A SYSTEMATIC REVIEW ON FOOD WASTE MANAGEMENT STRATEGIES

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Our research aims to identify and evaluate effective strategies to improve sustainability by reducing food waste. We explore the use of organic matter and microbial inoculants to enhance composting and biodegradation processes. Using systematic review, we identified and evaluated the most effective strategies for food waste management. PubMed and Google Scholar were searched using keywords like “food waste OR agricultural waste” and “composts OR digests,” resulting in 585 relevant papers. Rayyan AI was used to filter and narrow these to 44, excluding irrelevant publications. The most common technique was composting, including windrow, bin, vermicomposting, and anaerobic digestion. These methods were effective in minimizing food waste. The study also assessed the role of microbial inoculants in accelerating biodegradation. Key factors influencing effectiveness include biodegradation rate, microbial activity, CO2 emissions, and compost quality. Aerobic conditions and microbial inoculants significantly improved biodegradation, especially in composting banana peels. We recommend implementing food waste management policies, improving treatment technology, fostering collaboration, recovering energy, standardizing labelling and educating the public.

Key words: Food, waste, management, strategies, composting, biodegradation

1. Introduction

Major environmental problems have emerged because of the world's population growth, demographic shifts, and increased human activities. Deforestation, pollution of land, water and air represent some of the most challenging problems facing our society. The likelihood that these damaging effects, including the effect of greenhouse gases, could contribute to global climate change and endanger human survival. Prevention measures must be taken to mitigate the negative effects of human activity, particularly focusing on the large volumes of waste produced by the agricultural, animal, and horticultural sectors as well as the food production and processing industry (Shilev et al., 2007). In recent years, food waste generated from different sources in the production chain has received attention from all levels of society. This includes the generation of large amounts of waste that occupy habitual land, the emission and release of gases that negatively affect human health, environmental pollution of fertile soils, waters, air, loss of biodiversity, disruption of the balance of the nitrogen and phosphorus cycle, etc. Based on the report published by WRAP - in Great Britain, about 2 million tons of food is thrown away after it has not been consumed in time and the food has spoiled, whether fresh foods or foods that have not yet been opened (WRAP, 2015). The development of sustainable and ethical systems of food production and consumption requires a deep commitment to food waste management. Scientific literature often uses terms such as "food waste" and "food loss" to describe materials that were originally intended for consumption by consumers, but which, for various reasons such as spoilage, contamination, damage during transport, have not been consumed (Girotto, F. et al., 2015). "Food loss" is defined as food materials that are intended for consumption by consumers, but which during the stages of harvesting, transport, processing, food supply, retail and wholesale, are damaged, contaminated and lose their nutritional characteristics. (FAO, 1981; Gustavsson et al., 2011). "Food waste" according to the European Fusions Project is defined as: "Any food, including non-edible parts, removed from (lost or diverted from) the food supply chain in order to be recovered or treated appropriately (including composting, land use, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewerage, disposal, landfilling or dumping at sea"(Ostergren et al., 2014). Reducing food waste and losses along the food supply chain is essential for strengthening food security and sustainability in the world. According to the Food and Agriculture Organization (FAO), one third of food production along the food chain is wasted or lost (Gustavsson et al., 2011). By adopting measures such as improving infrastructure, optimizing production, educating consumers, and distributing surplus food, stakeholders can significantly contribute to reducing the harmful effects of food loss and waste on food security and environmental sustainability. Promoting efforts at every level of the supply chain and among consumers, a more sustainable approach to food production and consumption can be achieved, thus reducing the global burden of food waste. Effective strategies for dealing with food waste will be presented through this systematic review, showing some of the most effective methods used in different countries. Fig.1 summarizes the key elements used and identified on the literature systematic review on food management strategies. It emphasises four main areas: recommendation for improving practices, composting techniques, the use of microbial inoculants and the research methodology.

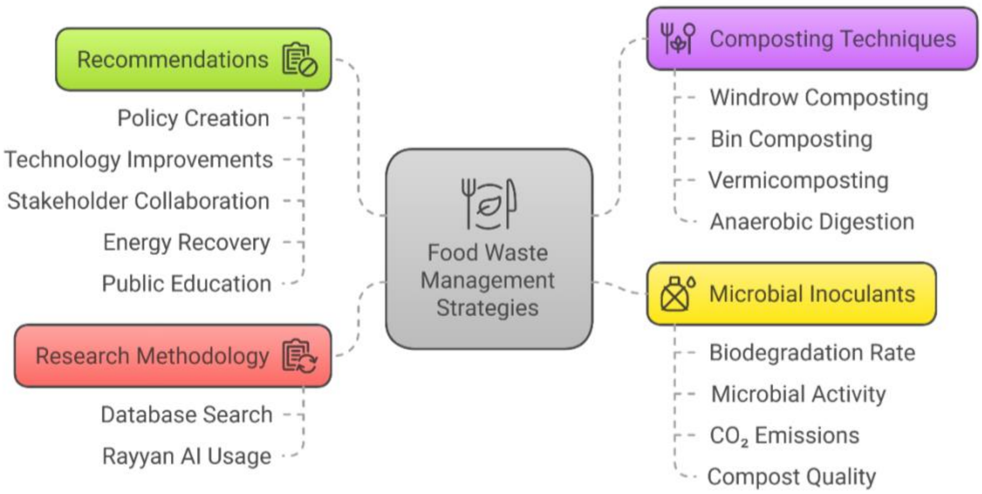

Figure 1. Overview of food waste management strategies identified in a systematic literature review

2. *Materials and methods*

A systematic review methodology was used to identify effective strategies for food waste treatment and management. The review aimed to highlight key variables influencing food waste generation and its proper treatment, with attention to factors that support or hinder reduction initiatives. Given the broad scope of the field, systematic review is suitable for extracting focused results (Kitchenham, 2004). This method follows a defined search strategy and ensures accuracy (Petticrew & Roberts, 2006). The Fig. 1 presents a visualisation of each steep followed during the review process. To define inclusion/exclusion criteria and explore food waste management strategies, an initial search was conducted in PubMed and Google Scholar. Criteria included only studies addressing food waste management. Using the Boolean operator "OR," the keywords "food waste OR agricultural waste" and "composts OR digests" were applied (Stangherlin & Barcellos, 2018). PubMed resulted in 7806 studies, Google Scholar 19,000. From Google Scholar, the first 100 were screened; PubMed filtering yielded 485, summing up to 585 relevant publications.

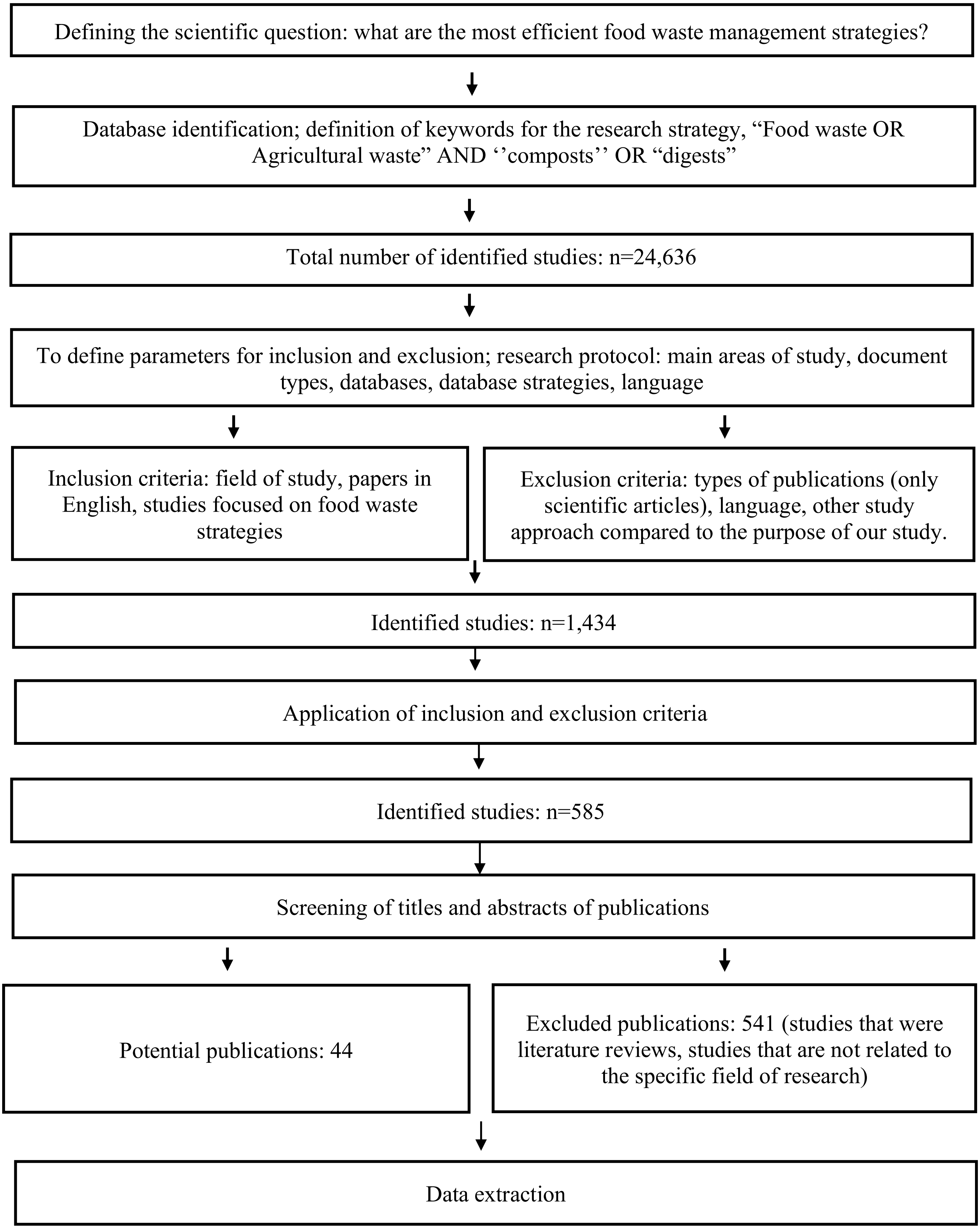

Figure 2. Research flow diagram adapted from Sampaio and Mancini (2007), Petticrew and Roberts (2008), Kitchenham (2004), Tranfield et al. (2003) and Bossle et al. (2016)

After data extraction, the first step involved importing data into the Rayyan system (Ouzzani et al., 2016), a web-based tool designed to assist researchers in conducting systematic and scoping reviews. A file was created to import selected scientific articles from PubMed and Google Scholar. Rayyan's overview menu includes tools for search, import, conflict resolution, analysis, and reporting. An initial exploration defined inclusion and exclusion criteria, with keywords entered the databases yielding 485 articles from PubMed and 100 from Google Scholar. This data was reviewed using Rayyan's screening menu, where each abstract was read and studies were either included or excluded based on their relevance to food waste management strategies. A total of 44 papers were selected 33 from PubMed and 11 from Google Scholar. These were fully analysed, focusing on methodologies, results, and final products. Data were organized in Excel using variables like author, year, title, abstract, methodology, results, and energy loss to evaluate the effectiveness of various food waste treatment strategies.

3. Results and discussion

Based on data from 44 scientific articles, Fig.2 illustrates the most common methods used for the treatment of food waste. 40% of the articles used composting as an effective method for food waste management given the attributes such as simplicity, low cost and effectiveness in converting organic waste into useful compost. The least used method in the articles was anaerobic fermentation with 10%. This technique requires more specialized application in the production of specific bio-products such as organic acids. The presented distribution of this methods gives insights on focusing on practical and sustainable waste management strategies that are beneficial for generating energy and environmentally friendly.

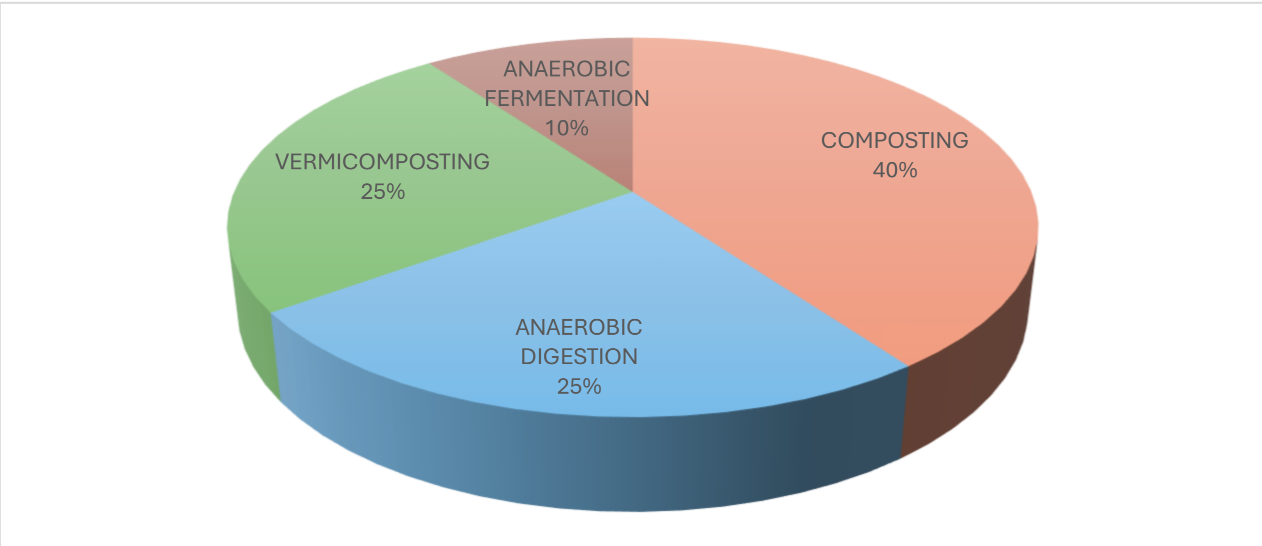

Figure 3. The most common methods used for treating food waste

The quality of the final products obtained from waste treatment methods is inflected by several factor explained in table 1 that involve the used organic material, specially during composting, anaerobic fermentation and anaerobic digestion. All of three processes depend on the organic matter content, pH level and the presence of essential nutrients like nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur, which are necessary for microbial activity and the production of final products with high quality such as compost, biogas, or organic fertilizers. On the other hand, parameters controlling the environment differ: composting requires attention to texture and aeration, reflecting its aerobic nature, whereas anaerobic fermentation and digestion are influenced primarily by temperature and inhibitory substances or toxins that may slow down or disrupt the microbial processes. Maturity and contaminants specifically affect composting, indicating the importance of the compost being fully decomposed and free of harmful substances (Rashwan et al. 2021). In contrast, anaerobic processes require careful management of reactant concentrations and retention time to ensure effective breakdown of materials and maximum production of biogas or other useful by-products.

Table 1. Factors that affect the quality of final products

Composting	**Anaerobic fermentation**	**Anaerobic digestion**
Organic matter content	Organic matter content	Organic matter content
Presence of nutrient elements (nitrogen, phosphorus, potassium, calcium, magnesium, sulphur)	Presence of nutrient elements (nitrogen, phosphorus, potassium, calcium, magnesium, sulphur)	Presence of nutrient elements (nitrogen, phosphorus, potassium, calcium, magnesium, sulphur)
pH level	pH level	pH level
Microbial population	Microbial population	Microbial population
Texture	Temperature	Temperature
Maturity	Inhibitors and toxic compounds	Inhibitory substances
Contaminants	Reactant concentration	Retention time
Aeration		

In reviewed articles, the key parameter that determine the quality of the final product are type and the origin of food waste. It is common that food waste is mixed with other types of waste such as municipal solid waste, agricultural waste, green waste, or semi-solid residues from wastewater treatment (sewage sludge). In Bavaria, Germany, a case study investigated the potential use of a mixture of sewage sludge combined with dairy farm waste via anaerobic digestion (Sembera., 2019). This case study demonstrates specific parameters and biogas production results at the Moosburg wastewater treatment plant, which operates a co-digestion facility processing a high-percentage mixture of sewage sludge, food waste, and dairy waste. The waste mixture ratio and the organic loading rate are defined (tab. 2), significantly showing an increase in methane production (300% ± 50%) that indicated the effective synergistic effect of mixture of food waste with other types of waste. This boost biogas yield and can improve energy recovery potential. The annual operational costs are estimated at €48,000 ± 5,000. However, the common challenges during this process include monthly buildup of solid residues (5 m^3), rising the levels of nitrogen load (65%), and a decrease in hydraulic retention time (HRT) to 1.18 days. These factors must be managed carefully to optimize the digestion process and maintain system stability. The use of sequencing batch reactors (SBR) with lactose for denitrification as a side treatment suggests a tailored approach to address nitrogen-related issues (Sembera, 2019).

Table 2. Biogas Production from Anaerobic Digestion: Case Study in Bavaria

Parameter	WWTP Moosburg (Bavaria, Germany)
Type of waste	Sewage sludge, food waste, dairy waste
Waste Mixing Ratio	35:47:18 (Sewage Sludge: Food Waste : Dairy Waste)
Organic Loading Rate	3.0 kg VS/(m^3 day)
Increase in Methane Production	300 ± 50%
Annual fees	€48,000 ± 5,000
Challenges	Monthly accumulation of solids (5 m^3), increase in nitrogen load (65%), loss of HRT (1.18 days)
Side treatment	Sequencing batch reactors (SBR) using lactose for denitrification
Potential for Energy Neutrality	High potential

Historical Context	Technology dating back to 1906

Different source of food waste among the articles were observed. The data shown in Fig.3 reveals that the households food waste has the highest impact in food waste generation (40%), indicating that consumer behaviour at home seeks for intervention. The lowest contributors to food waste generation were small-scale retailers and markets (8%), suggesting more efficient control or limited data at this stage. This distribution of food waste sources suggested that the household and consumer waste play a significant role in total food waste. Tackling this issue effectively would require focused public awareness campaigns, better food planning tools, and education on portion sizes and expiration date interpretation.

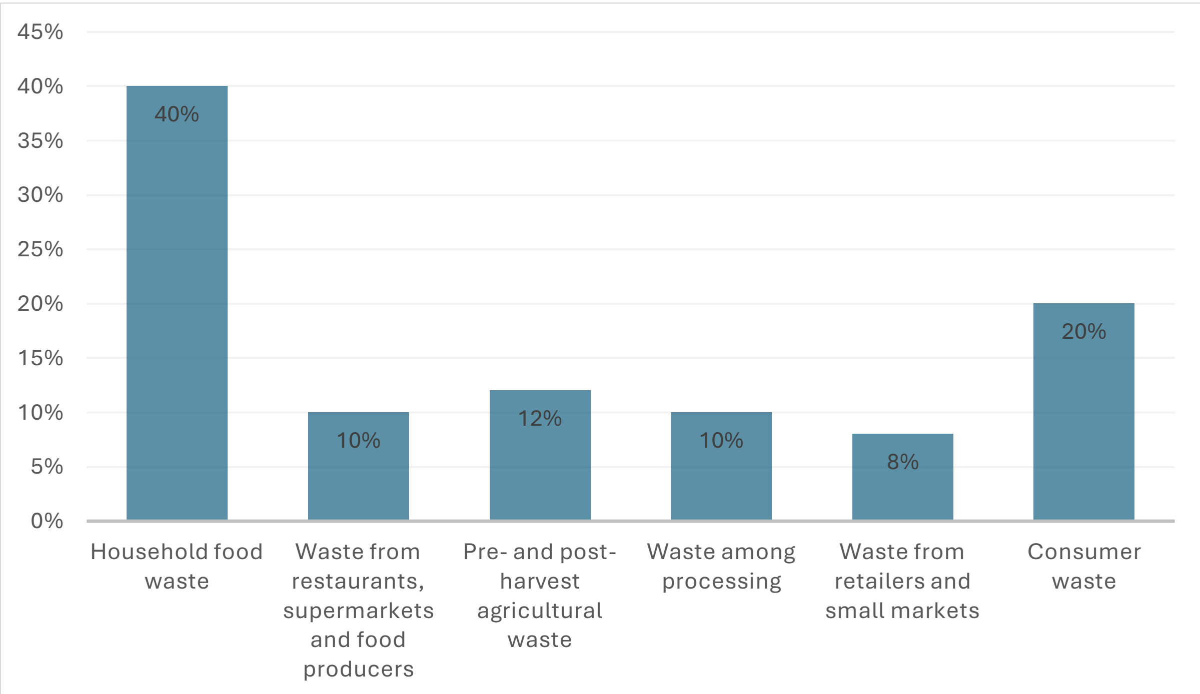

Figure 4. Percentage distribution of the main food waste sources

As mentioned before, food waste can be combined with other waste types. Tab. 3 presents a classification of organic co-materials that diversify and enhance wood waste treatment. Green waste, animal manure, agricultural waste, biosolids, sewage sludge, and processing waste present a scope of material suitable for food waste treatment along composting or anaerobic digestion. This approach, play a positive role in the environmental aspect, reducing amounts of waste and creating new opportunities to recover energy by enhancing the nutrient profile and efficiency of end products like biogas and compost. Challenges in real world implementation are numerous such as waste contamination and regulatory and infrastructure constrains regarding biosolids and sewage sludge. (Gianico et al., 2021)

Table 3. Materials used together with food waste during its treatment process

Green waste	Organic materials such as: grass clippings, leaves, garden maintenance waste
Animal manure	Livestock waste, such as cow dung, poultry litter, or horse manure.
Agricultural waste	Crop residues, straw, husks or stalks left over from agricultural activities.
Sewage sludge	Organic solids separated during wastewater treatment processes.
Biosolids	Organic materials derived from wastewater treatment processes.
Fruit and vegetable processing residues	By-products created during fruit and vegetable processing, such as peels, seeds, and pulps

Combining food waste with microorganisms during composting process has showed positive results in enchasing the efficiently, safety and the nutritional values of the final product-compost. Rhizosphere microbiomes help breaking down the organic matter and boosting the compost quality due to their presence in plant-root environments (Ding et al., 2023). Thermo-tolerant actinomycetes present ideal microorganisms to be used during composting under high temperature, impacting the speed of decomposition and the compost maturity, specially Thermoactinomyces vulgaris A31 (Ke et al., 2010). Lactobacilluiss spp. and Serendipita indica can be used in composted made from sewage sludge to reduce mycotoxin and heavy metals. (Youssef et al., 2020; Zhan et al., 2023). Thermophilic bacteria play a major role as breaking dwon components of lignocellulose-rich materials present in dairy manure imporving composting attributes. (Zhang et al., 2021). Bacillus strains increase phosphorus availability making it useful during the composting of kitchen waste. (Zhang et al., 2021).

Table 4. Microorganisms used and their effects during the food waste decomposition process

Used microorganism	Effect	Authors
rhizosphere microbioms)	In peer-reviewed scientific articles, the importance of the rhizosphere microbiome focuses on bacterial compost during wilting and composting from household food waste.	Ding et al. 2023
thermo-tolerant actinomycetes	Thermoactinomyves vulgaris A31 has been used in many works due to its role in composting food waste and its impact on compost maturity.	Ke et al., 2010; Levis et al., 2010
lactobaciles	The effect of lactobacillus colonies is discussed in reducing the risks from mycotoxins and heavy metals in contaminated sewage sludge and composts.	Youssef et al., 2020; Zhan et al., 2023
serendipita indica	This specific type of mushroom can reduce the risks associated with contaminated sewage sludge and its composting.	Youssef et al., 2020
thermophilic bacteria phosphate-digesting bacteria (bacillus)	Thermophytic bacteria have found use in the degradation of lignocellulose during composting of dairy manure. Bacillus species are known for their role in regulating microbial interactions to improve phosphorus mobilization during the composting of kitchen waste.	Zhang et al., 2021
trametes versicolor	These fungi are effective in reaching compost maturity when mixed with spent coffee grounds, olive mill	Hachicha et al., 2012

	wastewater sludge, and organic poultry manure.

4. *Conclusion and recommendation*

Effective strategies for food waste management are essential in addressing the global issue of uncontrolled food loss across the entire supply chain—from primary production to post-consumption. Reducing food waste can significantly save resources such as water and energy used in food production and distribution. The current trajectory of unsustainable food systems worsens environmental impacts, especially when these resources are spent on food that ultimately goes to waste. Minimizing food waste not only reduces environmental harm but also enhances food security. The foundation of food waste reduction policies should involve active stakeholder participation. In Fig. 4 are presented recommendations to reduce food waste.

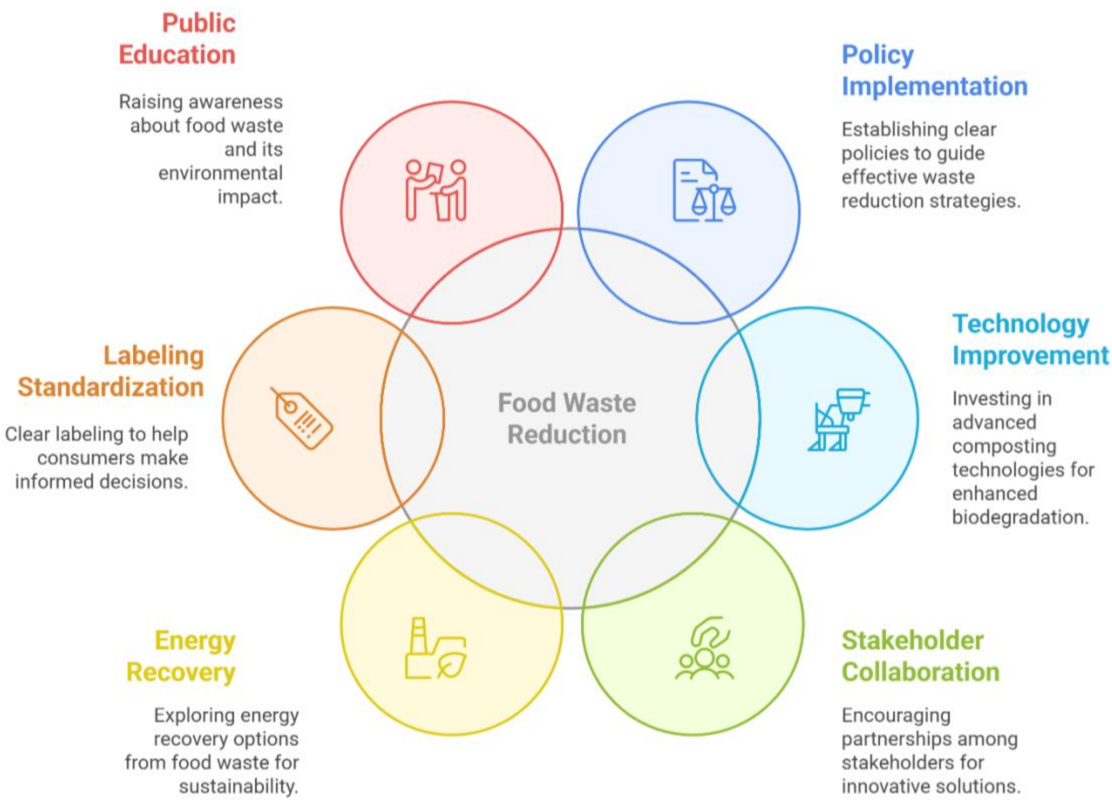

Figure 4. Strategies for Reducing Food Waste

Some of the proposed recommendations are:

- Policy development-develop and implement food waste laws and policies at the local, national and international levels to encourage businesses, producers and consumers to use sustainable food waste management practices
- Technology integration- provide the necessary resources to support research and advancement of innovative food waste treatment technologies, with a primary focus on suitability, environmental sustainability and efficiency.
- Collaboration-promote collaboration between government bodies, non-governmental organisations, corporations and research institutions to create a comprehensive and coordinated food waste management strategy.
- Creating methods to convert food waste into energy sources-using methods to transform food waste into energy from renewable sources helps to provide energy in a sustainable way, while also addressing environmental issues. Our efforts to convert food waste into energy and to highlight the possibility of producing clean energy from organic waste help to create a more sustainable and environmentally friendly image.
- Standardized production date labelling- promote and standardize the expiration date on food products to minimize confusion and prevent the throwing away of food that may still be edible. Educate consumers on the meaning of food declarations by distinguishing between ‘’use by” and “best before”
- Social education: Develop educational programs to inform people, families and companies about the negative effects of food waste and the benefits of implementing efficient waste management techniques.

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