

The Utilization of Food Waste: Challenges and Opportunities

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Abstract

Food waste is a global challenge from collection to disposal. The problem associated with food waste is on the increase ranging from its discharged, lost, degradation and contamination. Food wastage can be effectively managed through proper storage, purchasing what is needed and giving excess to those in need. The most effective means of managing food waste is through effective sorting at source and recycling for industrial processes for the production of value-added products, thereby reducing the options of incineration and landfilling. Research has been carried out on food waste for the production of energy and other value-added products. This review aims to provide a brief overview of food waste from the farm gate, retailer, household and the impact of the pandemic in the increase of food waste. The potential strategies of effectively management of food waste both in developed and developing countries are discussed.

Keywords

Food waste, Value-added products, Disaster, Food waste management

Introduction

Globally, about 1/3rd of the food produced is wasted according to the Food and Agriculture Organization (FAO) statistics in 2011 [1]. The problem of food waste (FW) is a global challenge facing humanity worldwide. According to FAO, food loss (FL) is defined as “the decrease in quantity or quality of food that makes it unsuitable for human consumption”. Food waste is part of food loss and refers to food products discarded at the retail and consumer levels which could be as a result of an excess purchase, surplus supply of perishable where there is low demand, deliberate/in deliberate attitude to have leftovers at the household levels and market glut from surplus harvest [2, 3]. Food waste also refers to food intended for consumption that is discarded along the food supply chain, which cannot be consumed. Food waste typically consists of 82.5% moisture content, 51.2% carbon, 7.2% hydrogen, 38.1% oxygen, 2.8% nitrogen and 0.7% sulphur [4].

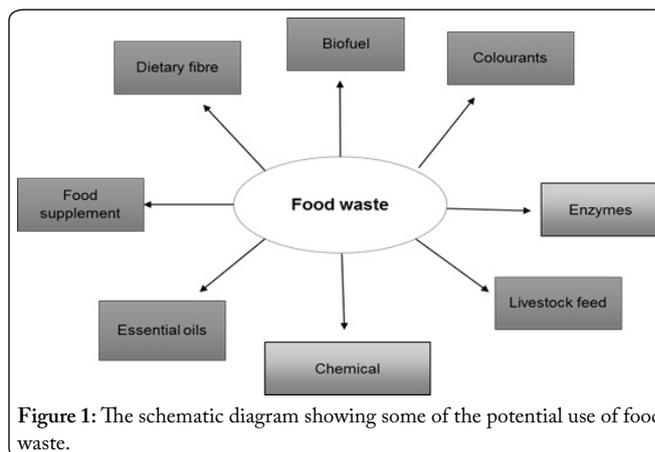
According to the FAO of the United Nations, global food waste is estimated at 1.3 57 billion tons per year of food produced for human consumption, which is being lost or wasted throughout the supply chain. Part of the sustainable development goals (SDG) agenda by the United Nations (UN), proposed a goal of halving worldwide food waste and substantially reducing global food loss by 2030. Meanwhile, food waste in the European Union is expected to rise from 89 million tons in 2006 to 126 million tons in 2020 where the household sector accounts for 42% of this total figure [5]. Currently, UK households generate 6.5 million tons of food waste per year, of which 4.5 million is edible. Japan,

China and the Republic of Korea produced 357 million tons of food waste per year, South and Southeast Asia produced 275 million tons annually. In contrast, Sub-Sahara Africa, Latin America, North America and Oceania, North Africa and Western and Central Asia produced around 100 million to 130 million tons of food waste annually [6]. The food waste includes food such as cereal, root and tubers, oilseed and pulses, fruits and vegetables, meat, seafood, milk and egg [7]. In Sub-Sahara Africa, post-harvest losses account for a more significant percentage of food waste [8], which reflects the potential harvested foods leaving the farmers' field without getting to the consumers. Yearly in Nigeria, 123 million metric tons of food is wasted before getting to the market [9]. The extent of food losses and waste is greater in developed countries where food still suitable for human consumption are being disposed, which is predominantly higher at the retail and consumer levels. However, in developing countries, food loss occurs mainly in the food supply chain at the postharvest and processing levels with less food wastage at the consumer level [9]. Table 1 shows the level of food waste generated at household, retails/food service, production, and processing stage around the world.

Table 1: Estimation of food waste in percentage generated in selected areas around the world.

Selected Area	House hold (%)	Wholesale& Retail (%)	Production & Process-ing (%)	Refer-ences
Africa	N/A	40	40	[10]
Australia	20	N/A	N/A	[11]
Europe	53	5	30	[12]
Canada	43	7	21	[13]
Mexico	15	16	36	[13]
United States	45	7	19	[13]
South America	28	39	34	[14]

Food waste consists of a heterogeneous mixture of carbohydrates (cellulose, hemicellulose, and lignin), proteins, lipids, and inorganic compounds [15, 16], biodegradable waste discharged from all waste management sectors from production to disposal. The management of food waste is a global effort due to its environmental, social and economic impacts [17]. There is a great emphasis on the recovery, recycling and reconditioning of food waste recently. These efforts are made to convert food waste into value-added products, as shown in figure 1. Currently, the food waste generated is mostly recycled as animal feed and compost, while the remaining quantities are disposed on landfills or incinerated. The inappropriate disposal of food waste may lead to severe health and environmental issues such as greenhouse gas, which significantly contribute to climate change [18]. Food waste also occupies landfill space, contaminates freshwater and increases carbon footprints [19]. In 2019, according to the United Nations Food and Agriculture Organization (UNFAO), about 4.4 billion metric tons of carbon dioxide was produced due to food waste disposal. The carbon dioxide emission is so enormous and has a detrimental effect on human health [20].



The food production system or supply chain requires the combined efforts of actors such as the farmers, industries, retailers and consumers and many factors such as fossil fuels, land, water and human resources are interplayed in this process. During this production process, eutrophication occurs as well as greenhouse gases (GHG) are emitted, which thus, affect the environment. Eutrophication is the process by which the environment becomes enriched with nutrients, increasing the amount of plant and algae growth to coastal waters [21]. Eutrophication from food waste can be generated food waste disposed on landfills, which are washed off to aquatic environment through soil leaching and rain. The first step in reducing food waste generation is by preventing the over-production and over-supply of food. For the food waste generated, studies have been carried out to utilize food waste as raw materials for the production of a broad spectrum of commercially essential products, including: dietary fibre, livestock feed, biogas [22], biopolymers, bioplastic, biofuels (i.e., bioethanol, bio-butanol, biodiesel), enzymes [23, 24], nutraceutical, single-cell proteins, [18], food flavors, bio adsorbents [25]. The production of chemicals, materials and energy can be derived from food waste [6] via a sustainable and environmentally friendly process to reduce its effect on the environment [26]. This review focused on the utilization of food waste for the production of value-added products, how effective food waste management could help minimize global food wastage, the impact of pandemic on food wastage, its challenges and opportunities.

Current Practice of Food Waste Generation and Management

Food wastage has been connected to issues such as climate change, biodiversity loss, water loss, soil degradation and hunger as well as the loss of nutrient in diets. Food waste can be effectively managed at household levels, retails, production and processing as highlighted below.

Consumer education (awareness)

Awareness entails educating consumers on the importance of food waste reduction and recycling. Consumer education requires a gradual behavioral change and attitude towards household food purchasing, consumption and storage

pattern [27]. Consumer education was one of the highest-ranked solutions for food waste with an estimated food waste diversion potential of 584,000 tons/year and an economic value of \$2.65 billion/year in the United States [28]. A case study from Southern Italy reveals the impact of consumer behavior on household food waste. The result of the survey showed that age and education exposure were factors that influenced food waste. The younger age group and the less educated contributed significantly to food waste within the population [29]. Community engagement has been regarded as a potential avenue for communicating the reduction in food waste practices and its impact. There was a 50% reduction of avoidable food waste by participants through community engagement workshops by Yamakawa, Williams [30], which demonstrates the impact consumer education has in the reduction of food wastage. Food waste at household levels can also be reduced by extending food shelf life and reducing waste through chill out and safe store, learn your labels, getting creative with leftovers, and sharing surplus [9]. According to the World Food Program, if food waste can be curtailed, it would be enough to feed about two billion people each year and about 815 million people to lead a healthy, active life and 25% of people undernourished in developing countries [31]. A technology-based approach (Gamification) has been used such as smart bins [32, 33], bin cams [34], and fridge-cams [35], in monitoring and providing feedback on food waste. Gamification is a game element, design in non-game contexts for behavioral change delivered through technology such as apps by changing the way consumer make decisions in electronic stores [36]. Environmental campaign to consumers on the effect of food waste on the environment will give them a better understanding of its outcome and why it should be reduced [37]. In developed countries, there are separate bins for different waste pick up. In the UK, only about two-thirds of UK households have access to a separate or mixed food waste collection, and these are under threat due to the recent pandemic outbreak (coronavirus) [38]. The bins separation indicates some basic awareness of food wastage due to the need for waste separation at the source. These source separation of waste and municipal waste pick up are not available in developing countries.

Improving packaging materials

Improving the packaging materials of products to extend its shelf life and improving product quality is essential to curtail food waste [27]. Food waste can be minimized at the retail level if food products with short shelf life or close to expiry can be sold at a discounted price and made affordable so that consumers could buy it off the shelf before it gets deteriorated and wasted. Subsequently, perishable or food products with short shelf life should not be over-stocked up if the demand would not meet the supply. These food products could be given out to charity organizations or food banks for the vulnerable which includes the homeless, those with low income that cannot afford meals for their families and the poor [37].

Food waste valorization

Valorization of food waste in simple terms is food value

addition. Valorization implies the processing of surplus food into value-added products or the utilization of waste or unwanted food product waste, such as peels for animal feed production [27]. The abundant volumes of food waste generated globally throughout the food supply chain have emerged as potential resources, which can be employed as raw material to obtain high added-value products, for example, production of food packaging materials from rice straw and shrimp, fuels and chemicals [39, 40]. The implementation of the biorefinery concept could be an essential part of the successful valorization of food waste. Food waste can be used to produce a spectrum of bio-based products. Food waste biorefinery can complement fossil-based refinery to a certain extent and address the major drivers for bioeconomy such as climate, resource security, and ecosystem services [23].

Sustainable Development Goal (SDG) and Food waste reduction

In line with the Sustainable Development target 12.3 [41], which states that “By 2030, to half per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses”. There is a need to implore strategies that will reduce food waste minimally [41]. Food waste reduction will subsequently solve SDG 2, which is ending hunger and SDG 12, which is ensuring sustainable consumption and production pattern [1]. Adapting the sustainable development goal in reducing food waste has been implored in various ways. DuPont extended the shelf-life of yoghurt by ten days of plant-based foods, and this has reduced food waste drastically according to a case study collated by World Business Council for Sustainable Development (WBCSD) [42]. The company implored the use of a specially formulated bacteria to extend the shelf life of plant-based fermented food and this approach reduced yoghurt waste by about 30% in Europe thus, reducing waste due to early expiry in the supply chain [42]. International Flavors & Fragrances (IFF) reported a case study on the reduction of spinach losses by a drying technology. The company implored the use of gentle infrared drying technology in drying spinach into a powdery form, thus retaining its nutrients, color and taste. This method reduced food losses and waste and has generated about 1.3 million USD additional revenue [43]. This technology has made powdered spinach available on the shelf for households use in a beverage or incorporated in snack bars, thus improving vitamin K intake. Reducing food loss and waste through innovative plays a major role in improving food security and nutrition, promoting sustainable environment and natural resources, and lowering food production costs thus, meeting the SDGs Target 2 & Target 12.3 goal of zero hunger, reducing per global capital waste at the retail and consumer levels and food losses along global production and supply chains by 2030 [44].

The Production of value-added products from food waste

The management of food waste should follow specific policies based on 3R's concept, i.e., reduce, reuse, and recycle [15]. A sustainable bioeconomy can turn bio-waste, residues and discards into valuable resources and can create innovations.

The exploitation of food waste for the production of biofuels is in line with the 2030 Agenda for Sustainable Development set by the UN in 2015. More precisely, it is directly related to the Sustainable Development Goals: 7. Affordable and Clean Energy, 12. Responsible Consumption and Production, and 13. Climate Action and incentives to help retailers and consumers cut food waste by 50% by 2030 [5]. However, the use of food by-products and the conversion of food waste is still limited [15]. The current limitations in food waste include its quantification along the food supply chain, limited data on its quality and level of homogeneity, and differences in national implementations of the waste legislation [45].

There is an increasing effort currently focusing on the effective and stable means of obtaining biofuel and bio-products from food waste [23]. Food waste with nutrients composition of 30-60% starch, 5-10% proteins and 10-40% (w/w) lipids makes food waste a promising raw material [6]. Chemical and biological/enzymatic methods can be performed for the recovery of nutrients from food waste in the form of carbon, nitrogen and phosphorus compounds after solubilisation of the waste matter [26, 46-48]. Studies have shown that food waste has high crude protein values, minerals, as well as other bioactive compounds of nutritional benefits and this food waste, can also be channelled into animal feed production thus increasing livestock productivity [2, 49, 50].

Most of the food waste matters requires hydrolytic enzymes such as glucoamylases, cellulases, Makanjuola proteases and phosphatases for their hydrolysis [6]. A sorghum bran based bio-refining concept was developed by Makanjuola, Greetham [26] for the production of glucoamylase using *Aspergillus awamori*. The sorghum bran was hydrolyzed using the glucoamylase enzyme produced for the production of a sugar-rich fermentation medium and a glucose concentration of 38.7 g/L from 200 g/L sorghum bran was obtained. They indicate the potential use of sorghum bran hydrolysate as a generic fermentation feedstock for the fermentative production of biofuels and biochemical. Ahmed El-Imam, Greetham [51] exploited sorghum bran a sorghum milling waste for the production of fermentable feedstock using both enzymatic and dilute acid hydrolysis with a further investigation for the production of bioethanol.

Prasoulas, Gentikis [45] used the induction of *F. oxysporum* for the production of enzymes using wheat straw, wheat bran and corn cob. They exploited those enzymes for ethanol production through the hydrolysis of food waste. Energy valorization of food processing residues was carried out by Déniel, Haarlemmer [52] showing that liquid fuel can be produced from food waste using hydrothermal liquefaction (HTL).

Food waste obtained from fruits during fruit juice production such as the peels, rinds can be utilized into value-added products such as fibers which can be included in confectionaries and household frozen meals. Incorporation of fibre will improve the fibre content of such products which can be suitable for the elderly, diabetic patients and weight loss [53]. Citrus pulp and molasses serve as a substrate for

fermentation in the beverage-alcohol industry. In contrast, the pentose sugars that was not utilized by the beverage industry serve as an excellent source of energy for cattle feed [54].

Coffee husk and pulp are by-products obtained during the processing of coffee. Its richness in organic nature makes it suitable for the production of value-added products. Pandey, Soccol [55], report alternative uses of coffee husk and pulp for the production of fertilizers, livestock feed and compost. Attempts have been made to produce several products from the coffee husk and pulp such as enzymes, organic acids, and flavor and aroma compound through solid-state fermentation [54-56]. Some of the husks are used as organic fertilizer while the pulp also has its utilization in swine feeding [54]. Food waste could equally be compounded into organic manure for farming purposes [37].

The disposal of agricultural by-products such as cassava waste from processing activities from the farm and household is of great concern due to its environmental pollution in Nigeria. Converting these low-value cassava waste into biosorbent for the removal of toxic and valuable metals from industrial wastewater would help prevent its environmental pollution thereby, increasing their market value and thus benefit millions of cassava producers [54]. Uzochukwu, Oyede [57] has reported the effluent starch from garri processed from cassava for the production of 50.1% (v/v) ethanol. Table 2 lists some examples of recent studies on the utilization of food waste for the production of value-added products.

Table 2: Recent studies on the production of value-added products from food waste.

Substrate used	Method used	Products	References
Pea waste	Dual twin-screw extrusion & microwave hydrothermal treatment	Micro fibrillated cellulose	[58]
Berry pomace	Extraction	Phytochemicals	[22]
Municipal solid waste	Transesterification	Maggot biodiesel	[59]
Kitchen waste	Anaerobic digestion	Biogas	[60]
Sorghum bran	Submerged fermentation	Glucoamylase enzyme	[26]
Sweet sorghum	Fermentation	Bioethanol	[61]
Waste cooking oil	Valorisation	Biodiesel	[62]

Impact of disaster on food waste generation

Depending on the nature and severity of disasters such as flood, earthquake, hurricanes and other risks weaken food security and impact agricultural activities severely [63]. Disaster put food security at risk with food wastages occurring in different disasters where people are displaced from their settlements, death of people, and decrease in agriculture output [63]. Foods are discarded based on their contact with flood or storm water, perishable foods not properly

refrigerated due to power outage and if poorly managed on a large scale, the waste can have significant environmental and public health impacts.

Since, the emergence of the world pandemic coronavirus (Covid-19) the major fear has been food insecurity due to lockdown in several parts of the world. Thus, there is a reduction in food production, processing and distribution [64]. The lockdown has also affected several countries food export and imports trade system. The urban farming system has reduced in several parts of the world as vast swathes of the population are staying home with measures in place to reduce the rate of transmission, to remain safe and virus free [64].

An increase in food waste is expected to rise globally in as much as we are fighting food scarcity due to government instructions to limit trips to the shops for food as far as possible. The restriction has resulted in different household stocking up on food than they need with less need to go out, and this has contributed mainly to excessive food waste during this pandemic. Hence in a bid to have all food products available as at when needed, consumers have the risk to overstock on certain food products and eventually waste these food products. In contrast, some do not even have enough to consume [64].

Creating good habits for the future involves communities supporting one another and households playing their role in cutting down food waste. Individual purchasing what is needed, storing it safely and creatively using up leftovers, thereby helping the planet and supporting the whole community to access food during the challenging time [38] will reduce the amount of food waste generated. Post-harvest waste would be on the increase because of the reduced workforce on the farm to harvest, process and mainly distribute food products across borders due to the pandemic as a result of workers shielding due to underlying health issues, self-isolating and becoming sick themselves. Therefore, food production companies have delay receiving food crops supplies from the farms and on the arrival of some of this produce are unwholesome for processing, and all this contribute to food loss. Equally, the retailers may have logistic issues getting food produce on time from suppliers and on the arrival of this product they cannot withstand a longer shelf life in-store thus contributing to food waste at the retailer's level even before reaching the customers [64]. In Nigeria, 45% of food loss is due to lack of cold storage resulting in a 25% loss of annual income by small farmers [9]. There is a potential in investing in Africa's broken food security value chain as an opportunity to reduce food loss and food waste in all stages of food production.

A survey carried out by Jribi, Ben Ismail [65] during this Covid-19 pandemic in Tunisia showed a behavioral change towards food waste and thus, this reduced food waste in several households. However, the major causes of food waste during this pandemic were overstocking, inadequate food storage and overcooking. Based on the survey carried out baked products had the highest waste records followed by vegetables, then fruits, while fish and meat products had the least waste recorded [65].

Challenges and opportunities

It is challenging to quantify food waste from the retail and consumer level because most times, both the edible and the non-essential waste are mixed [41]. Regardless of the existence of various traditional methods of landfilling or biogas production used to harness food waste, effective conversion of food to valuable resources is often challenged by its heterogeneous nature and high moisture content [66]. The difficulties in proper collection, storage facilities, cooking methods, cultural lifestyles and bioconversion of food waste to valuable by-products are pointed out as a big hurdle in proper food waste management [37, 66]. Natural disasters, pandemics and civil unrest could contribute to food loss as well as food waste. During such situations, the goal is to be alive and safe, and there is a shift from harvesting and food production or processing. Many products are left unattended to with minimal attention, and this affects the wholesomeness and integrity of such food products right from the farm even before reaching the retailers and consumers, thus amounting to food waste. The use of food by-products and the conversion of food waste are still limited. Food waste is currently limited in its quantification along the food supply chain, limited data on its quality and level of homogeneity, and differences in national implementations of the waste legislation. The composition of food waste, as already said, is not stable. It presents significant variations related to the season, the area, and the dietary habits of the population. Despite the inevitable variation in the composition of collected food waste, recycling through anaerobic digestion is one of the ways in achieving zero-emission from food waste [15]. Food waste conversion to animal feed has some challenges such as high microbial load, high moisture content and the presence of anti-nutritional factors in plant-based food/crops, which could prevent nutrient absorption [67]. However, this challenge can be resolved by following food waste guidelines. The benefits associated with the utilizations of food waste from an environmental point of view include; reduction of methane gas emissions from landfills, preservation of natural resources such as coal and fossil fuels and from the social point of view due to criticism of food versus fuel [23]. The effective use of food waste as a raw material for the production of value-added products is essential for zero-emission, in reducing health and environmental issues associated with food waste landfill, economic and social benefits. The hydrothermal liquefaction remains an active research area with some processes already been developed at the pilot scale for the valorization of food wastes [52]. The industry is still facing technological and economic challenges in the development of HTL processes.

Conclusion

The development of sustainable food waste management is essential as it remains a big hurdle for the society. Effective food waste management provides social, economic and environmental benefits globally. Development of a sustainable food waste management could be achieved by redistribution of surplus to the needy or social services. Residues from the

farm gate, households, and retailers not suitable for human consumption can be utilized as feedstock for the production of value-added products such as biofuels, enzymes, colorants. Educating the public on getting what they need at a time during a pandemic will help reduce food waste in the future, thereby making food available for everyone. The opportunity of using food waste as feedstock in energy production seems a feasible option. The use of biotechnology processes in the conversion of food waste to value-added products is a crucial strategy in maximizing the utilizations of food waste, thereby reducing its effect on health and environment through incineration and landfills.

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