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From Plate To Patient: Engineering A Circular Economy Model For Hospital Food Waste And Green Initiatives

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Abstract
Hospitals generate significant volumes of food waste daily, creating both operational challenges and opportunities for sustainable resource management. Facility management units often lead green initiatives such as composting, where food waste is converted into organic fertilizer and distributed to external farmers. While this practice reduces landfill burden, it typically remains a linear process with limited benefits to the hospital itself. This study develops a circular economy model for hospital food waste, emphasizing quantitative measurement of waste generation, composting capacity, and compost yield. Food waste streams from inpatient kitchens and cafeterias were tracked to determine daily and monthly volumes, while composting outputs were analyzed in terms of nutrient-rich end products. The research focuses on the composting process through aerobic decomposition using a mechanical composter to assess its suitability for hospital food waste management. The proposed model closes the gap between waste disposal and hospital benefit: compost generated on-site is supplied to local farmers, who in turn return fresh produce that can be reintegrated into hospital kitchens and patient meals. This cycle from plate to patient not only reduces disposal costs but also strengthens hospital food supply resilience, promotes local farming, and aligns with national green policies of the Ministry of Health Malaysia (MOH). By positioning facility management as a driver of circular resource systems under the Sustainability Program, this research demonstrates how hospitals can transform food waste from a disposal problem into a strategic resource for patient care and sustainable healthcare delivery. By seeing the advantages, such as nutrient recovery, cost efficiency, and scalability, with the potential drawbacks, including operational complexity, cultural acceptance, and regulatory challenges, this research highlights the trade-offs that influence practical adoption. Ultimately, the findings aim to provide a decision-making framework for healthcare facilities to integrate food waste valorization into broader sustainability agendas, thereby advancing hospitals not only as centers of treatment but also as active contributors to environmental stewardship and resource innovation.

INTRODUCTION

Food waste represents a significant sustainability challenge, with nearly one-third of global food production lost or wasted annually (FAO, 2019). The healthcare sector is a major contributor, as hospitals operate continuously and generate large volumes of waste from diverse dietary services (Abdel-Shafy & Mansour, 2018). Traditional disposal through landfilling and incineration not only increases operational costs but also contributes to greenhouse gas emissions (Thi, Kumar, & Lin, 2015).

In response, many hospitals have adopted on-site composting as part of green initiatives. Composting reduces landfill burden and produces organic fertilizer, but the by-product is typically distributed freely to local farmers, representing a linear approach with limited benefits for hospitals (Lim, Chin, Yusof, Yahya, & Tee, 2016). The circular economy framework emphasizes resource loops where waste is transformed into value that re-enters the system (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). While healthcare sustainability research has emphasized energy, water, and biomedical waste (McGain & Naylor, 2014), hospital food waste remains underexplored. Composting is practical for hospitals, whereas more advanced methods such as black soldier fly (BSF) bioconversion face operational and cultural barriers (van Huis, 2020).

This study draws on empirical practices implemented at a hospital in Kedah, Malaysia where a food composter was utilized from 2018 to 2022. The investigation aims to identify effective strategies for managing such composting systems, not only within hospitals but also across other facilities that provide hospitality services, such as hotels and event managements. This study addresses this gap by quantifying hospital food waste generation, compost yields, and proposing a **circular "From Plate to Patient" model** in which compost supports local farming, and produce is reintegrated into hospital food services. The model demonstrates how facility management can serve as a key driver of sustainable healthcare delivery.

MATERIALS AND METHODS

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This research focuses on the composting process through aerobic decomposition using a mechanical composter as a method for managing hospital food waste (Figure 1). The study was conducted at Hospital Sultanah Maliha, Langkawi, which was selected due to its role as a pioneer in sustainable hospital practices. Food waste generated from inpatient wards and cafeteria services, managed under facility management contracts, was used as the input material.

Figure 1: Food waste composter used in the Hospital Sultanah Maliha, Langkawi

The composting method emphasizes the systematic collection, segregation, and mixing of waste before being processed in the in-vessel composter under controlled temperature and aeration conditions. This approach allows the waste to undergo accelerated decomposition, followed by curing and screening stages, ultimately producing compost that can be reused as organic fertilizer. Through this method, the study aims to evaluate the practicality and sustainability of hospital-based food waste management, with an estimated generation of approximately 50 kilograms of food waste per day. Refer to Figure 2 on the cycle of food waste.

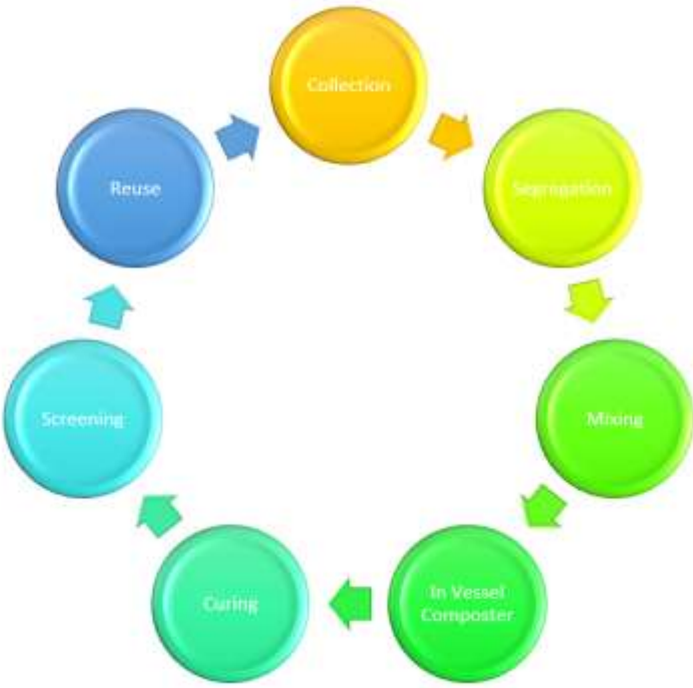

Figure 2: The cycle of food waste processing

The composting process begins with collection, where food waste generated from hospital inpatient and cafeteria services is gathered systematically. The collected waste then undergoes segregation, in which non-organic contaminants are removed to ensure only biodegradable materials proceed to the next stage. Following this, the organic fraction is subjected to mixing, where waste is blended to create a uniform composition and enhance microbial activity.

The homogenized waste is then placed into the in-vessel composter, a controlled environment designed to accelerate decomposition under optimized temperature and aeration conditions. Once primary decomposition is achieved, the material enters the curing phase, allowing further stabilization and maturation of the compost. After curing, the compost is subjected to screening to remove oversized or non-degraded particles, ensuring consistency and quality of the final product. The quality of the final compost largely depends on the type of leftover food used as input; higher grease content tends to reduce the efficiency and overall yield of the process. The characteristics of the waste are particularly important, as they significantly influence the outcomes of life cycle assessment (LCA) in food waste management (Bernstad, 2012).

The final step is reuse, where the processed compost is applied as organic fertilizer, supporting landscaping, horticulture, or agricultural purposes. This closed-loop process not only reduces landfill dependency but also exemplifies a circular approach to resource management in hospital operations.

RESULTS & DISCUSSION

The hospital employs on-site composting for food waste treatment using MAEKO composter. During the years of operation, food waste was not segregated by category, and the total collection was estimated at approximately 50 kg per day. This amounts to nearly 1.5 tons of waste generated monthly by the hospital. The initial composting process involved the addition of enzymes, and for each harvest, about 20% of the output was retained as inoculum to sustain the subsequent composting cycles in a continuous process. The outcome is a stabilized compost product that can be reused as an organic fertilizer, offering direct environmental and economic benefits.

The FAO (2019) reports that around 14% of food is lost before retail and even more wasted at the consumer stage, reflecting a major environmental and economic burden. In hospitals, where large volumes of uneaten meals are discarded daily, on-site composting directly addresses this issue by diverting food waste from landfills, reducing greenhouse gas emissions, and producing organic fertilizer for hospital landscapes or community use. This aligns with FAO's call for targeted waste reduction strategies and supports SDG 12.3, while systematic monitoring of hospital food waste (e.g., 50 kg/day) links well with data-driven sustainability practices recommended globally.

Rada and Ragazzi (2015) emphasize that sustainable municipal solid waste (MSW) management depends on selective collection and recovery processes, where organic waste streams such as food residues can be diverted into biological treatments like composting or anaerobic digestion rather than landfilling or incineration. This perspective directly applies to hospitals, where large amounts of food waste are generated daily. By segregating food waste from other clinical and general waste streams, hospitals can ensure higher quality composting outcomes while reducing disposal costs and environmental impacts.

In hospital food waste management, Chen et al. (2015) emphasize the importance of maintaining the right carbon-to-nitrogen (C/N) ratio in composting. Since hospital kitchens and wards produce food waste that is high in nitrogen (e.g., rice, vegetables, meat, soups), the C/N ratio is often too low, leading to ammonia release, bad odours, and nutrient loss. To solve this, hospitals can mix food waste with carbon-rich materials like dried leaves, sawdust, cardboard, or garden trimmings. This balances the C/N ratio, supports microbial activity, and improves compost quality, resulting in a stable and nutrient-rich soil amendment. Such a method not only improves hygiene and sustainability but also reduces greenhouse gas emissions.

One of the strongest environmental benefits of composting arises not during the composting process itself, but afterwards through compost utilization. When compost is applied to soil or used in growing media, it can substitute other carbon- or nutrient-rich materials that are otherwise highly greenhouse gas (GHG) intensive to produce. Compost achieves its strongest climate benefits when positioned as a replacement product for carbon-intensive materials (like peat) and energy-intensive inputs (like synthetic fertilizers). Without this substitution effect, the climate performance of composting is often less favorable due to direct emissions from the composting process (Boldrin, 2009).

From a sustainability perspective, the composting method contributes to reducing landfill dependency, lowering greenhouse gas emissions, and promoting resource circularity within hospital operations. The reuse of compost for landscaping or local agricultural purposes not only closes the waste loop but also demonstrates how hospital facility management can integrate green practices into daily operations. However, challenges remain, particularly in ensuring the continuity of composter functionality, as high repair and maintenance costs may hinder long-term implementation. Despite these limitations, the results suggest that aerobic composting represents a viable strategy for hospitals seeking to enhance sustainability while addressing food waste more effectively.

The findings from this study indicate that during the years of composter operation, food waste was collected and processed in bulk without source separation. Although this approach simplified handling, it limited the potential for more precise waste characterization and targeted reduction strategies. In hospital food services, waste can generally be categorized into three streams: plate waste from patients and staff dining, preparation waste generated during meal production in the main kitchen, and spoiled stocks arising from over-purchasing or inadequate storage management. Each category reflects different root causes of inefficiency, and their aggregation into a single waste stream obscures opportunities for process improvement.

Plate waste is often influenced by patient dietary requirements, menu acceptability, and portion control practices. Preparation waste is primarily linked to kitchen workflow, cutting losses, and food handling routines, while spoiled stocks arise from supply chain management and forecasting errors. Without separating these categories, facility managers face challenges in identifying where interventions would yield the greatest reduction in waste generation.

From a sustainability perspective, the absence of segregation represents a missed opportunity for applying lean management principles. Lean thinking emphasizes the identification and elimination of non-value-adding activities, with the objective of reducing inefficiencies across production systems.

Hospital food waste is usually high in nitrogen from items like meat, vegetables, and soups, which can cause ammonia release, odours, and nutrient loss (Chen et al., 2015). By implementing composting of food waste from kitchens, cafeterias, and patient wards, hospitals can reduce their share of this waste stream. Using United Nations Environment Programme (UNEP)'s methodology, hospitals can measure how much food waste they generate, track it over time, and assess how composting interventions reduce waste (UNEP, 2021). Composting in hospitals aligns with SDG 12.3, because it helps divert food waste from being discarded (which often leads to greenhouse gas emissions, landfill usage, etc.) and instead uses it productively (nutrient recycling, soil improvement). Hospitals can thus contribute meaningfully to both local sustainability and global waste reduction targets. Within hospital food services, applying lean management would mean addressing waste at its source rather than relying solely on end-of-pipe solutions such as composting. For example, regular audits of kitchen preparation processes could reveal opportunities to optimize ingredient use, while improved demand forecasting could minimize spoilage of stock. Similarly, feedback mechanisms on patient consumption patterns could guide adjustments in portion sizes and menu planning, thereby reducing plate waste. Previous studies in healthcare and hospitality have shown that lean-based interventions can substantially reduce operational inefficiencies and food loss when combined with waste audits and monitoring systems (Tuppura et al., 2016; Dora et al., 2013).

Another important factor in the performance of the hospital's composting system is equipment maintenance. The machine was operated continuously from 2018 without scheduled servicing or the addition of enzymes, both of which are essential for optimal decomposition. The lack of preventive maintenance and biological supplementation not only shortened the machine's efficiency but also slowed down the composting process, leading to potential operational inefficiencies. Prior studies emphasize that composting systems, whether mechanical or natural, require consistent monitoring of inputs, microbial activity, and system performance to ensure sustained efficiency and high-quality outputs (Kumar et al., 2010; Adhikari et al., 2008). In the absence of such maintenance, even well-designed systems may experience reduced performance and premature breakdown.

While composting is the most common method for managing hospital food waste due to its simplicity and ability to generate nutrient-rich fertilizer, biochar production represents an alternative approach with distinct advantages. Biochar, produced through pyrolysis of organic waste at high temperatures under limited oxygen, yields a stable carbon-rich material that can persist in soil for centuries, thereby serving as a long-term carbon sink and soil conditioner (Hossain, Strezov, Chan, Ziolkowski, & Nelson, 2010).

Compared to compost, which decomposes relatively quickly and may release greenhouse gases if poorly managed, biochar offers greater stability, enhances soil aeration and water retention, and contributes directly to climate change mitigation. For hospitals, adopting biochar technology could complement or substitute traditional composting, particularly where long-term soil enrichment and carbon sequestration are prioritized alongside waste reduction.

By integrating lean management into facility management practices, hospitals could move from a reactive to a proactive model of food waste management. Composting remains a valuable strategy within the circular economy framework, but without upstream interventions and consistent equipment maintenance, the system risks perpetuating a cycle where large volumes of waste continue to be generated, and processing efficiency declines over time. The implementation of lean-based monitoring systems, combined with segregation of waste categories and a structured maintenance plan for composting equipment, could significantly enhance both the efficiency of hospital food services and the sustainability of composting initiatives.

Future research may explore comparative analyses between traditional composting and black soldier fly (BSF) bioconversion. While composting has been shown to provide a practical and accepted solution for hospital food waste, BSF larvae offer an alternative pathway for rapid waste reduction and the production of high-value outputs, such as protein meal and frass fertilizer. A comparative study would enable researchers to assess not only the environmental outcomes but also the economic feasibility and operational suitability of each method in institutional contexts such as hospitals.

Compared to BSF bioconversion, refer to Table 1, composting remains more feasible for hospitals due to simplicity, safety, and acceptance. However, compost has lower market value, underscoring the importance of embedding it within a circular model that yields direct returns to hospitals. Implementing such a system could reduce disposal costs, enhance food supply resilience, and strengthen hospitals' role in national green initiatives.

Table 1: Waste composter versus BSF bioconversion

Aspect	**Composter**	**BSF Bioconversion**
Main Agent	Microbes (bacteria, fungi)	Black Soldier Fly larvae
Timeframe	Weeks to months (1–2 weeks if mechanized)	7–14 days (very fast)
End Product	Compost (soil fertilizer)	Protein-rich larvae (animal feed) + frass fertilizer
Waste Reduction	60–70%	80–90%
Economic Value	Low (compost often given free)	High (protein meal, animal feed market)
Suitability	Hospitals, agriculture, landscaping	Industrial scale, farms, protein production
Complexity	Low–moderate (simple monitoring)	Higher (needs insect farming expertise)

Ultimately, this study underscores that while technological solutions such as composting are essential, they must be complemented by managerial and operational strategies that address the root causes of waste generation. By embedding lean management principles alongside circular economy practices and ensuring proper machine maintenance, hospitals can achieve a dual benefit: reducing unnecessary food losses while ensuring that unavoidable waste is transformed into valuable resources for sustainable healthcare delivery.

CONCLUSION

This study concludes that aerobic composting using a mechanical composter provides a sustainable solution for hospital food waste management, converting an estimated 50 kilograms of waste daily into valuable organic fertilizer. To maintain machine efficiency and extend its lifespan, preventive maintenance is essential for ensuring optimum results. The process also opens opportunities for a closed-loop system, where farmers benefiting from hospital-produced compost can return fresh produce to the hospital, strengthening community collaboration. Looking ahead, the black soldier fly method presents a promising natural alternative for bioconversion; however, its high costs highlight the need for government support to promote adoption and enhance public interest in sustainable waste management.

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