbon/nitrogen ratio and aeration rate on the sheep manure composting process and associated gaseous emissions. *J Environ Manag* 323:116093. https://doi.org/10.1016/J.JENVMAN.2022.116093

Li MX, He XS, Tang J, Li X, Zhao R, Tao YQ, Wang C, Qiu ZP (2021) Influence of moisture content on chicken manure stabilization during microbial agent-enhanced composting. *Chemosphere* 264:128549. https://doi.org/10.1016/j.chemosphere.2020.128549

Li Y, Xu S, Chen Y, Zhang X, Xie X (2023) Effects of aeration rate on the cornstalks used for filtration of anaerobically digested manure centrate direct composting process: Maturity and gas emissions. *Environ Technol Innov* 32:103305. https://doi.org/10.1016/J.ETI.2023.103305

Lin YP, Huang GH, Lu HW, He L (2008) A simulation-aided factorial analysis approach for characterizing interactive effects of system factors on composting processes. *Sci Total Environ* 402(2–3):268–277. https://doi.org/10.1016/j.scitotenv.2008.04.056

López MJ, Elorrieta MA, Vargas-García MC, Suárez-Estrella F, Moreno J (2002) The effect of aeration on the biotransformation of lignocellulosic wastes by white-rot fungi. *Bioresour Technol* 81(2):123–129. https://doi.org/10.1016/S0960-8524(01)00112-2

Ma Q, Li Y, Xue J, Cheng D, Li Z (2022) Effects of turning frequency on ammonia emission during the composting of chicken manure and soybean straw. *Molecules* 27(2):1–21. https://doi.org/10.3390/molecules27020472

Mengqi Z, Shi A, Ajmal M, Ye L, Awais M (2021) Comprehensive review on agricultural waste utilization and high-temperature fermentation and composting. *Biomass Convers Biorefin,* 1–24. https://doi.org/10.1007/S13399-021-01438-5

Mishra SK, Yadav KD (2022) Assessment of the effect of particle size and selected physico-chemical and biological parameters on the efficiency and quality of composting of garden waste. *J Environ Chem Eng* 10(3):107925. https://doi.org/10.1016/j.jece.2022.107925

Murimi SM, Gbedemah SF (2018) Suitability of rice husk and chicken droppings as organic fertilizer for sustainable agriculture in Ghana. *JEIADC* 10(2):63–78.

Murshid N, Yaser AZ, Rajin M, Saalah S, Lamaming J (2022a) Vegetable waste composting: Effect of rice husk and chicken manure addition *The 1 St MYSUN National Conference* 62

Murshid N, Yaser AZ, Rajin M, Saalah S, Lamaming J, Taliban M (2021) Vegetable waste composting: Effect of chicken manure addition. *E-Symposium on Green Transformation of Agro Wastes(E-SGTAW, 2021)* 34

——— (2022b) Vegetable waste composting:A case study in Kundasang, Sabah. *J Sci Technol* 43:1–16.

Murugesan V, Amarnath DJ (2020) Bio-process performance, evaluation of enzyme and non-enzyme mediated composting of vegetable market complex waste. *Sci Rep* 10(1):1–12. https://doi.org/10.1038/s41598-020-75766-3

Nadhirah I, Zain M, Rahman HA (2021) Empowering youth and community wellbeing for sustainable development. *Int J Acad Res* 1(15):61–76. https://doi.org/10.6007/IJARBSS/v11-i15/10635

Ogunwande GA, Osunade JA, Adekalu KO, Ogunjimi LAO (2008) Nitrogen loss in chicken litter compost as affected by carbon to nitrogen ratio and turning frequency. *Bioresour Technol* 99 (16): 7495–7503. https://doi.org/10.1016/j.biortech.2008.02.020

Oviedo-Ocana R, Fernando MRL, Torres-Lozada P, Daza M, Andrade M, Torres-López WA, Abonia-Gonzalez R (2015) Effect of adding bulking materials over the composting process of municipal solid biowastes. *Chile J Agric Res* 75 (4): 1. https://doi.org/10.4067/S0718-58392015000500013

Peng L, Tang R, Wang G, Ma R, Li Y, Li G, Yuan J (2023) Effect of aeration rate, aeration pattern, and turning frequency on maturity and gaseous emissions during kitchen waste composting. *Environ Technol Innov* 29:102997. https://doi.org/10.1016/J.ETI.2022.102997

Rahman MHA, Sadi T, Athirah A, Alyani N, Abhar M, Hamid A, Abu R (2020) Inventory and composting of yard waste in Serdang, Selangor, Malaysia. *Heliyon* 6:e04486. https://doi.org/10.1016/j.heliyon.2020.e04486

Rasapoor M, Adl M, Pourazizi B (2016) Comparative evaluation of aeration methods for municipal solid waste composting from the perspective of resource management: A practical case study in Tehran, Iran. *Environ Manage* 184:528–534. https://doi.org/10.1016/J.JENVMAN.2016.10.029

Rawoteea SA, Mudhoo A, Kumar S (2017) Co-composting of vegetable wastes and carton: Effect of carton composition and parameter variations. *Bioresour Technol* 227:171–178. https://doi.org/10.1016/j.biortech.2016.12.019

Resmi G, Vinod V (2022) Development and fabrication of a portable shredding machine for rapid composting of organic waste. *Nat Environ Pollut Technol* 21(1):275–281. https://doi.org/10.46488/NEPT.2022.v21i01.032

Saalah S, Rajin M, Yaser AZ, Azmi NASA, Mohammad AFF (2019) Foodwaste composting at faculty of engineering, Universiti Malaysia Sabah. *Green Eng Campus Sustain,* 173–191. https://doi.org/10.1007/978-981-13-7260-5_13

Sarika D, Singh J, Prasad R, Vishan I, Varma VS, Kalamdhad AS (2014) Study of physico-chemical and biochemical parameters during rotary drum composting of water hyacinth. *Int J Recycl Org Waste Agric* 3 (3): 9. https://doi.org/10.1007/s40093-014-0063-1

Shafique I, Andleeb S, Aftab MS, Naeem F, Ali S, Yahya S, Ahmed F, et al. (2021) Efficiency of cow dung based vermi-compost on seed germination and plant growth parameters of Tagetes erectus (Marigold). *Heliyon* 7(1):10.1016/j.heliyon.2020.e05895.

Shimizu N, Karyadi JN, Harano M, Iwabuchi K, Kimura T (2018) Cattle manure composting in a packed-bed reactor with forced aeration strategy. *Engineer Agricul Environ Food* 11 (2): 65–73. https://doi.org/10.1016/j.eaef.2018.01.002

Sokač T, Valinger D, Benković M, Jurina T, Kljusurić JG, Redovniković IR, Tušek AJ (2022) Application of optimization and modeling for the composting process enhancement. *Processes* 10(2):229. https://doi.org/10.3390/PR10020229

Then YH, Lai JC, Then YL (2021) Study of forced aeration system for fruit and vegetable waste composting. *IOP Conf. Ser. Mater. Sci. Eng.* 1195 (1): 012059. https://doi.org/10.1088/1757-899x/1195/1/012059

Tiquia SM, Tam NFY (1998) Composting of spent pig litter in turned and forced-aerated piles. *Environ Pollut* 99 (3): 329–337. https://doi.org/10.1016/S0269-7491(98)00024-4

Tiquia SM, Tam NFYN (2000) Fate of nitrogen during composting of chicken litter. *Environ Pollut* 110:535–541. https://doi.org/10.1016/S0269-7491(99)00319-X

Torrijos V, Dopico D Calvo, Soto M (2021) Integration of food waste composting and vegetable gardens in a university campus. *J Clean Prod* 315:1. https://doi.org/10.1016/j.jclepro.2021.128175

Tratsch MVM, Ceretta CA, Souza DSL, Ademar P, Ferreira A, Brunetto G (2019) Composition and mineralization of organic compost derived from composting of fruit and vegetable waste. *Rev Ceres* 66(4):307–315. https://doi.org/10.1590/0034-737X201966040009

Xu M, Yang M, Xie D, Ni J, Meng J, Wang Q, Gao M, Wu C (2021) Research trend analysis of composting based on Web of Science database. *Environ. Sci. Pollut* 28(42):59528–59541. https://doi.org/10.1007/s11356-021-16377-x

Yaser AZ, Lamaming J, Suali E, Rajin M, Saalah S, Kamin Z, Safie NN, Aqeela NAS, Wid N (2022) Composting and anaerobic digestion of food waste and sewage sludge for campus sustainability:A review. *Int J Chem Eng* 2002:6455889. https://doi.org/10.1155/2022/6455889

Zayadi RA (2021) Current Outlook of livestock industry in Malaysia and ways towards sustainability. *J Sustain Natural Resour* 2(2):1–11.

Zhang J, Xu X, Lv Y, Zhu W, Zhang H, Ding J, Zhang X, Zhu J, Ding Y (2022) Research progress on influencing factors on compost maturity and cyanobacteria toxin degradation during aerobic cyanobacteria composting: A review. *Environ Sci Pollut* 29(47):70635–70657. https://doi.org/10.1007/s11356-022-21977-2

Zhang J, Zeng G, Chen Y, Liang J, Zhang C, Huang B, Sun W, et al. (2014) Phanerochaete chrysosporium inoculation shapes the indigenous fungal communities during agricultural waste composting. *Biodegradation* 25(5):669–680. https://doi.org/10.1007/s10532-014-9690-5