The OCEM Journal of
Management, Technology & Social Sciences

Received: Nov 20, 2025 | Revised: Nov 29, 2025 | Accepted: Dec 15, 2025 | Published: Jan 10, 2026

DOI: 10.3126/ocemjmtss.v5i1.89700 Paper Type: Research Article

Low-Cost Composting for Organic Waste Management in Urban Areas: A Systematic Review

Tulsi Mandal Dhanuk[1], Rajib Pokhrel[2]*
[1]School of Engineering, Pokhara University, Nepal
[2]Pokhara University, Nepal
*Corresponding email: rajibp@pu.edu.np

Volume 5, Issue 1

ISSN Print:2705-4845

ISSN Online:2705-4845

Abstract

This study explores low-cost composting methods for organic waste management in urban areas, specifically Windrow composting, Takakura composting, and Vermicomposting. While many studies discuss general composting, few reviews have comparatively analyzed the technical, economic, and environmental feasibility of these specific methods for the developing cities. A systematic literature review was con- ducted using the Scopus, Google Scholar, Science Direct, and Research Gate databases for the period 2015–2025, with the keywords: "low-cost composting," "windrow composting," "takakura composting," and "vermicomposting." Results indicate that while Windrow composting is well-suited for large-scale municipal operations, it requires a larger processing time (45-90 days) and significant land buffers to mitigate greenhouse gas emissions.

In contrast, Takakura composting is most suitable for high-density urban settings, offering a rapid 10-14 days decomposition period, 40-50% waste volume reduction, and emission reductions up to 132 tCO_2-eq/day in city-wise applications. Vermicomposting produces the highest economic value product (approx. $85/tonne or 10,000 BDT/Mt) but is constrained by strict temperature requirements (18-30°C) and longer duration (45-60 days). Ultimately, this review concludes that Takakura composting is the most viable solution for space-constrained households due to its speed and compactness. A hybrid approach–integrating Takakura bins with centralized Windrow facilities–can be used to maximize urban waste diversion and environmental sustainability. Further research on integrated approaches is recommended to maximize the benefits of these composting techniques in urban settings.

Keywords: *low-cost composting, organic waste management, Takakura composting, vermicomposting, windrow composting*

How to cite this paper:
Dhanuk, T.M., & Pokhrel, R. (2026). Low-Cost Composting for Organic Waste Management in Urban Areas: A Systematic Review. *The OCEM Journal of Management, Technology & Social Sciences*, *5*(1), 179-195.

Introduction

Urbanization has been a defining global trend since the Industrial Revolution, leading to the expansion and increased density of cities, particularly in developing countries. Population growth, modern lifestyles, and associated urbanization have greatly accelerated waste generation. In 2016 alone, over 2 billion tonnes of solid waste were generated globally (Nuzir et al., 2019; Sayara et al., 2020). More than half of this municipal solid waste (MSW) is organic in nature (Cotler, Marquez & Jimenez, 2025).

This organic fraction includes food and kitchen waste, crop residues, gar- den trimmings, animal manure, and other biodegradable wastes (Manea et al., 2024; Wei et al., 2021), originating primarily from households, businesses, and garden sources (Geethamani et al., 2021; Siqueira & Assad, 2015). Waste composition varies significantly with income level.

High-income countries generate approximately 32% organic waste, whereas middle- and low-income countries produce 53% and 56%, respectively. In Asian countries, MSW generation is currently estimated at 1 million tonnes per day (Mt/day).

This figure is projected to reach 1.8 Mt/day by 2025 (Fogarassy, Hoang & Nagy-Peresi, 2022). Many developing cities still rely on land- filling, incineration, or open dumping, despite these methods having low energy recovery rates and high costs (Nuzir et al., 2019; Wei et al., 2021). Such practices contribute to the degradation in quality of air, soil, and water reduce the lifespan of landfills (Fogarassy et al., 2022).

Improperly managed MSW poses a direct threat to public health and the environment due to heavy metal contamination, methane emissions, and leachate runoff (Manea et al., 2024). In urban contexts, adopting low-cost, appropriate waste management strategies is urgent for achieving sustainable solutions (Sayara et al., 2020).

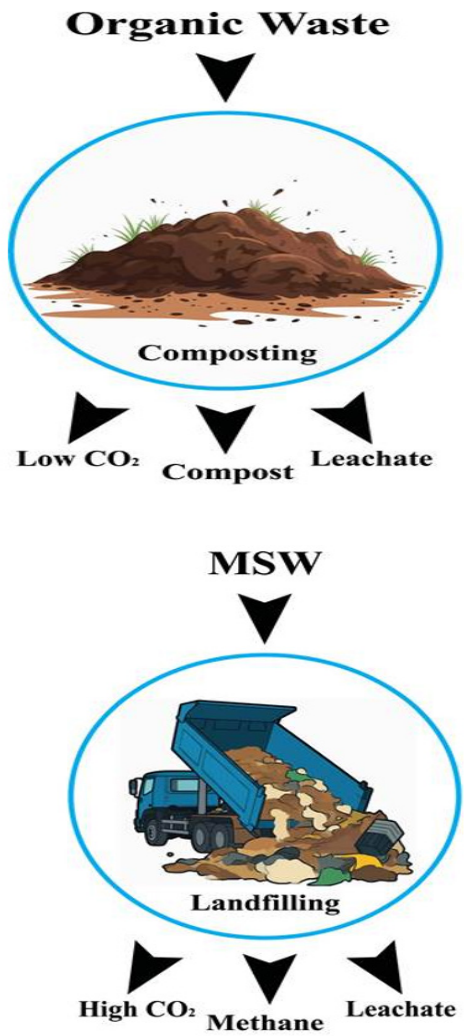

Figure 1. Composting vs landfilling of urban waste (adapted from Hoornweg et al., 1999)

Composting is a proven environmental technology that transforms organic waste into humus-rich fertilizer, thereby closing material loops and reducing reliance on landfills. As an aerobic process, it biologically decomposes organic matter into safe compost that improves soil fertility and supports plant growth (Manea et al., 2024; Wei et al., 2021). Cities are significantly adopting composting over conventional methods because it reduces waste volume by 40–50% and cut methane (CH4) emissions (Cotler et al., 2025; Fogarassy et al., 2022). Therefore, composting organic waste is an effective, environmentally friendly, and sustainable alternative for waste management (Cotler et al., 2025; Manea et al., 2024; Wei et al., 2021). However, there is a lack of comparative literature that specifically evaluates how different low-cost composting techniques perform under the technical and operational limitations of developing cities.

Consequently, this review focuses on three specific methods: Windrow (representing centralized, aerobic turning), Takakura (representing decentralized, microbial fermentation), and Vermicomposting (representing biological, high-value nutrient recovery). These were selected to cover the spectrum of low-cost solutions applicable from household to municipal scales. The scope of this study is strictly limited to technical performance and operational feasibility, excluding policy and regulatory frameworks to ensure a focused analysis on physical implementation and economic viability.

Review Methodology

A systematic literature review was conducted to identify and evaluate low-cost composting techniques for urban organic waste management. The databases searched included Scopus, Google Scholar, Science Direct, and ResearchGate, for articles published between 2015 and 2025. The search utilized combinations of the following keywords: "Low-cost composting," "Windrow composting," "Takakura composting," and "Vermicomposting." A total of 151 documents were initially identified through database searches. After removing duplicates and screening titles for relevance, seventy full-text articles were accessed for eligibility.

Ultimately, fourty-eight studies met the inclusion criteria, distributed as follows: General Composting (11), Windrow Composting (11), Takakura Composting (13), and Vermicomposting (13). Studies were included if they focused on technical process descriptions, environmental impacts, or economic assessments of one of the three methods in urban or peri-urban contexts, and to provided quantitative or qualitative data on performance, costs, or suitability. Data were extracted on: process parameters such as (C:N ratio, moisture, temperature), environmental outcomes (greenhouse gas emissions, soil health), economic metrics (setup cost, operating cost, payback), and urban suitability factors (land requirement, scale, user acceptance). The extracted data were synthesized qualitatively and, where possible, compared side-by-side (see Table 3).

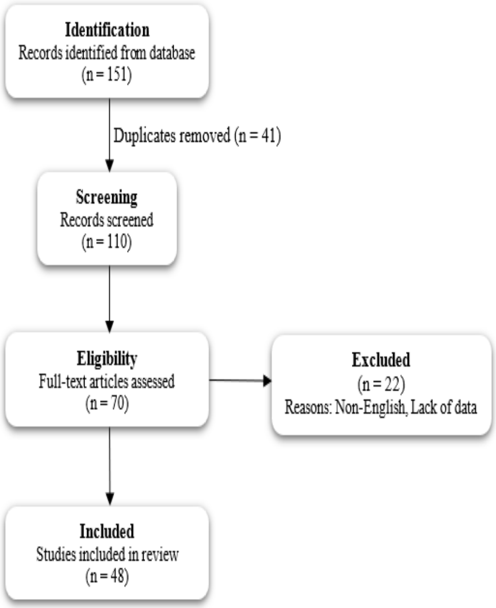

Figure 2. PRISMA flow diagram detailing the selection process of literature for low-cost urban composting

The review process was restricted to peer-reviewed articles and technical reports published in English, which may exclude relevant findings in local languages from non-English speaking developing nations. Additionally, publication bias may exist, as successful composting trials are more likely to be published than failed operational attempts. Both conference papers and case studies were included to provide practical, on the ground data often missing from theoretical journals.

Overview of Composting

Composting is a biochemical process that transforms organic materials into a stabilized, nutrient-rich compost through microbial activity (Sayara et al., 2020; Siqueira & Assad, 2015). Particularly in developing cities where space is limited, it could be a key alternative for managing organic waste effectively (Manea et al., 2024; Sayara et al., 2020). Composting reduces greenhouse gas (GHG) emissions and the volume of waste sent to landfills as well as supports a circular urban economy through compost reuse in agriculture (Cotler et al., 2025).

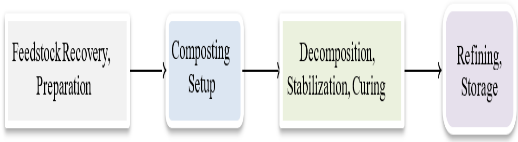

Figure 3. Typical Process Flow for Composting (adapted from Manea et al., 2024)

Aerobic and Anaerobic Composting

Composting is primarily categorized based on oxygen availability. Aerobic composting, utilizes oxygen-dependent microorganisms to rapidly decompose organic matter, generating heat (45°C to 65°C) and carbon dioxide (CO2) (Meena et al., 2021; Sayara et al., 2020). It is the preferred urban method due to faster processing and reduced odors. Anaerobic composting occurs in the absence of oxygen, producing methane and digestate (Meena et al., 2021). While useful for biogas recovery, it is less common in simple urban setups due to higher complexity and potential odor issues (Fogarassy et al., 2022).

Classification by Scale and System

Composting systems can also be classified based on their operational scale, ranging from household and community-scale systems to centralized, industrial-scale facilities.

Table 1. Classification of composting systems by scale, cost, and complexity

System	Scale	Cost	Complexity	Urban Suitability
Windrow	Municipal/ Centralized	Medium	Low-Medium	Large volumes of yard/ market waste; requires land buffers (Basheer et al.,2019)
Pit Composting	Household/ Rural	Very Low	Low	Simple backyards; impractical for paved urban zones (Dharnaik & Pol,2024; Sumiyati et al.,2020)
Vermi-composting	Household/ Community	Low-Medium	Medium	High nutrient recovery; requires temperature control (Nigussie et al.,2016)
Takakura	Household/ Neighborhood	Low	Medium	High-density residential; compact and Odor-free (Nuzir et al.,2019)
In-Vessel	Industrial	High	High	Strict Odor control areas; expensive infrastructure (Fogarassy et al.,2022)

Operational Parameters

Operational parameters guide the efficiency of composting and quality of final product where C:N ratio, moisture content, temperature, and aeration are among the most critical factors (Manea et al., 2024; Sayara et al., 2020).

C: N Ratio: Ideal range is between 25:1 to 30:1. Too low ratio can lead to nitrogen loss, while too high ratio can slow decomposition process (Geethamani et al., 2021; Sayara et al., 2020).

Moisture Content: Suitable range is around 40-70%. Moisture above 70% can create anaerobic zones, while below 40% can slow microbial activity (Manea et al., 2024; Wei et al., 2021).

Temperature: Composting progresses through mesophilic (20◦C to 45◦C) and thermophilic (45 ◦C to 65 ◦C) phases. Thermophilic temperatures are crucial for pathogen destruction and process acceleration (Manea et al., 2024; Sayara et al., 2020).

Aeration: Oxygen levels should be maintained above 5%. Deficiency leads to anaerobic conditions and odor generation (Wei et al., 2021).

Particle size also plays a key role; smaller particles decompose faster but can reduce airflow if highly compacted while coarser particles decompose slowly and are harder to handle. A mix- ture of fine and coarse materials is best suited for both microbial access and porosity (Manea et al., 2024; Meena et al., 2021). Crucially, these parameters are interdependent. For instance, excessive moisture (above 70%) fills soil pores and displaces air, effectively blocking oxygen transfer (Manea et al., 2024). This creates anaerobic pockets even in intended aerobic systems, necessitating more frequent turning or aeration to restore the balance (Wei et al., 2021). Imbalanced C: N increases heat and moisture loss (Sayara et al., 2020). Densed population density, mixed waste streams, improper management systems, weak source separation, and public resistance to odor in urban areas present unique challenges for composting (Cotler et al., 2025; Siqueira & Assad, 2015). Yet composting remains one of the most accessible, low-cost, and scalable solutions for MSW management (Manea et al., 2024). Small-scale systems such as household composting bins, community pits, and innovative methods like Takakura composting technique have succeeded across Asia and Latin America. They have been adapted to rooftops, balconies, and small sites with minimal infrastructure (Nuzir et al., 2019; Sayara et al., 2020). These methods support urban agriculture, close the nutrient loop, and reduce landfill burden and GHG emissions (Geethamani et al., 2021; Manea et al., 2024). The following section explores low-cost composting techniques tailored for developing urban areas.

Low-Cost Composting Techniques: Types and Features

Composting offers a nature-based solution to urban organic waste by reducing landfill volume and GHG emissions while enhancing soil quality. Since over 50% of municipal waste is organic and compostable, composting provides a significant opportunity for sustainable waste manage- ment. As a local, decentralized process, it supports job creation and the circular economy, with many systems operating with minimal investment. Low-cost composting methods rely on local materials and labor instead of expensive infrastructure. The resulting compost becomes a valu- able soil amendment, returning carbon and nutrients to soil and cutting disposal costs as well as methane emissions. Aligning with ‘zero waste’ principles, these approaches create green jobs and enable grassroots initiatives to convert food scraps and garden debris into resources. This section examines three such methods: Windrow, Takakura, and Vermicomposting, assessing their technical, environmental, and economic feasibility.

Windrow Composting

The practice of turning compost, maintaining moisture content, and reducing waste to smaller sizes helped maintain aerobic conditions and reduced odor and fly problems. As a result, mechanized windrow composting plants were developed, which used equipment to aerate and turn waste, regulate temperature, and moisture levels. This reduced composting duration and en- hanced efficiency (Vigneswaran, Kandasamy & Johir, 2016). Windrow composting is an outdoor system in which organic waste is arranged in long, nar-row piles (windrows). The piles are manually or mechanically turned regularly to enhance aeration and fast decomposition (Lim et al., 2017; Vigneswaran et al., 2016). It is an efficient and technically viable composting technique economically which can process high organic waste volumes when sufficient land is available (Lim et al., 2017; Pergola et al., 2020). Compared to static piles (heaps), windrows decompose faster and yield more consistent compost. In Western countries, low-tech, aerobic open-windrows have been widely adopted for managing yard and garden waste, with some municipalities expanding to large-volume industrial systems (Sabki et al., 2018; Vigneswaran et al., 2016).

Process Overview

Windrow composting is conducted on paved or compacted surfaces that include channels, drainage wells, and sometimes irrigation or electrical systems. These pads allow for leachate manage- ment and machinery access (Pergola et al., 2020). Aerobic conditions are maintained by man- ually or mechanically turning the piles, with turning frequency influencing oxygen diffusion, microbial activity, and decomposition rate (Lim et al., 2017).

Feedstock Recovery and Preparation: Waste is separated and shredded or crushed to a particle size of 5–25 mm. The C:N ratio is adjusted to 30–45:1 by adding bulking agents such as coconut hulls or sawdust. Moisture content is maintained at 60–65% by watering, and checked by the hand-squeeze method (Rashid et al., 2022; Vigneswaran et al., 2016).

Design of Windrows: The composting area is calculated based on total annual feedstock volume, window size, spacing, curing zones, and storage areas. A single windrow's vol- ume is determined using its length and cross-section. The number of windrows required can be calculated by dividing the total feedstock volume on the composting pad by the volume of a single windrow (Vigneswaran et al., 2016). Windrows can handle more than 10 tonnes of waste per day. Drainage systems and runoff ponds are designed using rain- fall data from past 30 years, and buffer zones are incorporated as safeguards (Lim et al., 2017).

Windrow Formation: In small-scale systems, waste is handled manually. For larger setups, waste is transported using trucks or lugger boxes, and added with front-end load- ers. Mechanical turners mix and move the waste on the pad. Windrows are formed by layering blended feedstock over a thin layer of bulking agent, with an optional top layer. (Pergola et al., 2020; Vigneswaran et al., 2016). According to Lim et al. (2017), compost piles should be larger than 1 m3 (L x W x H), as in Basheer et al. (2019), who used 4.5 ft x 2.5 ft x 1 ft piles with a 2 ft spacing. Vigneswaran et al. (2016) suggested a ratio of 1:1 can be used for organic waste to bulking agent for developing cities.

Figure 4. Windrow composting facility in Virginia (Coker, 2022)

Composting, Stabilization, and Curing: Microbial decomposition is supported by main- taining thermophilic temperatures (45 ◦C to 65 ◦C), measured daily at 2 m intervals for small-scale systems and 5–10 m for large-scale systems using a bi-metallic thermometer. The piles must be turned daily or every second day, depending on the temperature and watering (Vigneswaran et al., 2016). Lim et al. (2017) highlighted that regular turning and moisture control are critical for achieving thermophilic temperatures. Watering is done via trucks until compost piles reaches field capacity.

Vergara and Silver (2019) sug- gested that around 50% moisture content is best for 02 diffusion and microbial growth rate. Basheer et al. (2019) also suggested maintaining moisture content at 40-60%. Com- posting process generally completes in 45 to 90 days depending on the waste stream and quality of the final product (Rashid et al., 2022; Vigneswaran et al., 2016). Increased turning and bulking agents reduce this period by over 30% (Lim et al., 2017). The use of appropriate equipment, such as mechanical turners, tractors, trucks, front-end loaders, shredders, mixers, and screening units, helps improve efficiency and compost quality (Lim et al., 2017; Pergola et al., 2020).

Refining and Storage: Final compost is screened to remove metals and inert contam- inants, enhancing quality. Storage depends on market demand (Lim et al., 2017; Vigneswaran et al., 2016).

Environmental and Economic Feasibility

Windrow composting reduces landfill volume and methane emissions while yielding quality compost that enhances soil structure and fertility (Lim et al., 2017; Liu et al., 2020). The com-post can be used instead of chemical fertilizers, supporting sustainable agriculture (Chaher et al., 2021; Vigneswaran et al., 2016). Properly managed systems can also stabilize nitrogen and minimize nutrient leaching (Lim et al., 2017). Pergola et al. (2020) found that compost improves soil organic matter and crop yields. This demonstrates environmental benefits of composting. Moreover, studies have shown that windrow composting consumes significantly less energy per tonne than landfills or mechanical treatments (Lim et al., 2017; Lin et al., 2019; Vigneswaran et al., 2016).

Windrows can emit ammonia (NH3) and nitrous oxide (N2O) under high temperatures with inconsistent turning (Liu et al., 2020) while global warming potential of nitrogen dio-oxide is 310 times that of carbon dioxide over 100 years (Vergara & Silver, 2019). Total of 45% of nitrogen is lost in windrows due to turning, while only 10% in aerated static piles (ASP) (Lim et al., 2017). To reduce these GHG emissions, additives can be used (Liu et al., 2020). Especially in tropical or high-humidity regions, odor generation and leachate formation are additional concerns (Vigneswaran et al., 2016).

Practical mitigation strategies include installing impermeable concrete pads with leachate collection channels to protect groundwater, and using semi-permeable geotextile covers (fleece) to reduce odor dispersion by up to 90% while maintaining necessary aeration (Pergola et al., 2020; Sabki et al., 2018). Furthermore, adjusting the turning frequency based on temperature feedback helps prevent the anaerobic conditions that cause foul smells (Rashid et al., 2022).

Economically, windrow composting is the most cost-efficient option for processing bulk municipal waste. In Asian contexts, operational costs are estimated between $10-$20 per tonne, which is significantly lower than incineration or sanitary landfilling (Sabki et al., 2018; Vi-gneswaran et al., 2016). A sample cost-benefit analysis by Vigneswaran et al. (2016) concluded that $106,500 can be saved annually from composting in windrows over disposal. Selling compost adds revenue and reduces fertilizer costs, improving economic viability, especially where land is sufficient (Lim et al., 2017; Pergola et al., 2020). A study by Chen (2016) in Taiwan showed increased sales revenue of fruits and cost saving for rice crop by 20-40% due to application of organic fertilizer. However, this low-cost comes with a trade-off in land usage; unlike compact takakura or in-vessel systems, windrows require extensive buffer zones of over 50 meters to prevent odor issues in residential areas (Lim et al., 2017).

Suitability, Challenges, and Opportunities

Windrow composting is best suitable where land is sufficient and high organic volumes exist. It can process over 10 tonnes per load of plant-based waste, with low odor emissions (Lim et al., 2017). Urban municipalities can use its scalability for food and yard waste streams (Sabki et al., 2018). This was exemplified by Taiwan's aerated system, which handles 9 tonnes/day of waste and produces 3.6 tonnes/day of compost (Chen, 2016). On farms, crop residues, trimmings, and manure are recycled to enhance soil health and reduce costs (Pergola et al., 2020). In the USA, more than 60% of yard trimmings are composted (Lin et al., 2019). In developing cities, its minimal technology requirements make it suitable for resource- limited centralized facilities (Vigneswaran et al., 2016). Commercial operations, from livestock farms to fertilizer companies, also adopt windrows for on-site waste management and compost production (Liu et al., 2020).

Windrow composting faces challenges related to infrastructure, land requirements, and labor. Large areas are needed for compost pads, curing, and storage (Vigneswaran et al., 2016), while manual turning is labor-intensive and mechanization adds to the capital cost (Lin et al., 2019). Windrow sites require distance from residential zones, increasing transportation costs (Lim et al., 2017). Operational difficulties, such as poor turning or moisture imbalance, can lead to odors, pests, and anaerobic conditions. This may require large buffer zones (Rashid et al., 2022). Waste separated at source is important for effective composting but hard to achieve in developing cities. Windrows sensitivity to climate is another limitation (Vigneswaran et al., 2016).

Windrow systems also offer major opportunities. Its low-tech setup is suitable for peri-urban municipalities and community composting (Vigneswaran et al., 2016). Use of innovations like as affordable turners and automated monitoring tools can reduce labor and also boost efficiency (Lim et al., 2017). Pergola et al. (2020) noted the potential for cost optimization through integration in circular models, while compost creates revenue opportunities. Rashid et al. (2022) demonstrated the benefits of windrow compost for local farming, and Gavilanes Teran et al. (2016) found it suitable for horticultural waste recycling. Use of pile covers and aeration tweaks can help to improve results across diverse climates (Sabki et al., 2018). Windrow composting can be a climate-smart waste management strategy, offering opportunities for carbon sequestration, organic matter recovery, and reduced methane emissions (Lim et al., 2017).

Takakura Composting

The Takakura Composting Method (TCM) is a low-cost, aerobic technique that uses fermen- tative microorganisms to accelerate the decomposition of organic waste. Developed by Koji Takakura in Japan and piloted in Kitakyushu, it has expanded to Surabaya and across Southeast Asia, Latin America, and Nepal (Hibino et al., 2023; Nuzir et al., 2019). Its core process relies on a 'compost seed' made of microbes cultured from fermented foods like yogurt, tempeh, natto, and cheese, ensuring rapid and hygienic composting (Nuzir et al., 2019).

Unlike traditional methods, TCM completes the composting cycle in 1–2 weeks, producing a nutrient-rich compost with superior physicochemical properties (Aguinaga et al., 2023; Jiménez-Antillón et al., 2018). This natural fertilizer enhances soil fertility and plant growth (Fazrian et al., 2025). Its minimal infrastructure and compact setup suit urban, household, and community scales (Hibino, 2020), fostering localized, sustainable waste management (AlKhadher et al., 2021; Saputra, 2024).

Process Overview

TCM is a decentralized, aerobic composting technique that utilizes locally cultured fermentative microorganisms and simple, ventilated containers to process organic waste rapidly and hygienically. It requires minimal infrastructure and can be especially suited for space-constrained urban households and community setup (Jiménez-Antillón, Calleja-Amador & Romero-Esquivel, 2018; Nuzir et al., 2019).

Fermentation and Seed Preparation: The process begins by cultivating microbes in a sugar or salt solution with fermented foods (yogurt, natto, tempeh, fruit peels, molasses) to create a fermentation liquid (Hibino et al., 2023; Nuzir et al., 2019). This fermentation liquid is then blended with soil and rice husks in a 2:1 ratio, to produce a microbial-rich substrate, referred to as the compost seed (Al-Khadher et al., 2021). Mature compost or humus soil also serves as compost seed (Hibino, 2020).

Composting Setup: The seed is placed in ventilated plastic or wooden bins (40 × 25 × 70 cm) lined with breathable fabric (cotton or jute) to maintain aeration and prevent pest intrusion (Jiménez-Antillón et al., 2018). This system is suitable for biodegradable kitchen scraps and garden trimmings free from contaminated or non-compostable items. Kitchen waste (excluding grease, bones, and raw meat) and garden waste is chopped to 2–5 cm and mixed with the seed in a 1:1 ratio by volume (Hibino et al., 2023; Nuzir et al., 2019). The Takakura composting is a flexible method which suits both indoor households and community units (up to 151.2 m²) processing 1 tonne/day (Hibino et al., 2023).

Decomposition and Stabilization: Once loaded, the compost is manually turned ev- ery 1–3 days to sustain aerobic conditions and as a result organic waste is decomposed quickly (Hibino, 2020). Temperature rises to thermophilic levels (45 ◦C to 65 ◦C), which increases decomposition rate and ensures pathogen elimination (Hibino, 2020; Jiménez- Antillón et al., 2018). Moisture is maintained at 40–60% by slow watering once a week and checked using the hand-squeeze method. Low moisture will slow decompostion whereas too much moisture can form anaerobic conditions (Fazrian et al., 2025; Hibino, 2020). Active composting completes within 1–2 weeks, followed by a 1–3 weeks curing phase to stabilize the material. The final product typically achieves a C:N ratio of 15:1 to 20:1 (Shuen & Wasli, 2024). No mechanical equipment is needed, making the method ideal for resource-constrained settings (Al-Khadher et al., 2021; Hibino, 2020).

Environmental and Economic Feasibility

TCM is a low-tech, decentralized alternative for urban areas with limited land and resources. It diverts biodegradable waste from landfills and reduces methane emissions. In Surabaya, Indonesia, TCM implementation from 2004–2009 cut daily landfill input by 30%, from 1,500 to 1,000 tonnes/day (Nuzir et al., 2019). The aerobic process, maintained via manual turning and ventilated containers, minimizes odor and avoids methane generation (Al-Khadher et al., 2021; Hibino et al., 2023). Resulting compost is nutrient-rich, enhancing soil fertility and supporting urban agriculture.

Table 2. Physicochemical properties of Takakura compost (data from Jiménez-Antillón et al., 2018; Shuen and Wasli, 2024)

Parameter	Value / Range
Nitrogen (N)	6,300 - 8,400 ppm
Phosphorus (P)	10.57 – 15.45 ppm
Potassium (K)	726.07 – 727.81 ppm
C: N Ratio	15: 1 – 20: 1
pH Level	7.0 – 8.0

Trials with crops such as Brassica rapa and chili plants showed comparable or superior growth compared to conventional compost, thereby supporting sustainable nutrient recycling (Saputra, 2024; Shuen & Wasli, 2024). However, improper aeration or excessive moisture may lead to odor generation and pest attraction, particularly in hot and humid climates. These risks require careful manage- ment, container hygiene, and regular monitoring to ensure effective composting (Al-Khadher et al., 2021; Jiménez-Antillón et al., 2018).

Figure 5. Home composting using Takakura baskets (UNEP, 2023)

Economically, TCM uses containers costing less than $10 and locally sourced materials such as rice husks, soil, and fermented foods (Nuzir et al., 2019). Composting centers in Bandung, Indonesia, expanded from 15 kg/day to 1 tonne/day within one year with no additional machinery or land (Hibino et al., 2023). Operational costs are minimal and generate local jobs, mainly in chopping, mixing, and monitoring. A cost-benefit analysis in Bandung revealed daily net eco- nomic benefits of approximately $1,144 for a 200-tonnes/day facility (Hibino et al., 2023). A comparison study by Aguinaga et al. (2023) concluded that TCM has high benefit among other methods, with approximately 78% of organic waste degradation.

A SWOT analysis in Pondok Labu concluded Takakura compost is an easy, economical, and effective technique for managing food waste (Kartini, Hasibuan & Turmuyu, 2021). Additionally, a Life Cycle Assessment (LCA) showed greenhouse gas emission reductions of 132 tCO_2-equivalent/day, making TCM the most favor- able option among six evaluated strategies in Bandung (Hibino et al., 2023). Compost reuse in municipal gardening and agriculture further cuts down fertilizer expenses and promotes circu- lar economy practices (Jiménez-Antillón et al., 2018). Also, one-third of the compost produced can be used as a starter to mix next batch of organic waste (Husna et al., 2023). From a sustainability perspective, Takakura offers distinct advantages over mechanical systems. Unlike aerated static piles or in-vessel reactors that require electricity for blowers and turners, the Takakura method operates with zero energy input, relying entirely on the oxidative heat generated by the fermentation microbes (Nuzir et al., 2019). Additionally, water usage is minimal; the process requires only occasional sprinkling to maintain moisture, avoiding the heavy irrigation demands often associated with open windrows in dry climates (Hibino et al., 2023; Vigneswaran et al., 2016).

Suitability, Challenges, and Opportunities

TCM offers a compact, low-cost, decentralized solution for urban areas with limited space and high organic waste. Its odor-free operation fits balconies, kitchens, offices, and serves 5–10 users per bin (Jiménez-Antillón et al., 2018).

Community composting applications include schools, cooperatives, and apartment complexes using bucket collection systems (Hibino et al., 2023). TCM has been piloted successfully in developing cities across Indonesia, Thailand, Nepal, and the Philippines, aligning with local economic and infrastructure constraints (Nuzir et al., 2019). To scale this decentralization, the method can be institutionalized through municipal policy. Cities can distribute subsidized 'starter kits' (baskets and microbial seeds) to households and integrate them into the formal collection system. By collecting finished compost rather than raw waste, municipalities can reduce collection frequency and fuel costs. This effectively transforms waste management into a resource recovery service (Hibino et al., 2023; Nuzir et al., 2019).

Despite its adaptability, TCM faces barriers in technical and social aspects. Manual chop- ping, mixing, and frequent monitoring may limit participation (Al-Khadher et al., 2021; Jiménez-Antillón et al., 2018), while clean, segregated waste inputs are essential yet hard to achieve in mixed urban waste streams (Nuzir et al., 2019). Improper aeration or moisture control can cause odors and pests in dense areas (Al-Khadher et al., 2021). Handling waste in shared spaces like community composting centers may face social resistance, and success often depends on con- sistent community involvement and training (Jiménez-Antillón et al., 2018). Scaling beyond small units demands extra land, logistics, and management (Hibino et al., 2023).

While challenges remain, TCM offers multiple opportunities as an economic and environ- mentally friendly waste management technique. Opportunities include citywide adoption, as in Surabaya and Bandung, providing local employment in sorting, collection, and monitoring (Hibino et al., 2023; Nuzir et al., 2019). Rising demand for organic compost opens markets in urban agriculture and reuse in public green spaces (Jiménez-Antillón et al., 2018). TCM could provide business opportunities for even an individual with food and organic waste raw mate- rials (Kartini et al., 2021). TCM supports waste reduction targets and is eligible for climate incentives (Hibino et al., 2023). Combining TCM with vermicomposting, biochar, or digital monitoring can enhance efficiency and quality (Zhang et al., 2023). Smart composting bins with takakura method can be one of the effective climate protection strategies at household and community level (Zakarya et al., 2021).

Vermicomposting

Growing of earthworms in organic wastes is known as vermiculture and decomposing organic wastes by using earthworms is called vermicomposting (Hajira Banu & Rafiya Fathima, 2018). Vermicomposting uses earthworms to convert organic waste into humus-like vermicast, aligning with circular economy principles by returning nutrients to soil (Hajira Banu & Rafiya Fathima, 2018; Ibrahim et al., 2024). This low-cost process transforms waste into nutrient-rich compost with minimal energy, suitable for household and community scales (Ify & Njoku, 2021; Katiyar et al., 2023). It is a clean, efficient, and zero-waste approach which can suit smaller waste quantities. (Ibrahim et al., 2024; Macktoobian, 2024).

Vermicast is rich in nitrogen (N), phosphorous (P), potassium (K), micronutrients, and bene- ficial microbes which improves soil fertility, water quality, and helps in contaminant reduction when applied as an amendment (Hajira Banu & Rafiya Fathima, 2018; Toor et al., 2024). When applied as soil amendment, it helps soil restore lost nutrients, enhances soil fertility, and facili- tates transfer of nutrients to plants (Katiyar et al., 2023; Olle, 2019). In addition, it can reduce 60-70% of organic waste in landfills, saving landfill space and reducing methane emissions (Ha- jam, Kumar & Kumar, 2023; Toor et al., 2024). Though sensitive to high temperatures and requiring clean feedstock, its simplicity and efficiency make it a preferred technology in many urban contexts (Ibrahim et al., 2024).

Process Overview

Vermicomposting is an eco-friendly technique which relies on specific species of earthworms to decompose and stabilize organic waste. Vermicompost setting at household, community, or even larger scales does not require complex equipment, heavy infrastructure, or costly materials (Ibrahim et al., 2024). Although methods like bins, beds, heaps, or pits vary by scale, each follows the same core process.

Site Selection and Waste Preparation: Choose a cool, moist, shaded site near water source; provide a thatched roof or shed if open (Chanu et al., 2018; Tambe, 2020). Collect waste, dry and shred to smaller pieces, then remove contaminants (Chanu et al., 2018; Ify & Njoku, 2021).

Pre-digestion: Pre-digestion of waste should be done by forming heaps with cattle dung slurry and watering regularly for at least 20-25 days to maintain moisture content and make material fit for earthworm consumption (Chanu et al., 2018). During pre-digestion, temperature of piles reaches to 50 ◦C to 55 ◦C which is crucial for pathogen elimination. Cool down heaps to approximately 25 °C before adding worms (Amaravathi & Reddy, 2015).

Earthworm Selection and Cultivation: The success of vermicomposting depends heav- ily on choosing appropriate species of earthworm. Eisenia foetida, Eisenia andrei, and Eudrilus eugeniae are best suited species due to high decomposition rate, rapid growth, and optimal performance up to 32 °C (Hajira Banu & Rafiya Fathima, 2018; Ibrahim et al., 2024). Prepare worm bed: bricks/pebbles base, 6-7.5 cm coarse sand layer, loamy soil

>15 cm height, bedding (newspaper/leaves), and feedstock (waste, manure) as food for earthworms (Katiyar et al., 2023; Toor et al., 2024). Worms thrive on a feed with pH of 6.5-7.5, thus Ibrahim et al. (2024) suggested mixing limestone with water and adding it to feed. Ibrahim et al. (2024) also added a 15% mix of dry stalks and stems to enhance feed quality. 60–80% moisture and temperature of 18 ◦C to 30 ◦C should be maintained to avoid reduced reproduction rate, mass exit, or mortality of worms (Chanu et al., 2018; Katiyar et al., 2023).

Preparation of Vermibed and Earthworm Introduction: For small-scale beds (6 × 2 × 2 ft) or pits (10 × 4 × 2 ft) can be prepared. For commercial-scale operations, beds upto 12m length with width less than 2.5 m can be used to ensure ease of operation and height should be limited to prevent overheating (Chanu et al., 2018; Sayara, 2020). Ibrahim et al. (2024) prevented overheating by restricting feeding layer thickness upto less than 0.3m. Beds are made with a base layer of broken bricks or pebbles, a thick layer of sand or soil, and a 10-15cm thick layer of bedding material such as dried leaves. The pre- digested material is then added in layers up to a total height of 0.3-0.4m. Earthworms are then released on the upper layer of bed (300-350 worms per m3 volume of bed) with scattering a small lump of animal dung and covering up to 10cm of dung with hay (Chanu et al., 2018; Katiyar et al., 2023). Water is sprinkled immediately after addition of worms and it is then covered with broad leaves or gunny bags to avoid loss of moisture. Boundary walls and nets can be used to protect worms from birds, pests, and rodents (Chanu et al., 2018; Ibrahim et al., 2024).

Composting and Monitoring: Vermicomposting involves interaction between earth- worms and microorganisms. Earthworms fragment waste while microbes enzymatically decompose it, producing loose vermicast. Organic matter undergoes complex transforma- tion in earthworm's gut where symbiotic microbes result in conversion of matter and pres- ence of digestive enzymes, coelomic fluids, and a reduced oxygen environment results in pathogen and parasite elimination (Macktoobian, 2024; Vuković et al., 2021). Maintain moisture (45–60%) with some sources recommending up to 85% for enhanced earthworm growth. Moisture content can be identified by simple smell test or hand squeeze method. Daily watering is necessary to maintain moisture levels (Chanu et al., 2018; Ibrahim et al., 2024; Katiyar et al., 2023). The temperature should be maintained at 20 ◦C to 30 ◦C and piles should be aerated by turning every 2-3 days without disturbing base layer (Chanu et al., 2018; Hajira Banu & Rafiya Fathima, 2018).

Harvesting and Storage: The vermicomposting process typically completes in 45-60 days (Zhang et al., 2023). Watering is stopped 5 days prior to the harvesting. Compost is piled in small heaps and left under ambient conditions for 2-3 hrs until worms gather at the bottom of heap. Remove vermicompost on top and carefully collect the worms settled down at the bottom for use in the next batch of vermicomposting (Chanu et al., 2018; Toor et al., 2024). Harvesting can also be done manually while Earthworms and cocoons are separated by sieving. Compost is stored in cool, dark, moist conditions for maintaining its nutrient level (Chanu et al., 2018; Ibrahim et al., 2024).

Figure 6. Vermicomposting tanks in car parking basement (Tripura University, 2019)

Environmental and Economic Feasibility

Vermicomposting process utilizes earth-worms which help to maintain the aerobic condition to decompose the organic matter and consequently reduce methane emissions and odor (Amaravathi & Reddy, 2015; Macktoobian, 2024). Organic waste may divert from landfills that lifespan of landfill site will be increased as well as reduces the GHGs, especially methane gas emission from the landfill site (Ify & Njoku, 2021; Toor et al., 2024). Macktoobian (2024) reported an exceptionally low global warming potential of only 0.11 kg CO2-eq per kilogram of waste. Vermicompost is nutrient-rich, containing N, P, K, micronutrients that boosts plant growth.

Zhang et al. (2023) reported 50% and 88% increase in fresh pod pepper production in 2021 and 2022 respectively. It also reduces soil contaminants and heavy metals, thus increasing soil fertility (Hajira Banu & Rafiya Fathima, 2018; Toor et al., 2024). It can also help to reduce large quantities of toxic pollutants, plastic and pesticide residue, and has a positive impact on plants as well as soil-dwelling microorganisms (Hajam et al., 2023). Economically, vermicomposting systems are cost-effective and suitable for households, communities, or even at a larger-scale. Unlike conventional composting methods, vermicompost ing can be achieved with minimal electricity or enzymes, resulting in reduced operational and equipment costs.

In a study of a medium-scale plant in Bangladesh, an initial investment of approximately $5,100 (0.60 million BDT) resulted in a production cost of just $17/tonne. With a market selling price of $85/tonne (10,000 BDT/Mt), the facility achieved a payback period of 2–3 years, proving its viability as a micro-enterprise model (Ibrahim et al., 2024). Similarly, Chanu et al. (2018) reported an annual net benefit of $160 (Rs. 13,485) for small-scale setups, confirming profitability even at household levels. Furthermore, Zhang et al, (2023) reported a 22% and 59% increase in net income in 2021 and 2022 respectively. Vermicomposting also provides local job opportunities and aligns with circular economy principles (Ify & Njoku, 2021). These findings demonstrate environmental and economic suitability of vermicomposting for urban organic waste management.

Suitability, Challenges, and Opportunities

Vermicomposting's simplicity, low cost, and minimal infrastructure make it adaptable from household bins to community-scale systems for municipal organic waste management. It thrives in low- and middle-income cities. It works without electricity, enzymes or mechanical equip- ment, cutting operational costs (Ibrahim et al., 2024). As a nutrient-rich soil amendment, vermi- compost improves soil structure and fertility on-site, recycling crop residues, farm waste, and manure (Ify & Njoku, 2021; Toor et al., 2024). While often small-scale, commercial plants (5–10 MT/day) in India and Southeast Asia demonstrate its enterprise potential (Chanu et al., 2018; Ibrahim et al., 2024; Ify & Njoku, 2021).

The successful implementation of vermicomposting at household level or commercial-scale is constrained by some operational and environmental challenges. Maintaining a temperature of 18 ◦C to 30 ◦C and 45–60% moisture is critical; extremes can reduce worm reproduction or cause a mass exit, and anaerobic zones can harm worms (Chanu et al., 2018; Ibrahim et al., 2024; Macktoobian, 2024). However, maintaining the strict temperature range of 18 ◦C to 30 ◦C is a major constraint in urban environments, where rooftops or balconies often exceed these limits in summer. Solutions for urban residents include utilizing polystyrene-insulated bins to buffer against thermal spikes, or locating vermibeds in basements and underground parking areas where temperatures remain stable year-round (Tripura University, 2019).

To address the potential odors in high-density apartments, ensuring a 5 cm top layer of dry carbon material (sawdust or shredded paper) effectively acts as a bio-filter, suppressing smells and preventing fruit fly infestations (Ibrahim et al., 2024). Moreover, worms sometimes attempt to escape despite clean bedding, adequate moisture, and sufficient food.

Ibrahim et al. (2024) reported that escapes can be prevented by better aeration, the addition of dry paper, or limestone-treated feed. If not properly protected, birds, rodents, or other pests can be harmful to worms (Chanu et al., 2018). Continuous monitoring is necessary for effective progression of vermicomposting and quality of final product.

Despite these constraints, vermicomposting can be scaled from municipal systems to house- hold bins, generating local jobs in waste handling, vermiculture, composting, and marketing (Ify & Njoku, 2021; Olle, 2019). It closes the nutrient loop, reduces fertilizer imports, and quickly yields high-quality compost as a climate-friendly alternative to chemicals (Macktoobian, 2024; Olle, 2019).

It also supports local food system by enhancing soil fertility and nutrient availability in community gardens and urban farms (Toor et al., 2024; Zhang et al., 2023). Vermicomposting offers clear potential as an economical and environmentally friendly waste management system. After studying the technical, economic, and environmental suitability of these three methods in urban areas, Table 3 provides a structured side-by-side comparison.

Table 3. Comparative summary of Windrow, Takakura, and Vermicomposting

Parameter	Windrow	Taka kura	Vermi composting
Infrastructure Requirement	Medium (pads, turners, drainage)	Very low (baskets, fermented seed, sawdust)	Low (vermibeds, shaded area, local materials) (Lim et al., 2017; Pergola et al., 2020)
Optimal C:N ratio	25–30:1 (adjust with bulking agents)	25–35:1 (seed-bal-anced)	25–30:1 (manure/ residue bal-anced(Rashid et al., 2022; Vigneswaran et al.,2016))
Moisture content	60–65%	50–60%	60–80%
Composting duration	45–90 days	10–14 days	45–60 days (Al-Khadher et al.,2021; Hibino et al., 2023;)
Environmental Impact	Moderate GHG if misman-aged; leachate possible	Low GHG, minimal odor	Very low GHG; soil health benefits (Jiménez-Antil-lón et al., 2018; Nuzir, et al., 2019)
Setup cost	Medium (land prep, tools)	Very low (bins & seed)	Low (beds & worms) (Chanu et al., 2018; Hajira Banu and Rafiya Fathima, 2018; Ibrahim et al., 2024; Ify and Njoku, 2021)
Urban suitability	Medium (space-demand-ing)	High (compact, rooftop/ house-hold)	High (modular, community scale)

Conclusion

This systematic review highlights that Takakura Composting is the most suitable standalone method for high-density urban households due to its rapid decomposition (10–14 days), compact footprint, and zero energy requirement. While Windrow composting remains the most economically efficient solution for centralized, municipal-level processing of bulk green waste, it requires significant land buffers that are often unavailable in city centers. Vermicomposting, although demanding strict temperature control, offers the highest economic return through nutrient-rich fertilizer production, making it ideal for community-scale micro-enterprises.

Their combined use offers untapped benefits. For instance, seeding Takakura bins with vermicast and then curing in windrows could speed processing, boost nutrient recovery, and cut GHG emissions. This hybrid approach, rarely ex- plored in current literature, bridges the gap between scale and speed while promoting a circular, adaptable organic waste management system for cities of all sizes

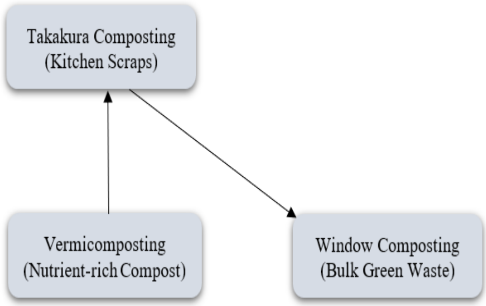

Figure 7. Proposed Hybrid-Cascade Model

A cascading model: windrows handling bulk green waste, Takakura reactors processing kitchen scraps, and vermibeds receiving nutrient-rich compost. In this model, municipalities distribute Takakura starter kits to households for source-stabilization of kitchen waste, signifi-cantly reducing volume and odors before collection. The semi-processed material is then col-lected and transported to centralized Windrow facilities for final curing. This approach resolves the scalability limits of household bins while mitigating the land constraints of large-scale plants, creating a seamless flow from kitchen to farm.

Findings also reveal that practices such as hand moisture checks, can lead to ±15% variability from the ideal. Simple, low-cost moisture monitoring (±15% variability to ±5%) can accelerate thermophilic phases and shorten curing without heavy machinery, increasing throughput. Success across systems depends on microbial compatibility and climate: windrows struggle in cold, vermicomposting falters with mixed feedstocks, and Takakura bins require correct starters. Seasonal "starter culture banks" (lactobacilli in monsoons, thermophiles in winter) could lift efficiency by 25–40%.

Beyond waste treatment, this study proposes that composting should be viewed as a strategic buffer system for cities facing climate shocks and supply chain disruptions. By requiring zero electricity and enabling on-site fertilizer production for rooftop agriculture, systems like Takakura can enhance urban resilience against food supply chain disruptions during climate shocks. This theoretical framework suggests that decentralization prevents landfill overload during disasters, offering a layer of urban security that centralized systems cannot provide.

A limitation of this review is the reliance on formal academic literature published in English, which may underrepresent informal or indigenous composting practices prevalent in developing regions. Future research should focus on conducting long-term Life Cycle Assessments (LCA) of the proposed Hybrid-Cascade model to quantify its specific economic and environmental benefits. Additionally, field studies measuring the social acceptance of Takakura 'starter kit' distribution programs in low-income settlements are recommended to validate scalability.

References

Aguinaga, D. A. L., Pinedo, E. N. S., Guevara, K. V. B., Benites-Alfaro, E., & Cumpa, R. O. (2023). Traditional composting, bokashi and takakura: Efficiency in the degradation of organic waste. *Chemical Engineering Transactions*, 100, 79–84. https : / / doi . org / 10 . 3303/ CET23100014

Al-Khadher, S. A. A., Abdul Kadir, A., Al-Gheethi, A. A. S., & Azhari, N. W. (2021). Takakura composting method for food wastes from small and medium industries with indigenous compost. Environmental Science and Pollution Research, 28, 65513–65524. https://doi. org/10.1007/s11356-021-15011-0

Amaravathi, G., & Reddy, R. M. (2015). Environmental factors affecting vermicomposting of municipal solid waste. *International Journal of Pharmacy and Biological Sciences, 5*(3), 81–93. https://www.ijpbs.com/ijpbsadmin/upload/ijpbs_55e876018dbe4.pdf

Basheer, S., Nazir, M., Rashid, H., Nasir, A., Hussain, E. M., et al. (2019). Development of efficient windrow composting technique for food waste and its optimization. *Earth Sciences Pakistan (ESP), 3*(2), 18–26. https://doi.org/10.26480/esp.02.2019.18.26

Chaher, N. E. H., Chakchouk, M., Nassour, A., Nelles, M., & Hamdi, M. (2021). Potential of windrow food and green waste composting in Tunisia. *Environmental Science and Pollution Research, 28*, 46540–46552. https://doi.org/10.1007/s11356-020-10264-7

Chanu, L. J., Hazarika, S., Choudhury, B., Ramesh, T., Balusamy, A., Moirangthem, P., Yum- nam, A., & Sinha, P. K. (2018). A guide to vermicomposting-production process and socio economic aspects. Extension Bulletin, 81, 30. https : / / www . researchgate . net / publication/331112674_A_Guide_to_ vermicomposting- production_ process _and_ socio_ economic_aspects

Chen, Y.-T. (2016). A cost analysis of food waste composting in Taiwan. *Sustainability, 8*(11), 1210. https://doi.org/10.3390/su8111210

Coker, C. (2022). Calculating a composting facility footprint. Retrieved July 5, 2025, from https://www.biocycle.net/calculating-a-composting-facility-footprint/

Cotler, H., Márquez, A. H., & Jiménez, A. L. R. (2025). Unlocking on-farm composting: Key drivers in Mexico City's peri-urban areas. Cleaner Waste Systems, 10, 100200. https ://doi.org/10.1016/j.clwas.2024.100200

Dharnaik, A. S., & Pol, P. (2024). A review on composting of organic solid waste. *IOP Conference Series: Earth and Environmental Science, 1326*(1), 012130. https://doi.org/10. 1088/1755-1315/1326/1/012130

Fazrian, S. A., Widyastuti, S., Al Kholif, M., & Pungut, P. (2025). Evaluation of pathogen reduction and compost quality in takakura method composting of organic waste and disposable diapers. *Journal Sumberdaya Alam dan Lingkungan, 11*(3), 110–117. https ://jsal.ub.ac.id/index.php/jsal/article/view/20014

Fogarassy, C., Hoang, N. H., & Nagy-Pércsi, K. (2022). Composting strategy instead of waste- to-energy in the urban context— A case study from Ho Chi Minh City, Vietnam. *Applied Sciences, 12*(4), 2218. https://doi.org/10.3390/app12042218

Gavilanes-Terán, I., Jara-Samaniego, J., Idrovo-Novillo, J., Bustamante, M. A., Moral, R., & Paredes, C. (2016). Windrow composting as horticultural waste management strategy – A case study in Ecuador. Waste Management, 48, 127–134. https://doi.org/10.1016/j.wasman.2015.11.026

Geethamani, R., Soundara, B., Kanmani, S., Jayanthi, V., Subaharini, T., Sowbiyalakshmi, V., & Sowmini, C. (2021). Production of cost affordable organic manure using institutional waste by rapid composting method. Materials Today: Proceedings, 45, 764–768. https: //doi.org/10.1016/j.matpr.2020.02.803

Hajam, Y. A., Kumar, R., & Kumar, A. (2023). Environmental waste management strategies and vermi transformation for sustainable development. Environmental Challenges, 13, 100747. https://doi.org/10.1016/j.envc.2023.100747

Hajira Banu, R., & Rafiya Fathima, M. (2018). Vermicomposting of organic waste using Epigeic Earthworm Eudrilus Eugeniae (Kinberg) on soil fertility. *International Journal of Research and Analytical Reviews (IJRAR), 5*(4), 638–647. https://www.ijrar.org/papers/ IJRAR1944600.pdf

Hibino, K. (2020). Operation manual for small-to-medium scale compost centres using the takakura composting method. Institute for Global Environmental Strategies, 3. https ://doi.org/10.57405/iges-10774

Hibino, K., Takakura, K., Nugroho, S. B., Nakano, R., Ismaria, R., Haryati, T., Yulianti, D., Zusman, E., Fujino, J., & Akagi, J. (2023). Performance of Takakura composting method in the decentralised composting center and its comparative study on environmental and economic impacts in Bandung City, Indonesia. *International Journal of Recycling of Organic Waste in Agriculture, 12*(1). https://doi.org/10.30486/ijrowa.2022.1945234. 1379

Husna, A. R., Wiliyanarti, P. F., Putri, I. D., & Az-Zahra, R. N. (2023). Community empowerment: Processing household organic waste into compost using the takakura technique. *Journal of Community Empowerment for Multidisciplinary (JCEMTY), 1*(1), 49–55. https://doi.org/10.53713/jcemty.v1i1.76

Ibrahim, A. S. M., Mohammad, A., Khalil, M. I., & Shams, S. N. (2024). Viability of medium scale vermicompost plant: A case study in Kushtia, Bangladesh. *Formosa Journal of Applied Sciences, 3*(3), 787–796. https://doi.org/10.55927/fjas.v3i2.8160

Ify, E., & Njoku, K. (2021). Vermicomposting of organic wastes using eudrillus euginae. Nigerian Journal of Botany, 20(1), 57–69. https : / / www . researchgate . net / publication / 352056806_Vermicomposting_of_organic_wastes_using_Eudrillus_euginae

Jiménez-Antillón, J., Calleja-Amador, C., & Romero-Esquivel, L. G. (2018). Food waste re- covery with takakura portable compost boxes in offices and working places. *Resources, 7*(4), 84. https://doi.org/10.3390/resources7040084

Kartini, A., Hasibuan, H., & Tumuyu, S. (2021). A Swot analysis of takakura compost as a treatment for household food waste (case study in Pondok Labu urban village). IOP Conference Series: Earth and Environmental Science, 940(1), 012075. https://doi.org/10.1088/1755-1315/940/1/012075

Katiyar, R. B., Sundaramurthy, S., Sharma, A. K., Arisutha, S., Khan, M. A., & Sillanpää, M. (2023). Optimization of engineering and process parameters for vermicomposting. *Sustainability, 15*(10), 8090. https://doi.org/10.3390/su15108090

Lim, L. Y., Bong, C. P. C., Lee, C. T., Klemes, J., Sarmidi, M. R., & Lim, J. S. (2017). Review on the current composting practices and the potential of improvement using two-stage composting. *Chemical Engineering Transactions, 61*, 1051–1056. https://doi.org/10. 3303/CET1761173

Lin, L., Shah, A., Keener, H., & Li, Y. (2019). Techno-economic analyses of solid-state anaer- obic digestion and composting of yard trimmings. *Waste management, 85*, 405–416. https://doi.org/10.1016/j.

wasman.2018.12.037

Liu, Z., Wang, X., Wang, F., Bai, Z., Chadwick, D., Misselbrook, T., & Ma, L. (2020). The progress of composting technologies from static heap to intelligent reactor: Benefits and limitations. *Journal of Cleaner Production, 270*, 122328. https://doi.org/10.1016/j.jclepro.2020.122328

Macktoobian, M. (2024). Life cycle assessment of vermicomposting process [Master's thesis, University of South-Eastern Norway]. https://hdl.handle.net/11250/3135778

Manea, E. E., Bumbac, C., Dinu, L. R., Bumbac, M., & Nicolescu, C. M. (2024). Composting as a sustainable solution for organic solid waste management: Current practices and potential improvements. *Sustainability, 16*(15), 6329. https://doi.org/10.3390/su16156329

Meena, A. L., Karwal, M., Kj, R., & Narwal, E. (2021). Aerobic composting versus anaerobic composting: Comparison and differences. *Food and Scientific Reports, 2*, 23–26. https://doi.org/10.13140/RG.2.2.21424.69125

Nigussie, A., Kuyper, T. W., Bruun, S., & de Neergaard, A. (2016). Vermicomposting as a technology for reducing nitrogen losses and greenhouse gas emissions from small-scale composting. *Journal of Cleaner Production, 139*, 429–439. https://doi.org/10.1016/j.jclepro.2016.08.058

Nuzir, F. A., Hayashi, S., & Takakura, K. (2019). Takakura composting method (TCM) as an appropriate environmental technology for urban waste management. *International Journal of Building, Urban, Interior and Landscape Technology (BUILT), 13*, 67–82. https: //doi.org/10.14456/built.2019.6

Olle, M. (2019). Vermicompost, its importance and benefit in agriculture. *Journal of Agricultural Science, 30*(2), 93–98. https://doi.org/10.15159/jas.19.19

Pergola, M., Persiani, A., Pastore, V., Palese, A. M., D'Adamo, C., De Falco, E., & Celano, G. (2020). Sustainability assessment of the green compost production chain from agricultural waste: A case study in southern Italy. *Agronomy, 10*(2), 230. https://doi.org/10. 3390/agronomy10020230

Rashid, H., Nasir, A., Akbar, M. U., Maqsood, A., Manzoor, A., et al. (2022). Efficient and eco-friendly management of different types of solid waste using windrow composting

technique and effect of sewage as additive on physico-chemical characteristics of composts. *Journal of Wastes and Biomass Management (JWBM), 4*(1), 26–31. https://doi. org/10.26480/jwbm.01.2022.26.31

Sabki, M. H., Lee, C. T., Bong, C. P., & Klemes, J. J. (2018). A review on the economic feasibility of composting for organic waste management in Asian countries. *Chemical Engi- neering Transactions, 70*, 49–54. https://doi.org/10.3303/CET1870009

Saputra, Y. (2024). Utilization of organic waste as takakura compost and its effect on the growth of chili plants. *Preventia : The Indonesian Journal of Public Health, 9*, 67. https://doi. org/10.17977/um044v9i22024p67-76

Sayara, T., Basheer-Salimia, R., Hawamde, F., & Sánchez, A. (2020). Recycling of organic wastes through composting: Process performance and compost application in agriculture. *Agronomy, 10*(11), 1838. https://doi.org/10.3390/agronomy10111838

Shuen, K., & Wasli, M. E. (2024). Growth performance and yield of brassica rapa var. chinensis with takakura and conventional compost. *OnLine Journal of Biological Sciences, 24*, 358–366. https://doi.org/10.3844/ojbsci.2024.358.366

Siqueira, T. M. O. D., & Assad, M. L. R. C. L. (2015). Composting of municipal solid waste in the state of Sao Paulo (Brazil). *Ambiente & Sociedade, 18*, 243–264. https://doi.org/10.1590/1809-4422ASOC1243V1842015

Sumiyati, S., Lantip, D., Huboyo, H., Ramadan, B., Hadiwidodo, M., Samadikun, B., Wirawan, A., Rofiq, I., & Yumaroh, S. (2020). Pit composting methods for community based waste treatment (a case study in Ngadimulyo Village). *Journal of Physics: Conference Series, 1655*(1), 012124. https://doi.org/10.1088/1742-6596/1655/1/012124

Tambe, R. (2020). Vermiculture & vermicomposting production. *International Journal of Sci-entific Research, 9*(12), 1–3. https://doi.org/10.36106/ijsr/1631471

Toor, M., Javed, M., Malook, M., Sultan, Y., Mughees, M., Ud Din, M., & Ay, A. (2024). Exploring the role of vermicompost in mitigating environmental pollution: A review of its effects on soil contaminants and water quality. *Journal of Xi'an Shiyou University, Natural Science Edition, 19*(6), 9–16. https://www.xisdxjxsu.asia/V19I06-02.pdf

Tripura University. (2019, September). Vermicomposting project [Last updated: 27 May 2025; setup in September 2019]. Retrieved July 5, 2025, from https://tripurauniv.ac.in/site/ index.php/en/vermicomposting-project-en/

United Nations Environment Programme. (2023). Composting: Solution to food loss and waste. UNEP. Retrieved July 5, 2025, from https://www.unep.org/ietc/news/story/composting- solution-food-loss-and-waste

Vergara, S. E., & Silver, W. L. (2019). Greenhouse gas emissions from windrow composting of organic wastes: Patterns and emissions factors. *Environmental Research Letters, 14*(12), 124027. https://doi.org/10.1088/1748-9326/ab5262

Vigneswaran, S., Kandasamy, J., & Johir, M. (2016). Sustainable operation of composting in solid waste management. *Procedia Environmental Sciences, 35*, 408–415. https://doi. org/10.1016/j.proenv.2016.07.022

Vuković, A., Velki, M., Ečimović, S., Vuković, R., Štolfa Čamagajevac, I., & Lončarić, Z. (2021). *Vermicomposting—facts, benefits and knowledge gaps. Agronomy, 11*(10), 1952. https://doi.org/10.3390/agronomy11101952

Wei, Y., Wang, N., Lin, Y., Zhan, Y., Ding, X., Liu, Y., Zhang, A., Ding, G., Xu, T., & Li, J. (2021). Recycling of nutrients from organic waste by advanced compost technology- A case study. Bioresource Technology, 337, 125411. https://doi.org/10.1016/j.biortech. 2021.125411

Zakarya, I. A., Nasir, N. A. N. M., Kamaruddin, S. A., & Beson, M. R. C. (2021). Household food waste management through smart compost bin (SaCoB). Proceedings of Malaysian Technical Universities Conference on Engineering and Technology (MUCET), 203–204. https://crim.utem.edu.my/wp-content/uploads/2024/05/100-203-2041.pdf

Zhang, M., Liu, Y., Wei, Q., Liu, L., Gu, X., Gou, J., & Wang, M. (2023). Effects of biochar and vermicompost on growth and economic benefits of continuous cropping pepper at karst yellow soil region in Southwest China. Frontiers in Plant Science, 14, 1238663. https://doi.org/10.3389/fpls.2023.1238663.