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FOOD WASTE GENERATION AND MANAGEMENT STRATEGIES AND POLICIES

Insights into the management of food waste in developing countries: with special reference to India

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Abstract
Up to one third of the food that is purposely grown for human sustenance is wasted and never consumed, with adverse consequences for the environment and socio-economic aspects. In India, managing food waste is a significant environmental concern. Food waste output is increasing in Indian cities and towns as a result of the country's urban expansion, modernization, and population growth. Poor management of food waste can have negative consequences for the environment and pose a risk to the public's health issues. This review focuses on the current challenges, management strategies, and future perspectives of food waste management in India. The efficient management of food waste involves a comprehensive study regarding the characterization of food waste and improved waste management methods. In addition, the government policies and rules for managing food waste that is in effect in India are covered in this review.

Keywords Sustainability · Environment · Impact · Valorization · Solid Characterization

Introduction

Before understanding food waste management, we should first learn about food waste. Different workers have adopted different criteria for defining food waste. Whereas Brian et al. (2013) defined food waste as "food that is of acceptable quality and qualified for human consumption but is not consumed because it is squandered either before or after it deteriorates," Parfitt et al. (2010) described it as the "spoilt food arising at the end of the food cycle, which refers to retailers' and consumers' practice." Food waste is defined as food suitable for human consumption that is wasted, whether it is held over its expiration date or left to deteriorate (FAO 2013). Although some amount of food waste occurs commonly at the retail and consumption stages of the food chain, most of it is produced as a result of carelessness or a cautious decision to throw the food away. Food waste is not only confined to the non-utilization of edibles but also includes inappropriate waste of energy, water, and land resources (Tsang et al. 2019). In addition to these losses, significant depreciation of environmental quality should also be taken into consideration (Mishra et al. 2020). The global human population is very much inclined to rise to around 10 billion by 2050, which is accompanied by a substantially raised demand for food all around the globe, thereby crippling the world's food supply structure (Haldar et al. 2022). According to a recent report by the Food and Agriculture Organization (FAO), 750 billion dollars worth of food weighing around 1.3 billion tonnes is wasted globally each year (FAO 2017). India, with a population of over 1.3 billion, produces 0.5 kg of organic waste per individual per day (Paulraj et al. 2019). Hostels, supermarkets, apartments, restaurants, cafeterias in airplanes, and the food processing industry all produce a significant amount of food waste in India. In India, 90 kg of food waste per capita per year was reported in the high-income group, which was 68, and 63 in the middle- and poor sectors, respectively, according to the United Nations Environment Programme's (UNEP) Food Waste Index Report 2021 (Chaudhary et al. 2021). A tremendous amount of food and kitchen waste is piled up annually due to ordinary food waste management practices (Sharma et al. 2021). The 1.3 billion tonnes of food waste produced annually occupy

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roughly 28% of the total agricultural land, which is identical to 1.4 billion hectares of usable cultivable area (Paritosh et al. 2017; Sharma et al. 2021). The United Nations' Sustainable Development Goal (SDG) 12.3 established in 2015 also concentrates on food waste management, with the goal of "halving per head global food waste at the retail and consumer stages and diminishing food losses along production and supply chains, inclusive of post-harvest fall by 2030" (United Nations 2015). This goal is based on a broad understanding of the negative consequences of food losses and waste, which include the waste of land, water, and energy while causing unnecessary greenhouse gas emissions (Närvänen et al. 2020).

When we study the sources of food waste extensively, it mainly falls into four categories, i.e., production of food and its harvesting, food processing, and its storage, domestic food waste, and last retail counters. Crops can be subjected to insect infestations and harsh climates from the time they are planted, resulting in pre-harvest losses. Cultivators who use heavy machinery for crop harvesting also generate food waste because they are unable to distinguish between ripe and immature crops or may collect only a portion of a crop (Kantor et al. 1997). Food waste due to processing is also caused by losses in nutritional value, caloric value, and edibility of crops caused by the extreme range of temperature, high humidity, or the action of unwanted microbes (FAO 2012). Heat along with high humidity creates favorable grounds for the breeding of pests which is a common cause of food waste during storage (FAO 2012). A significant amount of food waste is generated at the retailer's level. When it comes to food, retailers typically have rigorous criteria for appearance. As a result, if fruits or vegetables appear to be bruised, they are frequently not placed on the display. The fishing business wastes a lot of food; in Europe, between 40 and 60% of fish are wasted because they are of inappropriate kind or size (Stuart 2009). The dairy sector is one of many forms of the food business that can be found all over the globe. It produces a wide range of goods, including milk, milk powder, butter, and cheese while also producing a significant amount of solid and liquid waste (Jaganmai and Jinka 2017). Waste from the dairy sector poses a serious environmental danger due to its high organic content. Internationally, 4–11 million tonnes of dairy waste are dumped into the environment annually, posing a severe threat to ecosystems (Ahmad et al. 2019).

In order to understand the challenges of food waste management, we need to understand the characteristics of food waste (Dutta et al. 2021). Carbohydrates, proteins, lipids, and traces of inorganic substances make up the majority of food waste (Paritosh et al. 2017). Strong variations can be seen in the physicochemical properties of food waste, such as in the C/N ratio, moisture content, pH, and, moisture and volatile solids (Abo et al. 2019). Food waste made up of vegetables and rice is heavy in carbohydrates, whereas food trash made up of meat and eggs is high in proteins and lipids (Paritosh et al. 2017). Food waste can be utilized as a feedstock for butanol fermentation because it contains a lot of carbohydrates. Potato peels, whey, and apple pomace contain a very high concentration of carbohydrates making them a suitable substrate for butanol fermentation (Smithers 2008; Kosmala et al. 2011; Li et al. 2015a, b). Kitchen garbage, other food waste, and restaurant waste all contain 84% water, with the remaining 16% of these wastes' weight being made up of solids (Kim et al. 2017). It was noted that the compositional features of food waste from various sources typically varied. To ascertain the changes in compositional content for five distinct forms of food waste, including kitchen waste, a comparative examination was conducted (Ho and Chu 2019). The highest protein content (approx. 26%) was found in household food waste (Haldar et al. 2022).

Food waste management is a significant research subject that has expanded quickly in recent years. There are many excellent examples of research that seeks to manage food waste sustainably; however, these studies typically focus on just one aspect of sustainability, such as its effects on the environment, the economy, or society (Garcia-Garcia et al. 2017). An effective method for managing food waste is to produce methane through anaerobic digestion. The procedure is less expensive, produces less leftover garbage, and uses food waste as a sustainable energy source (Nasir et al. 2012; Morita and Sasaki 2012). The ideal substitute for foods that are good for animal farming but unfit for human eating is animal feeding with only farm animals such as cattle, sheep, and poultry, being relevant in this category (Garcia-Garcia et al. 2017). Composting is another method of sustainable food waste management which is a process of aerobic decomposition of waste. Composting has seen a resurgence in popularity over the past two decades as a strategy for overcoming today's waste management issues, particularly for lowering landfill dumping and the accompanying methane emissions from organic material degradation (Waste & Resources Action Programme (WRAP): Quality Protocol 2007). An alternative method of food waste management is valorization which uses naturally occurring manure rich in nutrients to transform municipal solid waste into energy (Banerjee and Arora 2021). Valorization is the method of giving waste materials or remnants from an economic activity a financial benefit through reuse or recycling in order to produce resources with a positive economic impact (Kabongo 2013). The prominence, timely consumption, and the way food are kept in the refrigerator all have a big impact on how much food waste is generated on daily basis. According to Haldar et al. (2022), there are two types of suggestions for using refrigerators and freezers in order to reduce food waste. The first category of food waste reduction focuses on enhancing information, labeling, and recommendations to persuade consumers to keep potentially wasteful goods chilled or frozen, and the second category includes technological advancements that assist clients in keeping track of their inventories and formulating better meal plans. Besides these techniques, there is a multitude of physical, chemical, and biotechnological methods that can be utilized for food waste management strategies.

Sources of food waste

The generation of food waste (FW) is increasing day by day from diverse industrial, agricultural, commercial, domestic, and other sources due to changing lifestyles and the fast urbanization of the global population. The Food and Agriculture Organization (FAO) estimated almost 1.3 billion tonnes of wasted food are generated annually which is one third of the total food production on a global scale (Gustavsson et al. 2011). FW also leads to the significant loss of other resources like water, land, manpower, and energy. There are several sources such as food processing industries, agricultural waste, and commercial and household kitchens, for the generation of FW illustrated in Fig. 1 (Sharma et al. 2020; Saber et al. 2022). Food waste production in Pakistan is 93, 74, and 118 kg/capita/year (JICA 2015); in India 63, 68, and 90 kg/capita/year (Grover and Singh 2014; Sinha and Tripathi 2021); South Africa 27, 30, and 45 kg/capita/year (Nahman et al. 2012); and Ghana 80, 86, and 86 kg/capita/year (Miezah et al. 2015) in the specific study area by low, medium, and high-income group respectively. In North American countries such as Canada and the USA, household sector produced 79 and 59 kg/capita food waste respectively (Environmental and Climate Change Canada 2019; United States Environmental Protection Agency (USEPA) (2020) and Sinha and Tripathi (2021) reported household food waste for Southern Asian countries such as Bhutan (79 kg/capita/year), Bangladesh (65 kg/capita/year), and Afghanistan (82 kg/capita/year).

Agricultural waste

Agricultural waste included straw, bagasse, molasses, spent grains, grain husks (rice, maize, and wheat), nut shells (walnuts, coconuts, and groundnuts), fruit and vegetable skins (potato, jackfruit, pomegranates, bananas, and avocados), crop stalks (cotton, plant waste), and animal and bird dung all constitute agriculture waste (Dai et al. 2018). Inappropriate use and handling of refrigeration can also lead production of agricultural waste eventually. In India, there are various sources that produce more than 350 million tonnes of agro-industrial waste annually (Madurwar et al. 2013). Dai et al. (2018) reported that maximum agriculture waste including crop straw livestock and poultry manure is produced by the largest grain-producer countries such as China. Consumers are less interested in misshaped or blemished food products therefore cosmetic flaws (resulting in so-called "ugly produce") are another substantial source of food waste on farms both before and after harvest. Inappropriate use and handling of refrigeration can also lead production of agricultural waste eventually. In recent years, farmers have been forced to leave food in the fields due to labor shortages caused by changing immigration laws (Natural Resources Defence Council 2017). Dai et al. (2018) reported that maximum agriculture waste including crop straw livestock and poultry manure is produced by the largest grain-producer countries such as China.

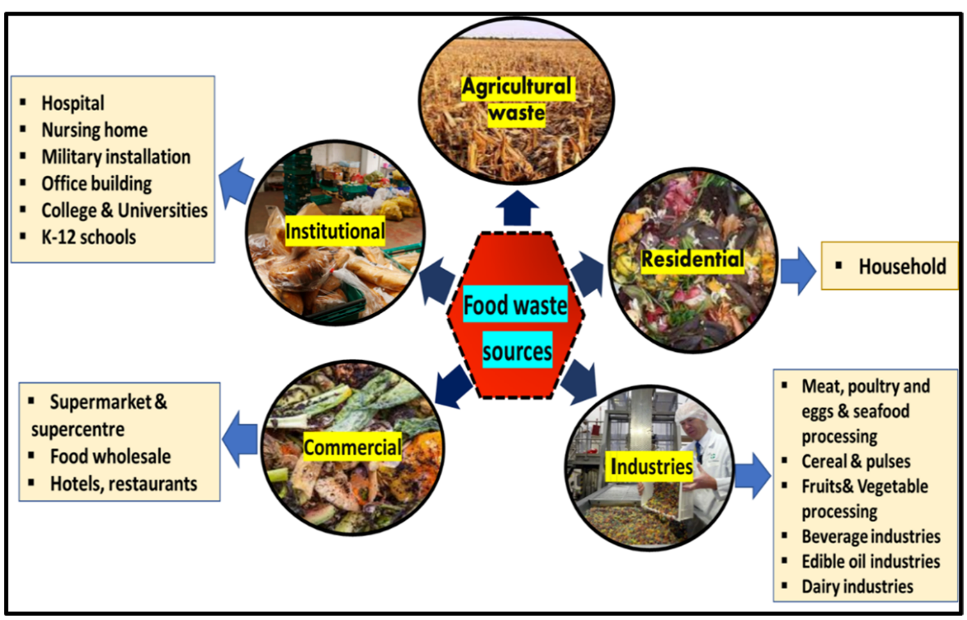

Fig. 1 Different sources of food waste

Residential waste

Urbanization, rapid economic growth, and unregulated population growth have intensified food consumption, which has raised the proportion of kitchen garbage production each year (Zhao et al. 2017). Kitchen waste (KW) is a type of anthropogenic organic waste that is typically produced by canteens, restaurants, homes, public catering facilities, factories, etc. (Liu et al. 2019). A wide range of preparation techniques, comprising handling, processing, production, storage, transportation, and consumption are major causes to generate KW. Kitchen wastewater from both commercial and residential kitchens is also produced when food is washed, rinsed, cooked, dishes and cooking utensils are cleaned, and when basic housekeeping is performed (Sharma et al. 2020). Typically, KW is made up of 38.2% of fruits, 41.52% of vegetables, 7.62% of staple foods, 7.22% of egg shells and bones, 2.52% of shells and pits, and 2.32% of meat on a wet basis (Zhao et al. 2017). A wide range of preparation techniques, comprising handling, processing, production, storage, transportation, and consumption, are major causes to generate KW. Kitchen wastewater from both commercial and residential kitchens is produced when food is washed and rinsed when food is cooked when dishes and cooking utensils are cleaned, and when basic housekeeping is performed (Sharma et al. 2020).

Food processing industries

Food processing industries include cereal grain, fruit and vegetable, beverage, dairy products industry, meat, poultry, and egg processing industry, seafood industries, and edible oil industry. The cereal grain (wheat, rice, barley, maize, sorghum, millet, oat, and rye) production reached 2577.85 million tons globally in 2016 (FAO). FAO Amis (2017) estimated that the production of coarse grains (cereal grains other than wheat and rice) used primarily for animal feed or brewing was 1330.02 million tons. According to Anal (2017), the processing of grains and pulses results in significant amounts of by-products like bran and germ. India is the greatest producer of pulses in the world, and during processing, a significant amount of husk is obtained (Parate and Talib 2015). In the case of fruit and vegetable, waste was produced at several stages of the farm-to-table food supply chain, including those for production, processing, packaging, handling, storage, and transportation (Ji et al. 2017). It produces waste only when a consumer removes them from the range of acceptance due to several factors such as microbial attack (rotting, softening, and product surface growth), thermal treatment, biochemical reactions (enzymes, antioxidants, oxygen, phenolic, and flavonoid compounds), discoloration, wounding or chilling, and degree of ripening (Sharma et al. 2020). Several countries produced fruit waste and vegetables such as India (50 million tons) (Panda et al. 2016), Central de Abasto (895 tonnes), China (1.3 million tonnes) (Ji et al. 2017), and the UK (5.5 million tonnes) (FAO 2014). India produced about 50 million tons of fruit waste (Panda et al. 2016), Central de Abasto produced 895 tonnes of fruit waste per day, China produces 1.3 million tonnes of fruit waste per day (Ji et al. 2017), and the UK alone produced 5.5 million tonnes of potatoes (FAO 2014). Kiran et al. (2014) reported that beverage industries generated approximately 105 kilotonnes of waste as broken packages, and spilled beverages. Europe produced around 29 million tonnes of dairy products wasted due to inappropriate handling, processing, and rotting of dairy products due to Fungal contamination and microbial attack (Mahboubi et al. 2017). The largest milk-producing country India generated 3.739–11.217 million m^3 of effluent waste per year during the processing of milk, while making cheese a significant amount of whey is produced as a by-product (Parashar et al. 2016). Meat poultry and egg processing industry produced a significant quantity of animal by-products (feathers, hairs, skin, horn, hooves, soft meat, and bones,), slaughterhouse waste (blood residue, protein, detergent residues, and high organic matter (carbon, nitrogen, and phosphorous)), and wastewater (washing and cleaning purpose) (Ning et al. 2018; Adhikari et al. 2018). European Union produced around 11 million tonnes annually of this type of waste (Sharma et al. 2020). In seafood and aquatic biotic life processing, approximately 50–70% of raw material is wasted every year (Kumar et al. 2018). Seafood waste, mainly in the form of crabs, shrimp, and lobster shells which about 6–8 million tonnes of waste worldwide, where a total of 1.5 million tonnes of waste are contributed by Southeast Asia. Waste is produced by the edible oil industry during several processing steps, including degumming, neutralization, bleaching, deodorization, and oxidative or hydrolytic rancidity (Okino-Delgado et al. 2017). It was reported that the edible oil industry generated 350.9 million tonnes of de-oiled cake and oil meal as a by-product yearly (Chang et al. 2018).

Commercial

Commercial waste is manmade organic biodegradable waste in sectors such as supermarkets, supercentres, food wholesale, restaurants, and hotels shown in Fig. 1. Supermarkets and supercentres have generated 8.7 million tons, and food wholesale generated 4 million tons of food waste. Restaurants produced 4 to 10% of raw food waste (Sharma et al. 2020). According to Afzal et al. (2022), the hotels and restaurants sector procured 80% and 92% of chicken and vegetables daily, respectively, and some high-end restaurants and hotels have chicken and meat stock for up to many days in case there is a delay in the supply. Some food was still wasted because several restaurants had a policy of not using certain commodities the next day, such as bread, salad veggies, and dairy goods, and induced the production of food waste due to the size, shape, color, and texture of vegetables and chicken/meat, and they simply discarded those that did not meet their criteria (Diaz-Ruiz et al. 2018). The primary source of food waste is reported to be the food leftover by customers in the restaurant, caterers, and buffet settings (Silvennoinen et al. 2015; Pirani and Arafat 2016) as well as preparing 10–15% of extra food at every event (Afzal et al. 2022). The actual cause of plate leftovers depends on various factors such as the restaurant type, their diet price, and the quality of food they served. The second and third biggest causes of food waste in hotels and restaurants were overproduction and food rotting, whereas the major significant causes of storage space and food waste during serving and preparation (Ferreira et al. 2013; Afzal et al. 2022).

Institutional waste

It is included a hospital, nursing homes, military canter, office buildings, colleges, universities, and K-12 schools that produce 7.2 million tons of wasted food that is harmful to the environment (Food waste warriors report 2020). Food, however, is a significant part of the daily waste stream that is generated by patients, healthcare professionals, and visitors. According to the United Nations Environmental Program (2012), hospitals produce 71% of all healthcare-related solid waste of which 10–15% of food waste is generated during the preparation of food and prepared food that is not consumed or is discarded by patients (Practice Greenhealth 2021). Thirty-nine percent of the total meals served to patients have wasted food that was brought back to the kitchen (Saber et al. 2022). FW generation in educational institutions varies depending on the number of total meals served to patients where wasted food was brought back to the kitchen (Saber et al. 2022). FW generation in educational institutions varies depending on the number of students on campus or off during the summer and winter sessions holidays and school breaks. According to several reports, "the 46 schools created 17.8 kg of food waste per student per year on average at the national level". The Harvard School of Public Health found that school lunches are wasted annually to the amount of approximately US$ 1.2 billion. However, the WWF (World Wildlife Fund's) Food Waste Warriors initiative has given classrooms new resources to reduce waste and increase students' access to healthy food. According to WWF, schools may waste as much as 481,000 metric tonnes of food annually. That is roughly equivalent to the annual food consumption of Atlanta, Georgia's 510,000 residents (Food Waste Warriors Report Shows Can Be on Frontline Against Food Waste 2020). University-contributed FW generation was higher than average during September to November and February to April sessions. Depending on the university schedule, attendance in the months prior to and following these seasons varies and FW generation trends for August, December, January, and May modify correspondingly. FW generation is substantially decreased but not eliminated during the June and July month due to the faculty, graduate students, and scheduled summer events (Armington et al. 2020).

Characterization of food waste

Several physical (moisture content, bulk density, and pH) and chemical (carbon, hydrogen, oxygen, nitrogen, sulfur, particle size, C/N, and total carbohydrate) characteristics also include high biodegradability, low handling expenses because of minimum collection and transport cost of food waste make it useful for further waste to worth materials (Cheng and Lo 2016). Characterizations of food waste, which is generated in India and some other countries, are shown in Table 1. Some characteristics of food waste are described below:

Table 1 Characterization of food waste in different countries

Country	Source	Moisture (%)	pH	C/N ratio	Total solid (%)	References
India	Domestic food waste	85	NA	36.4	89	Sinha and Tripathi 2021
Germany	Mixed municipal sources	90	NA	NA	80	Du et al. 2012
Australia	Mixed municipal sources	74	NA	NA	90–97	Du et al. 2012
Korea	Dining hall	93	NA	18.3	94	Du et al. 2012
Japan	Institute dinner hall	94.62	3.65		7.21	Wu et al. 2016
China	University canteen	23.1	6.86	18.24	24.9	Li et al. 2017
UK	University farm	11.3	4.3	13.6	12.8	Shamurad et al. 2020
Singapore	Kitchen waste: university canteen	NA	5.1	NA	3.2	Menon et al. 2017
Brazil	Fruit-vegetable waste	12.88	4.5	NA	13.8	Edwiges et al. 2018

Solids content

Compared to animal sludge and sewage sludge, food waste contains more solid matter due to the presence of heavy organic material and its thickness. The use of solids abundant in organic matter is based on their solubilization and consequent microbiological biodegradation. Total solids content estimated was about 20% in household waste (Izhar et al. 2021) and less than 10% estimated in garbage collection companies (Kawai et al. 2014) and institute dinner hall (Wu et al. 2016). The wet bulk density increases significantly from June to August, as compared to May of the FW (Adhikari et al. 2008).

C/N ratio and pH of food wastes

Food waste has a low C/N ratio and pH, compared to fruit-vegetable waste due to its high lignocellulose content (Izhar et al. 2021). A balanced C/N ratio showed pellets produced from wheat bran, chopped hay, and leftover cattle feed and neutral pH values indicated for pellets of wheat straw, wheat residue, chopped hay, and cardboard. Similarly, the pH of FW was found to be the highest in May and dropped in June, July, and August (Diaz et al. 1993; Adhikari et al. 2007). Due to natural acidity, the pH of food waste ranges between 7.26 and 8.14 except for wet market food waste. Most citrus fruits, apples, and tomatoes are an example of naturally acidic in nature, whereas meats and vegetables generally have a pH between 4.6 and 5.3 (FDA (Food and Drug Administration) 2012).

Fatty acids

Generally, food waste has a high ether extract content (Fung et al. 2018). Restaurant food waste ranged from 17 to 24% ether extract content on a dry basis (Myer et al. 2000; Chae et al. 2000), and lower ether extract content in food waste from a dining university and leftover food (Cho et al. 2004; Fung et al. 2018). Lower ether extract content in food waste from commercial and residential locations was reported by Castrica et al. (2018), whereas higher ether extract content in leftover food was generated by restaurants and a hotel (Asar and Genç 2018). Our traditional diet contained significantly higher saturated and monounsaturated fatty acid contents than restaurant food waste (Choe et al. 2017).

Vitamins

Several studies have been done on the vitamin contents in food waste. These findings differed from those of earlier research, according to Georganas et al. (2020), in which the niacin and pantothenic acid concentrations of restaurant and hotel waste were more. Animal proteins in the poultry diet have been shown to perform better than plant proteins in prior studies during this century. B-complex vitamins are present in all animal products, but not in plants especially attributed higher content of riboflavin in dried skimmed milk and whey. Therefore, food waste that contains animal, as well as microorganism products, may have considerable contents of vitamins important in swine and poultry nutrition, which is much higher than in plant-based food waste (Leeson and Summers 2001).

Minerals

According to Myer et al. (2000), mineral content in restaurant waste ranged from 3 to 6% on a dry basis in different observations. Food waste from a university canteen, restaurant, hotel, and commercial and residential areas contained minerals equal to 5.01%, 14.75%, 12.6%, and 14.56% on a dry basis, respectively (Kwak and Kang 2006; Asar and Genç 2018; Fung et al. 2018; Slopiecka et al. 2022). Macro and micronutrients such as phosphorus, potassium, magnesium, and calcium are also estimated in food waste generated from university, and college canteens, restaurants, and commercial and residential areas (Castrica et al. 2018; Fung et al. 2018).

Amino acids

Animal products (fish, eggs, flush, butter, whey, and milk) contain a higher concentration of amino acids compared to the protein supplements of plant-originated food products (Leeson and Summers 2001). Qualitative and quantitative dietary protein is significantly contained in poultry and swine nutrition. A different study showed that restaurant food waste, leftover food from households, and the food service sector contain 15 to 23%, 22%, and 27.6% respectively on a dry basis crude protein (Myer et al. 1999, 2000; Cho et al. 2004; Castrica et al. 2018). Fung et al. (2018) analyzed the amino acid profile of food waste generated from a university residential dining hall which was approximately 18.9% on a dry basis and Choe et al. (2017) analyzed the amino acid profile of restaurant waste and traditional meals for growing-finishing pigs and reported many amino acids were quite similar while some of the amino acids such as threonine and valine were higher concentration in restaurant food waste. Food waste from restaurants and hotels mainly leftover food from consumers contained higher crude protein (Asar and Genç 2018). Food waste recovered from restaurants and apartment complex sectors had a far lower concentration of most essential amino acids, like methionine and lysine than a cornmeal and soybean mixture produced (60%:40% ratio) (Chae et al. 2000). Additionally, due to the processing and heating of food waste, it is essential to determine the digestibility of amino acids present prior to feeding them to animals (Fung et al. 2018).

Biodegradability

The majority of municipal solid waste consisted of organic components that produced biodegradable food waste. Typically, food waste is made up of degradable carbohydrates (41–62%), proteins (15–25%), and lipids (13–30%) (Braguglia et al. 2017). Waste can be originated from food preparation or as fruit-vegetable waste, agriculture waste, pulses, and cereals are characterized as readily degradable, and this rapid biodegradability of volatile solids in the different types of food waste results in the acidification and volatile fatty acids accumulation (Izhar et al. 2021).

Factors affecting food waste biodegradation

The efficient decomposition of organic food wastes into mature natural composts depends on several important and dominating factors (Fig. 2). Assessing the development of preferred dominant parameters such as a change in the rate of aeration, carbon to nitrogen ratio, temperature, and pH is important to characterize the potential of a composting process of the food wastes (Juárez et al. 2015). These elements are crucial for creating an ideal environment for anaerobic microbes to function with high metabolic activity.

According to the study of Pathak et al. (2012), Jhansi City is a well-known district in Uttar Pradesh's Bundelkhand region, covering a land area of 502.75 thousand hectares. The district is located in the region's southwest corner at 24° 11′–25° 57′ N latitude and 78° 10′–79° 23′ E longitude. Food waste was collected from door to door in Jhansi City, Uttar Pradesh (India) in 2008, 2009, 2010, and 2011 and composted in a biocomposter for 135 days. The highest temperature recorded was 64 °C, which decreased to 32.7 °C at the ambient temperature, and the moisture content was 55.8%, which decreased to 21.7% on day 36. The loss of moisture content was caused by the high temperature. For the pH, an acidic pH was recorded during the early days of composting due to the production of organic acids; the pH rose to 8.6 but then dropped to 6.3. This was caused by the ammonification and mineralization of organic matter by microorganisms. The nutrient compositions of N, P, and K ranged from 1.16 to 1.20%, 0.03 to 0.053%, and 0.30 to 0.38%, respectively, while heavy metal content ranged from 45.25 to 48.39 mg/kg, zinc (51.1 to 54.4 mg/kg), and iron (1134.8 to1274.2 mg/kg). In 2008, 2009, 2010, and 2011, the EC (S/cm) of mature food waste compost was 1288.0, 1324.0, 1277, and 1251.0, respectively. In 2008, 2009, 2010, and 2011, the organic carbon (%) of mature food waste compost was 23.0, 24.0, 26.0, and 21.0, respectively. This study reveals a reduction in microbial counts as well as microbial succession without a definite pattern and lower microbial counts at the end of the composting period. Food waste compost contained a significant amount of nutrients for plant growth. Food waste composting has the potential to be a useful recycling tool. Its safe use in agriculture, however, is dependent on the production of high-quality compost, specifically compost that is mature and low in metals and salt content.

Gautam et al. (2010) conducted another study using mixed vegetable and fruit wastes. As a composting area, a heap 4′ high and 8′ long was used. The ambient temperature was measured to be between 35 and 45 °C. The initial moisture content was kept between 50 and 60%. Every 3 to 5 days, the compost heap was turned over to aerate it. During the composting process, the maximum temperature ranged from 48 to 50 °C. The moisture content and pH ranged from 25 to 41% and 7.75 to 7.84. The contents of N, P, and K ranged from 0.03 to 0.07%, 0.002 to 0.005%, and 0.32 to 0.36%, respectively. However, when compared to the standard concentration, the N concentration was insufficient. As

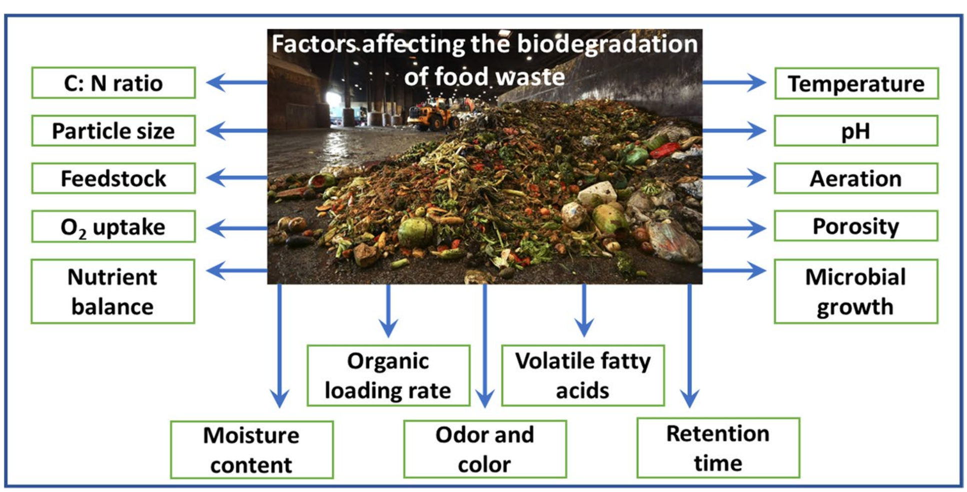

Fig. 2 Factors affecting the biodegradation of food wastes

a result, this study proposed adding phosphoric acid to avoid unnecessary ammonia volatilization.

In another study, Arslan et al. (2011) composted kitchen waste using an in-vessel composter. The composting process would take 22 days. The compost was mixed with 2 kg of sludge as inoculum and 3.5 kg of sawdust. On day 2, the temperature was recorded at 55 °C, and this temperature was maintained on day 7. The initial pH value was 5.5, and the moisture content ranged from 48 to 53%. The C: N ratio decreased from 35.92 to 19.69, while the total Kjeldahl Nitrogen (TKN) increased from 1.43 to 2.45% at the end of composting. Heavy metal content was tested for chromium, cadmium, zinc, copper, iron, and nickel. The cadmium concentration was below the detection limit, while the others were 22.4 mg/kg, 190.7 mg/kg, 35 mg/kg, 2641.75 mg/kg, and 15.33 mg/kg, respectively.

Food waste was primarily utilized in two stages in a study conducted by Patel et al. (2021). The carbohydrates and proteins from the food waste were extracted by following the enzymatic hydrolytic pathway by cultivating heterotrophic microalgae on the food waste products, resulting in a biomass yield of 0.346 ± 0.09/g sugars and a lipid yield of 0.216 ± 0.06/g sugars. In the second stage, oil (14.15% w/w) was extracted from the same food waste using hydrolysis and converted into biodiesel using a simple two-step transesterification reaction, yielding 135.8 g of fatty acid methyl esters/kg of food waste and 13.8 g of crude glycerol/kg of food waste, respectively. Finally, crude glycerol obtained from both processes was used at 20 g/L to cultivate heterotrophic microalgae, yielding cell dry weight and total lipid concentrations of 6.23 g/L and 2.91 g/L, respectively. This integrated process yielded 248.21 g of fatty acid methyl esters from 1 kg of food waste. This was one of the documented successful methods of producing biodiesel from food waste (Patel et al. 2019).

pH

pH level indicator is one of the main physical factors frequently used to track microbial activities during the composting of food wastes. pH typically exhibits a pattern of a fall in the early stages and an increase in the later stages of composting (Chan et al. 2016). The release of potassium and organic acids increases the saturation of the composting process during the ideal pH (7–8) of the compost (Kalemelawa et al. 2012). The pH of compost is decreased due to the mineralization of phosphorus and the volatilization of ammonium ions by nitrifying bacteria (Wang et al. 2016). Experimental evidence has demonstrated that the pH drops to an abnormally low level during the transition from a mesophilic to a thermophilic phase at the industrial level. However, as the organic component degrades, the proteins raise the pH, and this alkalinization may make it difficult for pH-sensitive microbes to persist during those that are sensitive to pH changes (Paradelo et al. 2013). Recent studies showed that the pH ranges between 7.5 and 8.5 (Zhang and Sun 2016), 6.7–9 (Rich and Bharti 2015), 5.5–8 (Chen et al. 2015), and 8.0 to 8.5 (Juárez et al. 2015). During the decomposition of food wastes, the additives such as wood ash, zeolite, and calcium carbonate are utilized at crucial stages to control the pH level bring the pH level into balance, and speed up the biodegradation process. (Paradelo et al. 2013; Juárez et al. 2015; Chan et al. 2016).

Temperature

Temperature is considered one of the key determining factor that advance the composting process in two stages: active and mature (final product, i.e., organic matter) (Zhang et al. 2012; Zhao et al. 2016a, b). An increase in temperature during the early phase typically speeds up the breakdown process of food wastes with dominant microbes, while a decrease in temperature makes the compost appropriate even with beneficial microorganisms (Kulikowska 2016). A change in temperature disturbs the physicochemical properties of organic composts, favoring some bacteria and increasing the strength of the substrates and composts, which has a direct impact on treatment effectiveness (Chen et al. 2015).

There are several temperature ranges where anaerobic digestion can occur, including psychrophilic (below 20 °C), mesophilic (25–40 °C), and thermophilic (45–60 °C) (Chiu and Lo 2016). According to research, mesophilic activity operates best between 35 and 45 °C and thermophilic activity around 55 to 65 °C (Moset et al. 2015). As the temperature rises, the rates of anaerobic digestion, methane production, bacterial growth, and metabolic rate all increase (El-Mashad et al. 2004; Kim et al. 2006). The production of biogas doubled when anaerobic digestion occurred under thermophilic conditions compared to psychrophilic ones. Additionally, it was noted that under thermophilic conditions, reduced ammonia inhibition was seen (Morales-Polo et al. 2018). In addition, Smith et al. (2005) showed that higher temperatures can accelerate the speed at which pathogens are destroyed during anaerobic digestion (Smith et al. 2005). However, high temperatures in thermophilic environments will have undesirable effects. Increasing the amount of free ammonia, for instance, may limit microbial activity and disrupt the thermophilic process. Lohani and Havukainen (2018) stated that the utilization of mesophilic conditions is more appropriate in the existing anaerobic digestion facilities, even though it requires a longer retention time (Lohani and Havukainen 2018).

Aeration

The regular turning of the organic materials throughout the composting process provides aeration which facilitates the digestion of organic materials by the microorganisms. Adequate aeration directly affects waste stabilization since excessive aeration or turning could cause vital components to be lost while insufficient aeration could shorten the composting process (Awasthi et al. 2014). A high rate of hygienization typically improves the turning ratio, and there is a correlation between the turning frequency and the physicochemical characteristics of waste that serve as a measure of composting effectiveness. In the meantime, it significantly affects other factors that influence the compost's maturity (Getahun et al. 2012). Aeration has been shown to be an efficient approach for degradation and homogeneity in composting processes involving various organic components (i.e., poultry manure, wheat straw, municipal solid wastes, sewage sludge animal dung, barks, and green waste) (Petric et al. 2012). According to Li et al. (2015a, b) and Mohee et al. (2015a, b), mixing the feed composition for 30 min each day increased the compost's quality. Rotating the feed mixture sustains air distribution and oxygen consumption (Petric et al. 2015).

C: N ratio

Microorganisms produce energy and release nutrients including C, N, P, and K through their metabolic activity during the decomposition of waste (Chen et al. 2011; Iqbal et al. 2015). The anaerobic microbes appear to require nitrogen as one of the main nutrients for growth. The uptake of nitrogen from the substrate is dependent on the nature of the microbes (Kondusamy and Kalamdhad 2014). The researchers Kondusamy and Kalamdhad (2014) concluded that bacteria use carbon 25–35 times more efficiently than they use nitrogen. As a result, Kondusamy and Kalamdhad (2014) suggested a C/N ratio of 25–30:1 to ensure the highest level of bacterial activity. Due to the lower microbial population, the digestion of carbon requires a longer time period in low nitrogen conditions. On the other hand, too much nitrogen can hinder a process since it results in the production of ammonia.

The toxicity of solid waste can be decreased by diluting it with water to decrease the effect of ammonia inhibition (Kondusamy and Kalamdhad 2014). Thus, it may be inferred that carbon and nitrogen are both necessary to support and increase the microbial population. In a pH-controlled condition, Wang et al. (2012) found that a C/N ratio of 27.2 produced the highest methane yield. Dairy manure, wheat straw, and chicken dung were employed as co-substrates in the study. In fact, introducing an ideal carbon content can have a good impact on preventing excessive ammonia inhibition (Pramanik et al. 2019). In general, the C/N ratio needs to be lower initially, though it might be greater and decrease the decomposition rate of waste (Chen et al. 2011; Awasthi et al. 2014). In order to increase the C/N ratio and porosity of the organic composition, bulking agents like rice husk (helps to boost the contaminant removal efficiency as well as protect the cell from stress responses due to changes in edaphic characteristics, i.e., pH, salinity, and toxicity) and peanut shells are added with it (Wang et al. 2015; Zhang and Sun 2016).

Moisture content

Changes in temperature, oxygen uptake rate, and open-air space during composting promote microbial development, but these factors also have a direct impact on the moisture content of degrading materials (Petric et al. 2012). The ideal moisture concentration for biological conversion ranged from 40 to 70%, and as the moisture content rises, the rates of gas diffusion and oxygen uptake may be decreased (Luangwilai et al. 2011). Compost's water content is influenced by temperature and, as it distributes soluble nutrients, slows microbial activities if the moisture range decreases (Guo et al. 2012; Varma and Kalamdhad 2015). Strong decomposition of waste is indicated by a decrease in moisture content since extremely low moisture levels might result in early dehydration while higher moisture levels can result in the formation of water logs and affect the composting process (Makan et al. 2014).

Porosity

The compost matrix must be air-circulated in order to maintain optimum porosity, which allows water and fully aerobic conditions for the proper growth of water-content microbes. The ideal porosity level is measured by locating a free air space using an empirical method that is dependent on bulk density and particle size. The ideal bulking agents are cereal residue pellets and wood chips, although the free air space is maintained at 30–33% (Ku¨lcu¨ 2015) or 30–50% throughout the process (Schwalb et al. 2011). Depending on how food waste is treated, it is always necessary to alter the porosity ratio (Ku¨lcu¨ 2015; Mu et al. 2017).

Particle size

Particle size contributes to maintaining aeration, and larger particle sizes typically slow down the process of decomposition while smaller sizes may cause the mass to condense. Particle size variation directly affects the water-holding capacity and gas-to-water exchange potentials (Zhang and Sun 2014). The composting process can determine the particle size by using a sieving method (Ge et al. 2015).

Feedstock

The inclusion of inoculating agents such as *Clostridium*, *Cellulomonas*, *Pseudomonas*, *Bacillus spp.*, and *Thermoactionmycetes* along with fungal species such as *Aspergillus*, *Trichoderma*, *and Sclerotium*, which accelerate the decomposition of organic materials, enhance the natural composting process (Karnchanawong and Nissaikla 2014; Onwosi et al. 2017). These inoculants may consist of a particular strain, e.g., seeding inoculums containing *Bacillus azotofixams*, *B. megaterium*, *B. mucilaginous*, effective microorganism (EM), and *Trichoderma* sp. In composting putrescible kitchen waste, cellulolytic strains and white-rot fungi were very efficient in accelerating the degradation rate of composting products (Zhao et al. 2016a, b; Hou et al. 2017), a commercialized mixture of many species such as *Trichoderma* spp. (60%, v/v) and *Phanerochaete chrysosporium Burdsall* (40%, v/v), lactic acid bacteria, yeast, and photosynthetic bacteria (Manu et al. 2017; Van Fan et al. 2018), or even mature compost (Karnchanawong and Nissaikla 2014; Kinet et al. 2015).

Nutrient balance

Food waste compositions typically contain greater salt concentrations; however, with the right grinding and filtering, any harmful contaminants could be eliminated. Compost contains heavy metals such as Pb, Cu, Cd, Cr, and Ni (Huerta Pujol et al. 2011).

Oxygen uptake

The rates of aeration, temperature, time, as well as circumstances, and location of the compost are the main factors focused on composting mass stability (Bari and Koenig 2012). Aeration supplies oxygen for oxidation while enabling excess moisture to evacuate, which has a direct impact on compost stability (Guo et al. 2012). Physicochemical characteristics are used to assess the breakdown rates of organic waste before and after composting to determine which is the best (Rich and Bharti 2015). According to Tata`no et al. (2015), forced aeration is also required to produce excessive heat. A vacuum pump is used for aeration (Sun et al. 2011), and a mechanical air compressor is employed to circulate the air. Airflow measurement is calibrated using an airflow meter (Petric et al. 2015).

Microbial growth

The major goal in controlling the composting system is to maintain the stability of compost, which is often regulated by the systematic development of the microbial community. The respiration index of microbes plays a direct effect in the breakdown of organic waste (Rich and Bharti 2015). A high surface area and a porous space are produced with sufficient microbial development, creating ideal conditions for composting (Luo et al. 2014).

Odor and color

The process of keeping compost stable results in gas emissions, which have a significant impact on the sustainability of the environment (Nasini et al. 2016). The primary sources of secondary environmental pollution, which have a significant impact on air quality, are typically by-product emissions such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), ammonia (NH_3), hydrogen sulfide (H_2S), and volatile organic compounds (VOCs) (Adhikari et al. 2013; Jiang et al. 2015).

Retention time

The retention time is another important characteristic that must be examined regularly. Retention time is the amount of time needed to finish substrate degradation or the average amount of time substrate spends in the digester (Deepanraj et al. 2014; Mao et al. 2015). For microorganisms to transform organic substrates into biogas, sufficient retention time is needed (Khoo et al. 2021). There are two different kinds of retention times: solid retention time (SRT) and hydraulic retention time (HRT). According to Deepanraj et al. (2014), HRT refers to the amount of time that the digester's liquid sludge will remain there, whereas SRT refers to the amount of time that the solid (bacteria) will remain there. In addition, it was demonstrated that the pace of bacterial development in relation to retention time depends on the OLR, substrate configuration, and operating temperature (Mao et al. 2015). According to studies (Kothari et al. 2014; Sánchez et al. 2015), organic waste have varied retention time depending on the temperature. For instance, mesophilic conditions call for a retention period of 10 to 40 days, but thermophilic conditions call for a shorter retention period. According to Mao et al. (2015), the average normal retention time in mesophilic anaerobic digesters is 15 to 30 days. Increased acclimatization to various pH ranges and types of hazardous substances will be brought on by a longer retention time, as will an increase in the digester capacity that must be used, a reduction in volatile solids, and a greater volatile solids reduction. Chandra et al. (2012) showed that when the retention time is shorter, less digester capacity is required, which reduces investment costs while maintaining the quantity and quality of biogas. According to Gerardi (2003), biological adaptation to hazardous chemicals may result in a rise in bacterial concentration and digester volume when a longer SRT is applied. According to studies, using a longer SRT decreased methane output (Chen et al. 2018). When the SRT was 6 days, the maximum methane output was noted.

Volatile fatty acid (VFA)

According to Luo et al. (2019), VFA formation may restrict anaerobic digestion and lower biogas generation. Furthermore, it was demonstrated that VFA concentrations can influence every stage of anaerobic digestion, particularly the hydrolysis and acidogenesis stages (Kondusamy and Kalamdhad 2014). According to Bouallagui et al. (2005), a decrease in pH results in the loss of activity of acid-sensitive enzymes, which inhibits the VFA of the methanogen. Additionally, a lot of undissociated acids may pass through cell membranes and break down macromolecules. In addition, it was shown that the ideal VFA range for metabolic activity is between 2000 and 3000 mg/L (Paritosh et al. 2017). Cellulolytic activity will be decreased when the VFA concentration reaches 2 g/L. Due to the effects of VFA on the rate of cellulose hydrolysis and glucose fermentation, biogas production can be significantly reduced when VFA concentrations are over 4 g/L. When cellulose and paper are co-digested, as demonstrated by Siegert and Banks (2005), biogas production decreases at a VFA concentration of 1 g/L. When VFA accumulates in a particular area, it disrupts the microbial consortia, which leads to process inhibition and failure (Kondusamy and Kalamdhad 2014).

Organic loading rate (OLR)

OLR stands for “chemical oxygen demand per unit reactor volume” or “substrate amount” (Dhar et al. 2016). This parameter needs to be under control because it could have an impact on stability, cost, and process performance. In the study conducted by Morken et al. (2018), it was demonstrated that as OLR raised from 1.8 to 5.0 kg VS/m^3 d, the methane output increased by 479%. It has been demonstrated that OLR can affect both the output of biogas and the microbial community. The best time to increase biogas production is when the OLR is at its ideal level. The phases of anaerobic digestion will be out of balance if the OLR is over the recommended amount, which will result in an accumulation of VFA and process inhibition. In reality, an elevated OLR will result in process failure and irreversible acidification. Under mesophilic conditions, the methane yield may be maintained when the OLR of 1.0 kg VS/m^3d is increased to 2.5 kg VS/m^3d (Guo et al. 2014). It was discovered that when mesophilic conditions were used, there was a larger diversity and abundance of microorganisms maintained in the anaerobic digester.

Current scenario of food waste generation in different countries

Food waste is gaining global attention as a type of municipal solid waste (MSW). According to the EPA’s 2018 wasted food report, the USA generates 93.4 million tonnes of food waste each year, which equates to approximately 285.8 kg per capita (United States Environmental Protection Agency (USEPA) 2020). Food waste accounted for 21.6% of all MSW generated in 2018, and food waste output has steadily increased over the last 50 years (United States Environmental Protection Agency 2022). Landfills are now the most popular destination for food waste, accounting for 36% of total food waste generated (United States Environmental Protection Agency (USEPA) 2020).

The estimate of household food waste, which is based on approximately 100 data points from a variety of nations representing 75% of the world’s population, is the most reliable of the three sectors, i.e., households, retail, and food services. The estimates for the retail and food service industries, in contrast, are based on each of about 30 data points, the majority of which are from high-income nations. For food service and retail, countries having measurable data points made up 32% and 14% of the global population, respectively. The table below lists the amount of household food waste produced in each UNEP area (Africa, Latin America, and the Caribbean, Asia and the Pacific, West Asia, North America, and Europe) (Table 2).

Food waste is mainly caused by consumer habits such as buying more food than necessary, cooking too much food for meals, and throwing away leftovers (von Massow and Martin 2015). According to estimates by Stenmarck et al. (2016), households in the European Union (EU) account for 53% (92 kg per person) of all food waste, compared to 12% (21 kg per person) from the hospitality and food services industry and 30% (51 kg per person) from the food production and processing sectors. Since 2010, consumer behavior and household food waste have received increased attention in the literature, and several reviews have been undertaken to summarize the available data (Principato 2018; Stangherlin and de Barcellos 2018). Household food waste is connected to a variety of consumer food-related behaviors (Schanes et al. 2018). When compared to other practices, some contribute to significantly higher levels of waste such as only shopping at major supermarkets, while others such as using shopping lists and meal plans contribute to lower levels (Stangherlin and de Barcellos 2018). These actions are part of larger household food provisioning activities that include planning, buying, storing, preparing, eating, and disposing of food (Roodhuyzen et al. 2017).

According to the most recent data collected by FSSAI (2022), India is the world’s second-largest producer of

Table 2 Households food waste generation from different countries across the globe

Name of country	Study area	Food waste (kg/capita)	References
Kenya	Nairobi	99	Takeuchi 2019
Nigeria	Sapele	189	Orhorhoro et al. 2017
South Africa	Johannesburg	12	Oelofse et al. 2018
	Nationwide	134	Ramukhwatho 2016
Brazil	Nationwide	60	Araujo et al. 2018
Mexico	Nationwide	94	Kemper et al. 2019
Australia	Nationwide	102	Arcadis 2019
Bangladesh	Chittagong	74	Salam et al. 2012
	Chittagong	57	Sujauddin et al. 2008
China	Shandong	21	Li et al. 2021
	Hong Kong	101	Lo and Woon 2016
	Urban China Total	150	Zhang et al. 2020
	Nationwide	23	Song et al. 2015
India	Dehradun	20	Suthar and Singh 2015
	Rajam, Andhra Pradesh	58	Ramakrishna 2016
Indonesia	Surabaya	77	Dhokhikah et al. 2015
Japan	Nationwide	64	Food Industry Policy Office August 2017
Malaysia	Bandar Baru Bangi	71	Watanabe 2012
	Nationwide	112	Jereme et al. 2013
New Zealand	Nationwide	61	Sunshine Yates Consulting 2018
Pakistan	Gujranwala (urban)	88	JICA 2015
	Gujranwala (rural)	60	
Sri Lanka	Jaffna	118	JICA 2016
	Nuwara Eliya	95	
	Thamankaduwa	79	
	Kurunegala	47	
	Trincomalee	21	
Viet Nam	Da Nang	67	Vetter-Gindele et al. 2019
Iraq	Karbala	142	Al-Masoudi and Al-Haidary 2015
Israel	Haifa	94	Elimelech et al. 2018
	Nationwide	105	Leket 2019
Saudi Arabia	Nationwide	105	SAGO 2019

food, accounting for nearly 10.1% of total global food production. Despite such values, India has nearly 196 million undernourished people, the second-highest number in the world, as India has been interpreted to house 25% of the world's hungry people, and statistical studies (primarily conducted and reported by the Food and Agricultural Organization) have revealed that as of 2021, the amount of food waste generated in India accounts for nearly 40% of its total food production (by weight), which includes household waste, with each individual throwing away approximately 50 kg of food per year (Roe et al. 2021). According to the article, Indian families waste 50 kg of food per capita per year, the lowest figure in South Asia. In 2019, 931 million tonnes of food were wasted worldwide, with households wasting the most (570 million tonnes), followed by the food service and retail sectors (Pal and Bhatia 2022).

According to Biswas and Parida (2021), food waste accounts for more than half of the solid waste produced in a country. Bobbili is a historic town in Andhra Pradesh's Vizianagaram district. It produces 21.5 tonnes of waste per day (320 g per person per day). The summary of waste generation (%), with food waste accounted for 34% and other non-biodegradable waste accounted for 66%. For more than 10 years, the town has prohibited the use of plastic bags and pouches. The town's crowning achievement, however, is the processing of food waste. In terms of waste processing rate, Bobbili is now one of the top ten municipalities in the country. It categorizes waste into three types and generates significant revenue from processing and recycling.

As per the data of Biswas and Parida (2021), Mysuru is located in the Chamundi Hills, 770 m above sea level. With a land area of 155 square kilometers, it is Karnataka's second-largest city after Bangalore. It is a popular tourist destination and is also known as the City of Palaces. Mysuru got its first municipal committee in 1862, a sanitary division in 1885, and the City Improvement Trust Board, India's first urban planning body, in 1903. To manage food waste, which accounts for the majority of municipal solid waste, Mysuru City Corporation has implemented decentralized waste management. Mysuru City attracts a large number of tourists throughout the year due to its cultural history and pleasant climate, which contributes to waste generation. Prior to 2014, the waste scenario was similar to that of other cities. Municipal solid waste is typically composed of approximately 55% food waste and 45% non-biodegradable waste. Mysuru City Corporation launched a decentralized biodegradable waste management system, also known as zero-waste management, in 2009. Mysuru City Corporation is a forerunner in the implementation of scientific waste handling and management practices. Following the collection of segregated waste, food waste is directed to a centralized compost unit on the outskirts of the city with a capacity of 200 tonnes per day (TPD). Non-biodegradable waste is collected at one of the city's 43 collection centers.

According to the study of Biswas and Parida (2021), Vengurla, a town in the Maharashtra district of Sindhudurg, has one of the state's oldest municipal councils. It reportedly generates over 3 tonnes of waste per day, with approximately 82% of that being food waste and the remaining 18% being all other waste. The town claims to be a zero-waste city because it processes 100% of its food waste. Until recently, the Vengurla Municipal Council (VMC) would collect all mixed waste and dump it in a dumping ground at Parabwada. The dumping ground not only contributed to poor air quality due to emissions and groundwater pollution due to leachate generation but it also contributed to marine pollution. The VMC (Vengurla Municipal Council) generates over 2.7 TPD (tonnes per day) of biodegradable waste, of which 2.5 TPD is processed centrally and 0.208 TPD is processed decentrally. This dual system has served the town well.

The Central Pollution Control Board (CPCB), with the help and support of NEERI, conducted a survey of solid waste management in 59 cities (35 metro cities and 24 state Capitals: 2004–05). Table 3 depicts the quantity and quality of generated food waste. Over the last few decades, the amount of waste generated per capita has increased at an annual rate of 1 to 1.33% (Shekdar 1999). If current trends continue, India's waste generation will likely increase from less than 40,000 tonnes per year to more than 125,000 tonnes by 2030. (Srishti 2000). Furthermore, in some cities, the rate of per capita generation is high (Port Blair, Kochi, Chennai, Vishakhapatnam, Pondicherry, Kolkata, Jammu, Delhi, and Hyderabad). This could be due to these cities' high living standards, rapid economic growth, and high levels of urbanization. Increased waste generation is frequently associated with economic growth, increased industrialization, population growth, and higher living standards (Minghua et al. 2009). Compostable materials (40–60%) and inerts (30–50%) make up most of the municipal solid waste in urban areas. Food waste (44%) made up the majority of MSW, followed by recyclables such as paper, plastics, glass, and metals (Mohee et al. 2015a, b). Food is the main source of all life and the most important consumable daily; as a result, it contributes significantly to MSW. Food waste is a significant constituent with a high percentage of all MSW constituents (Bhat et al. 2013).

Environmental impacts of food waste disposal

When food is wasted rather than eaten, the environmental effects of food production and consumption are further compounded. According to the FAO, one third of all food produced for human consumption worldwide is lost or wasted along the whole supply chain (FAO 2011). In 2019, around 931 million tonnes of food were wasted globally, accounting for 17% of all food consumed (Zhou et al. 2022). Owing to the country's distinctive eating patterns, food waste in India has excessive moisture, organic, and oil content (Li et al. 2016). As a result of incorrect and common food disposal practices, which have detrimental environmental effects, a significant amount of greenhouse gas (GHG) emissions and foul odor discharge occur (Xia et al. 2022). There have been several small-scale operations regarding the environmental impacts of food waste disposal but such studies have not been so fruitful. The execution of massive industrial practical applications and the field operating conditions could ensure the accuracy and reliability of the life cycle inventory in order to assess the environment associated with food waste disposal procedures (Matsuda et al. 2012).

According to Adhikari et al. (2009a, b), the most common five food waste disposal methods utilized in India are landfills, composting, animal feeding, incineration, and anaerobic digestion. India produces a lot of food waste, but its techniques for disposing of it are quite inadequate; instead, organic garbage is typically dumped at landfills (Thi et al. 2015). Landfills are the most common method of food waste disposal in developing nations including India, which accounts for approx. 90% of the total food waste (Thi et al. 2015). But this practice is not encouraged in the reality due to its increased probability of producing disease vectors and releasing greenhouse gases (Louis 2004; Adhikari et al. 2009a, b). Composting is one of the most effective techniques for food waste disposal in

Table 3 Food waste generated in different cities in India (CPCB 2004)

Sr. No	City	Population	Area (Km^2)	Food waste (%)	C/N ratio	Moisture (%)
1	Jabalpur	932484	134	58.07	28.22	35
2	Amritsar	966862	77	65.02	30.69	61
3	Rajkot	967476	105	41.50	52.56	17
4	Allahabad	975393	71	35.49	19.00	18
5	Vishakhapatnam	982904	110	45.96	41.70	53
6	Faridabad	1055938	216	42.06	18.58	34
7	Meerut	1068772	142	54.54	19.24	32
8	Nashik	1077236	269	39.52	37.20	62
9	Varanasi	1091918	80	45.18	19.40	44
10	Jamshedpur	1104713	64	43.36	19.69	48
11	Agra	1275135	140	46.38	21.56	28
12	Vadodara	1306227	240	47.43	40.34	25
13	Patna	1366444	107	51.96	18.62	36
14	Ludhiana	1398467	159	49.80	52.17	65
15	Mumbai	1437354	286	52.44	21.58	43
16	Indore	1474968	130	48.97	29.30	31
17	Nagpur	2052066	218	47.41	26.37	41
18	Lucknow	2185927	310	47.41	21.41	60
19	Jaipur	2322575	518	45.50	43.29	21
20	Surat	2433835	112	56.87	42.16	51
21	Pune	2538473	244	62.44	35.54	63
22	Kanpur	2551337	267	47.52	27.64	46
23	Ahmedabad	3520085	191	40.81	29.64	32
24	Hyderabad	3843585	169	54.20	25.90	46
25	Bangalore	4301326	226	51.84	35.12	55
26	Chennai	4343645	174	41.34	29.25	47
27	Kolkata	4572876	187	50.56	31.81	46
28	Delhi	10306452	1483	54.42	34.87	49

flourishing countries like India where there are presently more than 70 composting establishments, which recycle up to 5.9% of the annual total of food waste, producing over 4.3 million tonnes of compost (Thi et al. 2015). Because the organic portion of the waste stream is kept out of landfills, composting is one of the easiest ways to stop methane emissions. Although composting does release carbon dioxide into the environment, it is currently regarded as a carbon–neutral process since it does not take into account the removal of carbon dioxide from the atmosphere by photosynthesis to form organic matter (Hoornweg et al. 1999). Other beneficial effects of composting on the environment include less need for landfill disposal, reduced surface and groundwater contamination, lower air pollution from burning garbage, less erosion, and increased effectiveness of synthetic fertilizers (Hoornweg et al. 1999).

Although it is currently forbidden in the European Union to feed municipal food waste to cattle, this practice is widespread in developing nations like India, and there is rising interest in its potential to substitute for highly significant, more expensive than traditional livestock feed (Salemdeeb et al. 2017). Animal feeding as a method of food waste disposal is a very efficient practice in India that has several positive impacts on the environment with reduced methane emissions being a prominent one. Waste can be decreased by 95% and the amount of land required by incinerating it. Incineration uses filters to capture harmful gases and pollutants; therefore, it pollutes the environment less than landfills. Incinerators offer significant odor and noise reduction in addition to operating within the required pollution restrictions. Because they are running at a very high temperature, which is best suited for enormous calorific value waste, they eliminate germs and chemicals (Paulraj et al. 2019). These are some of the positive impacts of the incineration of food wastes which greatly improve the environmental quality.

Anaerobic digestion and in-vessel composting, two major natural food waste disposal technologies, are used to evaluate the impacts on the environment. These two techniques are the most often used for organized food waste disposal in large cities, with tonnages ranging from hundreds to thousands (Jin et al. 2021). The four metrics of global warming potential, nutritional enhancement, photochemical ozone production, and acidity are the major criteria used to assess the environmental impact of any method of disposing of food waste (Oyoo et al. 2014). Around 57.02 kg of CO_2-equivalent/tonne from anaerobic digestion went toward global warming capacity. With a value of 18.3 kg CO_2-equivalent/tonne, the incineration of biogas waste was the biggest contributor to global warming potential in anaerobic digestion (Zhou et al. 2022). The methane emission from both anaerobic digestion and in-vessel composting leachate treatment processes constituted a significant source of environmental burden for photochemical ozone formation. The primary source of nutrient enrichment in in-vessel composting was nitrate released into fresh water by the surface application of compost, with a quantity of 0.65 kg NO_3 equivalent/tonne. The avoidance of fossil CO_2 in the combustion cycle and carbon consistency through nutrient management use could prevent the transition from the burning of biogas left over the land application, increasing global warming potential avoidance by 52.8%. The environmental performance of the anaerobic digestion system may be more significantly impacted by advancements in the biogas residue management process (Zhou et al. 2022).

Sustainable approaches for food waste management

Various methods such as animal feeding, composting (organic fertilizers), anaerobic digestion, incineration, and landfill are applied for the treatment of food waste. Illegal open dumps and landfills are the primary methods frequently used in food waste management because of their high rate of use for treating food waste (Adhikari et al. 2006, 2009). Based on the current data for FW treatments in developing countries, the common FW treatment method is dumping/landfills, which account for over 90% of FW treatment, and the second most used method is composting which accounts for 1 to 6%. Anaerobic digestion is used for the treatments of 0.6% food waste whereas other treatments, such as incineration and animal feeding are rarely used.

Animal feeding of food waste

The legislative laws of Japan, South Korea, and Taiwan encourage using FW to feed animals which compose 33%, 81%, and 72.1% of total FW generation, respectively (Gen et al. 2006; Kim et al. 2011). The separation and collection of FWs are not properly practiced in developing countries and therefore, almost all of the generated FW is mixed with MSW, which could not be purified and utilized for animal feeding.

Anaerobic digestion of food waste

Since 2006, several affluent nations in Asia and the European Union have used anaerobic digestion (AD) extensively for FW treatment (Abbasi et al. 2012). Contrarily, it is noted that AD is still not widely used as a significant therapeutic strategy for FW control in developing nations. A number of institutions and NGOs in China and India have set up various anaerobic digesters on a domestic and commercial scale to improve AD technology (Christian and Dübendorf 2007). India, for instance, opened biogas facilities that are used by several institutions and adopted AD on a trial basis. In China, twenty MSW, FW, and manure co-fermentation AD projects are being planned for or are already in operation, despite the fact that FW-based AD facilities have not yet been constructed on a large scale. However, the majority of these AD may not operate well because of technical issues, poor operations, or management rules (Christian and Dübendorf 2007). To dispose of FW in landfills, Indonesia, the Philippines, and Vietnam typically combine AD with composting (Forbes et al. 2001). Meanwhile, employing AD and the aerobic composting technique, Thailand and Jamaica have made substantial progress in integrating FW treatment facilities. Thailand's Rayong facility utilizes organic MSW from foods, vegetables, and fruit waste to produce organic fertilizer and biogas (Christian and Dübendorf 2007). Carib Share Biogas Group in Jamaica processes FW using AD to provide energy for remote areas.

Composting of food waste

Composting is an effective way to get rid of FW load in developing nations. There are already more than 70 composting facilities in India that process mixed MSW. These facilities recycle up to 5.9% of the total quantity of FW to produce over 4.3 million tonnes of compost annually. Nearly every composting facility accepts mixed trash, while two units in Vijayawada and Suryapetare city in India are known to accept source-separated organic waste (Ranjith et al. 2012).

Incineration of food waste

Reduced waste volume and required landfill area can be achieved by effective incineration of food waste. Many nations including Singapore and the USA have adopted this technique (Khoo et al. 2010). Incineration is an expensive procedure when compared to alternative therapies (high capital and maintenance cost) and needs expensive equipment and highly sophisticated operations to reduce gas emission leftovers. According to Yates and Gutberlet (2011), incineration is not commonly used for FW treatment in developing nations, Brazil and Ukraine.

Landfill of food waste

The primary FW treatment technique used in all developing nations is open dumps or landfills, which account for 90% of all the FW, disposed of in landfills. Numerous modern landfills capture potentially hazardous landfill gas emissions and turn them into electricity (USEPA 2020). Many nations, such as Brazil, Turkey, Malaysia, Mexico, Costa Rica, Romania, South Africa, Belarus, China, Jamaica, Ukraine, Nigeria, and Vietnam, are currently disposing of unsorted foreign waste in landfills, and it is estimated that 20 to 80% of all the foreign waste worldwide has not yet been separated from MSW (Adhikari et al. 2006). Landfills are not currently seen to be a practical option for treating FW due to the biodegradability of FW and the possibility of disease vectors produced by FW in landfills, (Louis 2004). In addition, landfilling FW can result in an 8% rise in greenhouse gas emissions (Adhikari et al. 2009a, b).

India's current laws and regulations on the management of food waste

The Union Ministry of Environment, Forests and Climate Change (MOEF & CC) implemented the solid waste management (SWM) rule in 2016, with the goal of channeling waste to wealth through 3R (recovery, reuse, and recycling). All approach hotels and restaurants are expected to separate biodegradable garbage and set up a collection system to ensure that food waste is composted/bio-methanides on the premises. Indian government was required to notify a committee for food waste reduction in the Official Gazette under the mandatory food waste reduction bill introduced in 2018. The committee's duty was to publish a food waste reduction policy within 6 months of its formation, with the main goal of reducing food waste by half by 2025.

Starting in 2016, supermarkets and food processors were given the goal to reduce food waste by 30% by 2025. Starting with the 2016 baseline, an overall objective of 50% food waste reduction until 2030 has been established. This rule proposes that the committee carry out its responsibilities in collaboration with relevant entities and organizations such as supermarkets, food manufacturers, and food distribution organizations. The committee will conduct frequent inspections to ensure compliance and will take action if any provisions of this act are violated. The Indian government has expressed concern about food waste in restaurants, hotels, and weddings; it has yet to expressly address concerns about retail sector food waste (The Compulsory Food Waste Reduction Bill 2018). In June 2018, the Indian government proposed a new biofuel policy with an indicative aim of 5% biodiesel blending in diesel and 20% ethanol blending in petrol by 2030 (Dabas et al. 2021). With 200 scientists working in the field of biofuel, a platform with a focus on 2nd generation biofuel has been built. Under the Swacch Bharat Mission, the main focus in 2018 has been on generating energy from garbage such as municipal solid waste (MSW) and municipal liquid waste (MLW). The Department of Biotechnology (DBT) government of India has financed eight waste-to-energy projects that were begun to develop/demonstrate unique and feasible technology for the sustainable usage of MSW for cleaner and pollution-free environments and electricity generation.

Contemporary trends in food waste disposal in India

FW is wet waste and generally includes kitchen garbage such as cooked and uncooked food waste, eggshells and bones, flower and fruit waste such as juice peels and houseplant waste, green waste from fruit and vegetable vendors/shops, and rubbish from food and tea stalls/shops. In India, a nationwide lockdown coincided with the peak harvesting season for summer vegetables, paddy, and other grain crops which resulted in the production of massive food waste, as well as substantial economic losses for farmers; also, due to the country's unexpected lockdown, a large number of farm products was wasted. During such an economic crisis, the government of India implemented several measures such as adequate food supply to rural areas and effective maintenance of infrastructure. Hotels, hostels, restaurants, cafes, supermarkets, residential complexes, airline cafeterias, and food processing companies are major sources of food waste in India (Paritosh et al. 2017). Food waste is now prevalent in India. However, some of these are composted for fertilizer production and buried within the earth, resulting in land contamination and a rise in natural resources. The big picture of food waste management and the process of valorization is summarized in Fig. 3. It is not a long-term viable alternative and should be phased out.

Case study 1: conversion of hotel/restaurant food waste into a value-added product

While it has traditionally been stated that landfilling and composting are not long-term solutions for food waste disposal, AD of food waste is already an established technique that is used internationally for food waste treatment, along with other emerging technologies. Residential food waste at some places in Pune and Malur and commercial food waste in Chennai and Amul dairy waste disposal are some examples of food waste disposal and for by AD plants established in the city (Abanades et al. 2021). Food waste accounts for 10–12% of rubbish generated in India, and approximately 6.5 billion square feet of prime land in Delhi is used for

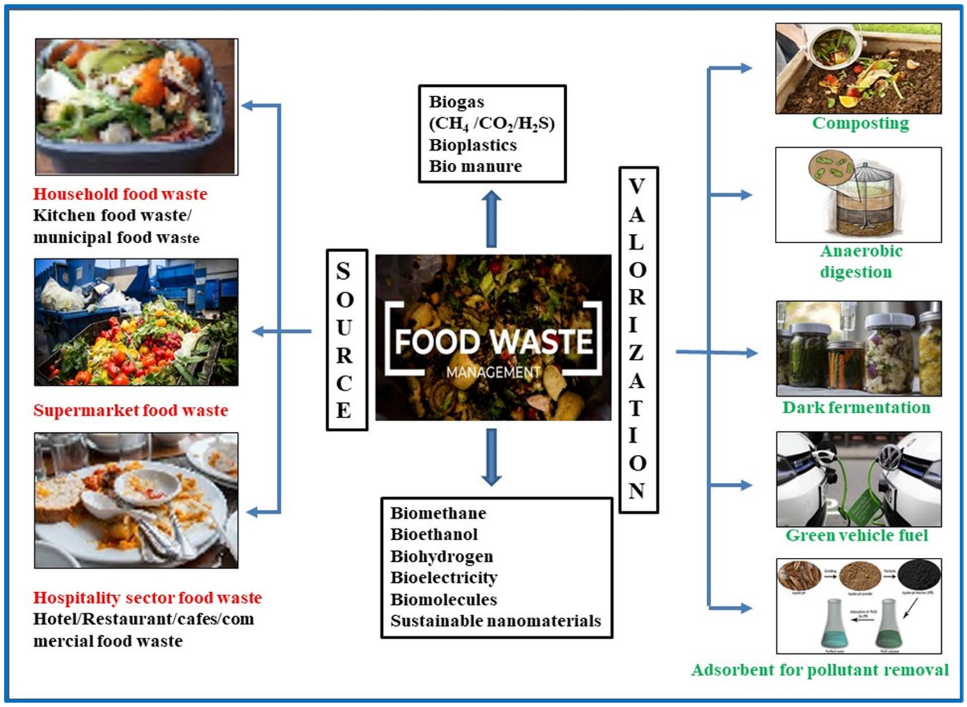

Fig. 3 Types of food waste and their sustainable utilization

garbage dumping. Large hotels (4-star or 5-star) have their own garbage disposal facilities, with smaller settings lacking; therefore, waste management is a serious issue in such settings. In most cases, municipal waste is collected and disposed of in landfills. The majority of them are caused by pre-preparation, expired shelf-life of products, and 50% of cooked food lost from tables or buffets (Dabas et al. 2021). Composting is still a standard way and every good restaurant has a composting machine on its premises because it is required for accreditation. A large hotel with 100 rooms generates 700–800 kg of garbage per day, with a processing capability of 100–200 kg per day. Other issues with composting/bio-methanation include air and soil pollution caused by the release of gas such as CO_2, CH_4, and H_2S as a result of rubbish composting.

To reduce the amount of food waste generated by restaurants in India, which is around 67 million metric tonnes per year and is valued at INR 92,000 crore, a new idea known as “Farm to Farm” has been introduced. This technique entails collecting food waste from various hotels and restaurants and fermenting it into nutritious organic bio-fertilizers. Restaurant food waste is indigestible due to the use of grease and spices during the cooking process. Incubating with microbial consortia for converting food to organic manure and gas was used in pilot research. This system handled 25 kg of garbage each day, but after a government grant, it was improved to one-tonne food waste per day. This study was conducted in Hyderabad, which produces 400–500 tonnes of food waste per day. This system was capable of processing 10 tonnes of food waste per day or 300 tonnes of food waste per month, and it is hoped that by 2022, 6000 metric tonnes of waste will be handled each day in 8–10 cities across India. The released gas will indeed be bottled, enhanced, and marketed as compressed biogas, which is 25% cheaper than ordinary LPG used in Indian households for cooking. Manure can be sold to farmers at a subsidized rate to enhance soil fertility, and there are no constraints because the same food that was grown on the farm is now being grown on another farm. Restaurants can obtain carbon credits by using a technology-based approach (Dabas et al. 2021).

Case study 2: bioethanol production from food waste

The viability of bioethanol production was tested in the laboratory from food waste generated in Greater Noida, Uttar Pradesh. After drying, food waste was collected and shredded for bioethanol production (Thapa et al. 2019). Hydrolysis and fermentation studies were conducted sequentially, and variables were controlled. The growth of yeast was connected with an ethanol output of 13.78 g/100 g of dry food waste. In theory, 329,756 L/day of bioethanol might be produced from Delhi municipal solid waste (MSW). It was determined that ethanol could be successfully created from the organic fraction of MSW through controlled fermentation using the *Saccharomyces cerevisiae* strain name and is a profitable valorisation alternative from an environmental standpoint, as well as an economically viable choice. Another study looked at kitchen waste, specifically tea waste and onion peel usage for bioethanol production was investigated as well as for wastewater treatment (Ganguly et al. 2021). Hydrothermal followed by acidic pre-treatment has been used for pre-treatment before bio-hydrolysis by *Aspergillus* sp. for reducing sugar production. The declining sugar yields 9.5 mg/ml from onion peel, compared to 4.88 mg/ml from tea waste *S. cerevisiae*-based anaerobic fermentation was reached, with 0.95 g/g and 0.66 g/g of bioethanol generated from onion peel and tea wastes, respectively. These wastes were also used to remove crystal violet pigment from the wastewater. To develop an effective treatment process for recycling lingo-cellulosic substances, these wastes were transformed into value-added products such as cellulose and lignin, which were then employed for dye removal from the wastewater.

Case study 3: Safal outlets

On average, the Safal branch disposed of food items of 18.7 kg per day. This suggests that 7.5 tonnes of food are thrown away every day at their 400 stores in Safal in Delhi. About 84.7% of total recorded food waste was thrown into the trash, the rest was opposed and was given to the poor and some animals. A good portion of the food waste container was still edible. Edible food waste produced by Safal is estimated to feed 2000 people if diverted every day (Sharma et al. 2021).

It is effective to manage potentially dangerous food waste by producing biogas with a food waste treatment system. Biogas is perfect for use in residential kitchens since it produces no smoke when cooking. In contrast, the soil's nutrients are restored by the organic manure that is created. Using this method, there is less need for chemical fertilizers and tree cutting. Composting organic food wastes and incorporating them into the soil can support plant growth. Compost has a light texture and is rich in minerals, giving your plant the nutrition it requires. Composting prevents food waste and yard trimmings from ending up in landfills, where they take up space and emit greenhouse gases.

Future perspectives

Byun et al. (2021) highlighted the feasibility of green vehicles running using green energy produced from food wastes in near future. There have been proposals for internal combustion engine cars (ICEVs) powered by biomethane and bioethanol, fuel cell vehicles (FCVs) powered by biohydrogen, and plug-in electric vehicles (PEVs) powered by bioelectricity. The top four FW-producing countries in the world, namely the USA, China, India, and Brazil, were evaluated for prospective green fuel generation, and greenhouse gas (GHG) emissions from each green car operation were analyzed and compared with 2030. The most significant reduction in GHG emissions can be achieved by conventional food waste treatment and biohydrogen production for FCV, operations. The study also identified crucial components that could be relevant for the sustainability assessment of future green energy vehicle technologies that use FW as an alternative resource to existing fossil fuels. Biohydrogen was discovered to be the most feasible choice for green vehicle GV energy production.

Recently, the efficacy of FW as an adsorbent for the removal of hazardous dye from wastewater has been examined (Sridhar et al. 2022). Pectin extraction from FW utilizing ultrasound-assisted extraction technology has previously been described, and the process was further refined for maximal extraction using response surface methodology (Shivamathi et al. 2022). Sustainable nano-materials such as cellulose, and SCNCs (spherical cellulose nanocrystals), have been extracted from non-edible parts of jackfruits (*Artocarpus heterophyllus* L.) (Trilokesh and Uppuluri 2019). Valorization of jackfruit peel for the production of SCNCs has many applications in food, paper, optics, pharma, environmental remediation, composite synthesis, etc. Similarly, non-genotoxic, non-hemolytic organometallic silver nanoparticles using spent hop extracts were synthesized in Greenway, characterized, and showed anti-bacterial and anti-cancer properties having potential application in the medical industry (Das et al. 2022).

Like other developing countries, India can implement steps to reduce food waste, like collaborating with charities and food banks to make sure that surplus food from stores is given to people in need. Food that has passed its expiration date and cannot be donated can be composted or transformed into biofuel for retail commercial vehicles. Removing expiry dates from non-perishable commodities (such as salt, sugar, and so on), enabling discounts on single goods (such as a separated banana), eliminating general shop promotions (such as buy-one-get-one-free), and mandating food waste statements in retail marketing are some of the important steps. Furthermore, obligatory employee training on food waste avoidance may significantly alter how the retail business treats food delivery.

Indian cities including Chennai, Kochi, Mumbai, Bangalore, and even Gurugram are rapidly adopting the usage of communal fridges to battle hunger. Installing communal fridges outside retail businesses is a humanitarian approach to offering free daily access to extra food to people in need.

Challenges in food waste management

Our houses generate a large quantity of food waste. According to Zhongming et al. (2021), an astounding 50 kg of food per person is thrown away in Indian homes each year. Every year, over 40% of the food produced in India is wasted due to disorganized food production systems and inefficient supply chains. This is the loss that occurs before the meal is even delivered to the consumer. Excess food waste typically ends up in landfills, where it produces strong greenhouse gasses with serious environmental consequences. Inadequacies in government services, a lack of transparency in income creation, insufficient storage facilities, and a lack of valid and complete inventories are some of the issues in the Indian food supply chain.

Infrastructure

India must spend heavily on its infrastructure. According to the World Economic Forum (2011), India is ranked 89th out of 142 nations in terms of infrastructure reliability and sufficiency. India's infrastructure shortcomings have a particularly negative effect on the agricultural sector since agricultural production and distribution depend on the nation's infrastructure to move and store millions of tonnes of food each year. Depending on the area and the crop harvested, the infrastructural issues appear differently.

Storage

The roads and rail connections in Punjab and Haryana, where the majority of the nation's grain is cultivated, are in fair to good condition. Logistics for transportation are also made quite straightforward by the area's proximity to a significant market, greater Delhi (Artiuch and Kornstein 2012). Yet, because the government buys a sizable share of each year's grain production to be given later as part of public redistribution schemes, storage is a significant concern in the northwest states. Grain is frequently kept outside beneath tarps made of plastic since the nation lacks sophisticated storage facilities like silos, which offer little defense against dampness and pests. Because of this, crops frequently deteriorate before they can be transported to other regions of the nation. Modern storage has been deemed a priority area for investment by the government, but new public and private initiatives have been difficult to get off the ground.

One of the main causes of food waste in India is frequently attributed to inadequate cold storage and cold chain transportation networks, which can increase the shelf life of goods from a few days to weeks or more.

Roads and transportation

Crops are frequently unable to be transported to marketplaces in rural areas of India due to poor transportation infrastructure. Farmers find it challenging to obtain fair pricing due to bad roads, a shortage of tractors and trucks, and large distances to city markets. Furthermore, it is sometimes uneconomical to harvest in the first place during bumper crop seasons when prices decrease due to the added expense of getting to market. Crops are thus left to rot on the field.

Typically, trucks are used to transport crops around the nation. For instance, everyday truck shipments from as far afield as 72 h arrive at Delhi's wholesale vegetable market. Bad roads might cause the entire truckload to be delayed and decay on any part of the journey from the origin to Delhi. In the humid summer months, fruits like bananas and mangos are particularly prone.

Government purchase and distribution schemes

In India, bureaucracy and corruption are well-known issues, and the food supply system is not exempt. Several government organizations and middlemen are involved in the extensive redistribution scheme of the Indian government. Corrupt administrators of storage facilities have been known to manipulate scales to show less grain entering the facility and divert the excess to the grey or black markets. According to some sources, administrators allowed waste and then over-reported it in an effort to market the surplus supplies. Similar problems occur while cargo is being transported and pieces of them have been known to disappear at railway yards and transfer stations. According to experts, the private sector is far better at preventing food waste since management there is often unable to profit from ongoing illegal activities.

Middlemen, bargaining power, and price transparency

Food is often transferred through a variety of mediators before it is delivered from a farmer to a consumer: dealers purchase and ship products while commissioning agents coordinate deals between farmers and traders. The mediators have an edge in terms of information and negotiating power because the ordinary farmer only cultivates a few acres of land and is not a significant supplier.

Before they visit the wholesale market, farmers frequently are unaware of the price of their products. It is not practical for the farmer to take the items back to wait for a better price once they are in the market, thus the commission agents can set the price. As they are paid based on the entire transaction value, without ever gaining possession of the product, commission agents have no motivation to reduce waste. They may make more money by closing as many deals as they can rapidly because they often only receive a 2.5–6% commission on sales; thus, it makes little sense for them to spend time looking for traders offering slightly higher pricing (Artiuch and Kornstein 2012).

However, dealers further along the supply chain lack many of the incentives to reduce waste. They can manage fewer items at a higher price easier than more goods at lower costs. As a result, waste frequently happens when these intermediates conspire to limit supply, which leads to higher pricing and fewer shipments. In isolated areas with few buyers, middlemen are more likely to conspire.

Price volatility

Farmers frequently decide to cultivate crops that have been successful in previous seasons. When this herding tendency takes place, following prices fall, making harvesting unprofitable. By the end of 2011, potato prices experienced this. Several farmers decided to switch to growing potatoes since they were previously profitable and abandoned other crops. The price fell as a result of the extra supply. The harvesting and transportation of thousands of tonnes of crops became unprofitable, and they were left to decay in fields and on city streets. For many different crops, there is a typical boom and bust cycle.

Making long-term investments that might increase future efficiency becomes significantly more dangerous when farmers are unable to predict their revenue for the upcoming year. Mechanisms that lower price volatility would decrease food waste and boost farmers' incomes, enabling them to make more long-term investments.

Financing, education, and training

Farmers frequently borrow the money they need from commission brokers for each growing season in India's undeveloped agricultural banking industry, repaying the loan after the crop is harvested. Because most small farmers find it challenging to invest in modern infrastructure and equipment that may increase output yields, efficiency, and quality, few farmers have the scale to justify major investments.

Moreover, farmers are not adequately educated on topics like crop planning, rotation, pesticide and fertilizer use, investment decision-making, and crop planning. The majority of farmers inherit family land holdings, and they generally learn their trade through word-of-mouth and family traditions. Because of this, India's sizable farming population struggles to adopt optimal practices in agriculture.

It is evident that the fragmented farming system in India has special educational obstacles. Hence, increasing information sharing and transparency as well as access to longer-term funding will be highly beneficial for raising agricultural productivity and farmer incomes.

The COVID-19 pandemic not only revealed but also exacerbated the problems of food waste. In response to the public health emergency, the United States Environmental Protection Agency (US EPA) released guidelines for recycling and sustainable handling of food waste. These recommendations cover how to manage food waste in homes, businesses, and institutions (United States Environmental Protection Agency (USEPA) 2020). Following last year's lockout, surplus grain inventories estimated at 65 lakh tonnes in the first 4 months of 2020 — continued to deteriorate in go-downs throughout India (FAO 2020). Food became exceedingly limited for the poor, particularly day laborers. Despite substantial food production, the UN Food and Agriculture Organization reports that over 190 million Indians are undernourished. Furthermore, it is stated that every third malnourished kid is Indian. Ironically, the same survey claims that over 40% of food produced in India is lost or squandered. It is also estimated that food waste costs in India are over 92,000 crores per year. This food waste, however, is not restricted to one level but pervades all stages, from harvesting through processing, packaging, and shipping to the final stage of consumption. Though food waste is a worldwide issue, India has the possibility to turn it into an opportunity if addressed appropriately.

Conclusion

Considering food waste is a serious cause for concern, it is crucial to take a holistic approach to its management. In this article, an effort has been made to examine the concerns, management strategies, challenges, and future perspectives regarding food waste management in India. Food waste in India is mainly generated from domestic, commercial, agricultural, and industrial sources. Like other developing countries, India may take steps to reduce food waste, like collaborating with charities and food banks to make sure that surplus food from stores is given to people in need. The study of the detailed characteristics of food waste helps in deciding efficient management methods. Nevertheless, these studies often concentrate on just one component of sustainability, such as its impact on the environment, commerce, or community. There are many cases in point of research that aims to regulate food waste sustainably. Valorization, anaerobic digestion, composting, landfill, etc. are some of the effective sustainable food waste management techniques used worldwide as well as in India. Anaerobic digestion can be used to create methane, which is an efficient way to manage food waste. The method is less expensive, generates less waste thereafter, and turns food waste into a green energy source. This review also discusses the environmental impacts of food waste disposal. Improper food waste disposal practices have several negative environmental effects such as pollution, spreading of diseases, and emission of GHGs. Furthermore, by focusing research and optimization studies on integrating various production processes for value-added products, the effectiveness of the management of food waste might be improved. The significance of this review is that it portrays a detailed description of different sources of food waste, its characterization, and the factors affecting its biodegradation. The challenges, future perspectives, and a multitude of approaches regarding sustainable management have also been discussed in the later part of this review which makes it unique.

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