Food Waste: A Driver to Sustainability and Innovation in Modern Food System

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1. ABSTRACT

Food loss and waste have emerged as critical issues worldwide, driven by a range of factors occurring throughout the food supply chain. These factors beginning at the production and harvesting stage, continuing through processing, packaging, storage, transportation, and distribution, and finally at the consumer level. At each of these stages, a substantial amount of food are loss or wasted; these not just gives outcomes in the loss of valuable resources such as water, energy, and labor but also has consequential environmental and economic consequences. However, if we look beyond confines food waste is not merely waste but a solution to sustainable practices once it is handled properly, it is usable for making valuables product, extracting bioactive compounds, Nutraceuticals, biofuels, animal feed etc. This article addresses on how food waste can be handle in a sustainable and innovative way in modern food System.

Keywords: Food waste**,** valuables products, bioactives compounds, Nutraceuticals

2. INTRODUCTION

With the steady rise in global population, the demand for both basic needs and evolving wants, particularly food has grown significantly. This surge encompasses all forms of food, whether raw products to semi-processed and fully processed foods. While efforts to meet this growing demand, there has been a substantial increase in food waste and food loss, now recognized as one of the most pressing challenges in modern food systems. This issue impacts not only food security; it also has profound implications for environmental sustainability, economic stability, and inclusive societal well-being.

The terms "food loss" and "food waste" are often used interchangeably, but they refer to distinct parts of the supply chain. According to (FAO 2023**) Food loss** refers to a decrease in mass (dry matter) or nutritional value (quality) of food that is originally intend for human consumption. These losses are effectively caused by inefficiencies in the food

supply chains, Such as poor infrastructure and logistics, lack of technology, insufficient skills, knowledge and management capacity of supply chain actors, and lack of access to markets. Furthermore, natural disasters play a role. **Food waste** refers to food appropriate for human consumption being discarded, whether or not after keeping beyond its expiry date or left to degrade. This is because food has spoiled but it can be for other reasons such as oversupply due to markets, or individual consumer shopping/eating habits.

In today's society, food waste derived from households (kitchens) and industries poses a critical environmental concern due to its underutilization and the lack of sustainable recycling. Moreover, food waste and industrial waste are sources of untapped bioactive compound and value added products. Although numerous possibilities for food waste management, the transformation of this waste into valuable resources through sustainable approaches is bounded (Sarker, A et al. 2024).

According to the United Nations Environment Programme (UNEP, 2024), approximately 1.05 billion tonnes of food are wasted globally in 2022. These averages out to 132 kilograms per person annually. The household sector is the primary contributor, accounting for about 60% of this waste. Food services such as restaurants contribute around 28%, while retail outlets are responsible for the remaining 12%. This overwhelming figure underscores the urgency of tackling food waste as a global priority. In fact, the issue has be directly addressed in the United Nations Sustainable Development Goal (SDG) 12, particularly Targeting 12.3, which calls for halving per capita food waste at the retail and consumer levels by 2030 and reducing food losses along production and supply chains.

While enormous amounts of food is discarded, millions of people around the globe still go hungry. According to the 2023 Global Hunger Index, the world scored 18.3, indicating moderate levels of hunger with only modest improvements in recent years. Take India, for instance. As per UNEP's 2021 Food Waste Index, Indian households alone waste more or less 68.7 million tonnes of food every year—about 50 kg per person. Meanwhile, food insecurity remains a persistent challenge for a significant portion of the population (Gogoi, M. et al. 2025).

3. CAUSES OF FOOD LOSS AND WASTE

The reasons behind food loss and waste (FLW) vary depending on a country's income level, infrastructure, and level of urbanization. In low- and middle-income countries, food is regularly strayed during Harvesting, production, improper handling, and storage, largely due to inadequate infrastructure, poor transportation systems, lack of refrigeration, and limited access to modern processing technologies. In developed economies, the majority of waste happens at the consumer and retail levels. Where over-purchasing, confusion over expiration labels (i.e. "best before" or "use by" date) poor storage practices, and preparing excessive portion sizes are among the most common causes.

Human error during processing also plays a role. According to Bhatia et al. (2023), It was estimated that about 30 to 40% of the food produced by farmers globally, was unconsumed and more than 10% of food was wasted at the manufacturing stage, often due to inadequate training of employee or a lack of standardized procedures.

Sector-Specific Waste like in Higher Education and Food service establishments, including university cafeterias and small canteens, are significant contributors to food waste. A study by Durán-Sandoval et al.(2024) in Chile found that poor inventory practices, over-purchasing of perishables, and inefficient kitchen management are among the major reasons for food waste in higher education food services. Such findings highlight the need for tailored interventions that address specific challenges in different sectors of the food industry.

Global Pattern Research by the Swedish Institute for Food and Biotechnology (SIK), commissioned by (FAO. 2011) revealed interesting Geographical patterns. In industrialized countries, consumers waste 95–115 kg of food per person annually. In contrast, consumers in Sub-Saharan Africa and South/Southeast Asia waste only 6–11 kg annually. However, developing nations are experiencing significant losses during production due to insufficient infrastructure and logistics. This contrast illustrates how both extreme inefficiencies in production and overconsumption and must be address in tandem to reduce food waste globally.

4. ENVIRONMENTAL IMPACT OF FOOD WASTE

Food loss and waste have a much deeper impact than just throwing away leftovers or spoiled items. When we discard food carelessly, especially in open dumping sites, it starts to create foul smells that not only make the area unpleasant but also become a breeding ground for pests and diseases. People living nearby often have to deal with unhygienic conditions that can seriously affect their health. Over time, these dumping areas grow bigger and bigger. Mountains of waste start to build up, taking over land that could have been use for better purposes—like farming, housing, or green public spaces. It becomes a visible reminder of how much we throw away without thinking of the consequences.

As the waste breaks down, it releases methane gas, which is a major contributor to climate change. Methane is far more potent than carbon dioxide when it comes to trapping heat in the atmosphere. So, something as simple as tossing out uneaten food is actually adding to the planet's warming problem. Food loss and waste account for 8-10% of annual global greenhouse gas emissions – nearly five times the total emissions from the aviation sector – and contribute to considerable biodiversity loss, using up almost a third of the world's agricultural land. (UN Environment Programme (UNEP) 2024)

It's not just the land and air that suffer—water sources are at risk too. When food waste are dump near rivers or lakes, harmful substances can leak into the water, making

it unsafe leading to serious health problems for communities that depend on those water bodies. Also, Farmers grow crops, workers process and package them, and a lot of energy, fuel, and water go into getting food onto our plates. When food ends up in the trash, all those resources go wasted too—not to mention the time and labor of the people involved.

There's an economic cost as well. Sellers lose money when food expires on store shelves and consumer's waste money when they buy more than they can use. In a world where many people still go hungry, this kind of waste is hard to justify. Alongside the economic waste, the ethical dimension is just as troubling. While vast quantities of food are discarded, over 820 million people worldwide face chronic hunger and under-nutrition. The contrast between abundance and deprivation highlights the urgent need for better food distribution systems and equitable access to nutrition (Galactic 2025).

5. VALORIZATION OF FOOD WASTE

Despite its challenges, food waste also presents unique opportunities. Through valorization—converting waste into valuable products—we can transform a global liability into a sustainable resource. Here are some innovative approaches to food waste valorization:

5.1 Bioplastics

Bioplastics are derive from renewable biological sources such as plants, starch, or agricultural by-products such as Potato peels, which form up to 30% of potato chip processing waste, can be convert into biodegradable bioplastics—reducing pollution and creating value (Mogra et al., 2021). Bioplastics are a type of plastic material, They are biodegradable or compostable under certain conditions unlike plastic. Fruit and vegetable byproducts rich in nutrients was used to make edible films, offering sustainable packaging alternatives (Kaur, 2023; Shaji & Hovan, 2023). Hence, they reduce dependence on fossil fuels and help mitigate plastic pollution by being biodegradable. They are increasingly use in packaging, disposable items, and even in automotive and medical applications.

5.2 Aquatic Waste Utilization

From the fishing and seafood industries waste like fish bones, shells, and seaweed residues are produce in large quantities. These wastes are processed into useful products such as fish oil, collagen, chitin, and fertilizers. At the moment chitosan based edible or biodegradable film and packaging has gained significance interest across various industry due to its natural antimicrobial compound, non-toxicity, biodegradability Smart biodegradable, edible coatings and films based on chitosan and beeswax–pollen grains for the postharvest preservation of Le Conte gave good result. Which was considered safe and effective coating for the fruit preservation (M. Sultan et al. 2021). Efficient use of

aquatic waste helps reduce environmental pollution and adds value to what would otherwise to be discarded.

5.3 Agro-waste

Agro waste refers to the leftover plant and crop residues produce during farming and food processing, such as bagasse, straw, husks, peels, pulps, stems, roots and shells. Instead of burning or discarding this waste, it can be transformed into useful products like compost, bio-energy, paper, or raw material for bio-plastics. Using agro waste effectively supports sustainable agriculture and reduces the environmental burden. In addition, agro-waste like cabbages, kale, and broccoli has been explored for its rich bioactive compounds with antioxidant and anticancer properties (Khaled et al. 2025).

5.4 Meat Rendering

It means recycling animal by-products from slaughterhouses and meat processing plants. Through rendering, fats and proteins were separated and processed into products like tallow, meat and bone meal, and animal feed ingredients. Rendering recovers fats and proteins from meat byproducts to make soaps, lubricants, and fertilizers—diverting waste from landfills and creating economic value (NARA, 2025). This process helps manage waste, reduces disposal problems, and creates useful resources for various industries, including pet food and bio-fuels.

5.5 Nutraceuticals

Nutraceuticals are define as food-derived products that provide health benefits beyond basic nutrition. They include functional foods, dietary supplements, vitamins, probiotics, and bioactive compounds that can help prevent or manage diseases and promote overall health. Wineries and juice industries produces a large amount of Grape skins, mango peels, and waste tea leaves, which are valuable sources of bioactive compounds like resveratrol, caffeine, and carotenoids, which support human health (Nasri et al.2024;Liu et al., 2023). The demand for nutraceuticals is growing as people look for natural ways to support a healthy lifestyle.

5.6 Biofuels

Biofuels are renewable fuels made from biological materials like crops, waste oils, or agricultural residues. Food and agricultural waste was increasingly used to produce ethanol, biodiesel, and biogas through anaerobic digestion—providing renewable energy and reducing reliance on fossil fuels (Guo et al., 2015; Bhatia et al., 2023). Common types include biodiesel, bio-ethanol, and biogas. They are helping to lower greenhouse gas emissions and support energy sustainability.

5.7 Organic Fertilizers

Organic fertilizers was mainly produced through anaerobic digestion, aerobic composting by microorganisms, chemical hydrolysis (using acidic or alkaline methods at

temperatures between 600–1000 °C), or the natural breakdown of organic matter in place (Liu, Z. et al., 2023). These methods transform biodegradable waste into nutrient-rich soil amendments that improve soil health and support sustainable agriculture.

5.8 Animal Feed

Animal feed is any material used to provide balanced nutrition to livestock, poultry, and aquaculture species. Producing high-quality animal feed supports healthy animal growth, improves food production efficiency, and helps utilized agricultural or food processing waste effectively. Discarded vegetables like cauliflower and romanesco was used as nutritious feed for livestock, supporting circular agriculture and reduces dependency on conventional feed sources (Aleisa et al., 2024; Evan et al., 2020).

5.9 Biosurfactants

Biosurfactants are surface-active compound derived from various microorganisms, including bacteria, fungi, and yeast. Unlike synthetic surfactants, biosurfactants are biodegradable and exhibit low toxicity making them environmental friendly. Food Waste from livestock and various food industries such as whey from the dairy industry can be repurpose as a substrate for biosurfactant production (Liu, Z. et al. 2023).

TABLE 1 : VALORIZATION OF FOOD WASTE

Waste Source	End Product	Use Case & Properties with	Reference
Mosambi peel powder and sago starch along	Edible spoons (Fig. 1)	Promising nutritional properties, creating biodegradable, designed to be both safe for consumption and ecologically friendly reducing agricultural waste and plastic cutlery.	Sustainable Food Technol., 2023, 1, 921
Finger millet, refined flour, jaggery, xanthan gum and brewer's spent grain (BSG)	Biobased edible bowl/cake mold(Fig. 2)	Antioxidant activity, biodegradable, and promising approach for producing a safer alternative to plastic-based cake mold/bowl.	Nehra, A et al. (2024)
Papaya skin pectin, wheat flour, gelatin flour, vegetable oil and water	Edible bowls (Fig. 3)	Decompose within 2 to 3 months. An alternative substitute for plastic packaging.	Wulandari. et al.(2023)
Chitosan (Crustacean shells waste), Pomegranate Peel Extract	Edible Films	Exhibited significant antibacterial activity against a food-borne pathogen (E. coli).	Kumar, N(2021)
Agri-food by-products (pumpkin seeds, broken rice and orange pectin) and wastes (quince peel, potato peel, potato pulp, orange peel, pumpkin peel).	Edible Films (Fig. 4)	Stand-alone protective barriers for a wide variety of food products and consumers can safely consume the edible film still intact, if they choose to.	Jorge et al. (2023)
Pomegranate peel and lentil protein	Edible film was used to coat a snack bar	Nutritional value and quality of the snack bars throughout storage	ACS Food Sci. Technol. 2024
Onion skins	Home-compostable packaging	Reducing the amount of fossil plastics in household waste.	packagingeurope.com

	materials, launched by HUID (Fig. 5)		
Animal fat (beef)	Candle (Fig. 6)	Appetizer and makes for the perfect dip for bread.	Caitlyn Fitzpatrick.2017.bestproducts.com
Animal fat (Beef Tallow), Olive Oil, Coconut Oil	Soap(Fig. 7)	Loaded with essential fatty acids and vitamin E and vitamin D that help maintain healthy, glowing skin.	www.SPARROWFNDS.COM
Oranges, mandarins, apples, pears, kiwis, strawberries, bananas, coconut, watermelon, honeydew melon, peaches, persimmons and pineapple.	Dried Fruit Photo supplied by RIND(Fig. 8)	Vitamins, minerals and health-promoting antioxidants	Steven Savage (2022)www.forbes.com
Rice Straw and Sugarcane Bagasse with Orange Peel Addition	Container	Degraded within two months in the soil	EMSE Tibalia et al 2023

Fig. 1: Eidble spoon
Source: Sustainable Food Technol.2023, 1,921

Fig. 2: Biobased edible bowl/cake mold
Source: Nehra A et al. (2024)

Fig. 3: Edible bowls
Source: Wulandari. et al.(2023)

Fig. 4: Edible films produced from agrifood
Source: Jorge et al. (2023)

Fig. 5: Home-compostable packaging materials **(HUID)**
Source: packagingeurope.com
PE Huid Onion

Fig. 6: Candle
Source: Instagram @jeffkepjones , Caitlyn Fitzpatrick.2017.bestproducts.com

Fig. 7: Soap
Source: WWW.SPARROWFNDS.COM

Fig. 8: Dried Fruit Photo supplied by RIND
Source: www.forbes.com

6. BENEFITS OF FOOD WASTE MITIGATION

Mitigating food waste offers various benefits, making it one of the most effective strategies for promoting sustainability:

- Utilizing food waste to produce bioplastics not only helps in minimizing the amount of discarded food but also contributes to reducing reliance on non-biodegradable plastics.
- Fruit and vegetable waste is rich in bioactive compounds that offer health benefits. These compounds are harnessed for use in nutraceuticals and functional foods, with potential to support disease prevention, including conditions such as cancer and cardiovascular disorders.
- Up-cycling food waste into high-value products reduces the burden on landfills and promotes more sustainable waste management practices.
- Processes like anaerobic digestion can convert food waste into biogas, biofuels, and compost, effectively lowering greenhouse gas emissions and supporting environmental protection.
- By reducing landfill and greenhouse gas release, these approaches contribute significantly to environmental sustainability.
- Repurposing food waste also offers economic advantages by enhancing cost-efficiency in material use.

7. CONCLUSION

Addressing food waste requires a comprehensive approach involving assessment, prevention, and mitigation strategies, from better post-harvest practices to smarter consumer behavior and innovative reuse strategies. Reducing food waste isn't just an environmental or economic goal—it's a humanitarian one. With collective effort, we can build a more sustainable, just, and resilient global food system.

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