Ozturk M *et al.* (2025)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 53, Issue 3, Article number 14683
DOI:10.15835/nbha53314683
Review Article

Livestock-mediated food waste conversion: Advancing resource efficiency and sustainable agriculture

Munir OZTURK[1], Iqra SIDDIQUE[2], Alvina GUL[2], Ibrahim Ertugrul YALCIN[3]*, Volkan ALTAY[4], Bengu TURKYILMAZ UNAL[5]

[1]*Ege University, Department of Botany and Centre for Environmental Studies, Izmir, 35100, Türkiye; munirozturk@gmail.com*
[2]*National University of Sciences and Technology, Atta-ur-Rahman School of Applied Biosciences, Department of Plant Biotechnology, Islamabad, 44000, Pakistan; iqrasiddique2811@gmail.com; alvina_gul@asab.nust.edu.pk*
[3]*Bahcesehir University, Faculty of Engineering and Natural Sciences, Department of Civil Engineering, Istanbul, 34353, Türkiye; ibrahimertugrul.yalcin@bau.edu.tr (*corresponding author)*
[4]*Hatay Mustafa Kemal University, Faculty of Science and Arts, Department of Biology, Hatay, 31060, Türkiye; volkanaltay34@gmail.com*
[5]*Niğde Ömer Halisdemir University, Faculty of Science, Department of Biotechnology, Niğde, 51240, Türkiye; bengu35540@hotmail.com*

Abstract

Food waste throughout the agri-food supply chain has significant environmental and economic consequences on a global scale. To address this issue, upcycling food waste through livestock is a promising approach that can help achieve sustainability goals. The upcycling of food waste via livestock involves feeding food waste to animals, such as pigs or chickens, instead of disposing of it as waste. This approach offers multiple benefits, including reducing the amount of food waste that ends up in landfills, reducing greenhouse gas emissions, and producing a source of protein, offering a sustainable solution to the food waste problem. Through utilizing food waste as a resource for animal feed, this process adds value while simultaneously tackling environmental concerns linked to food waste. Furthermore, this process can generate income for farmers and lower the cost of animal feed. However, there are regulatory and safety concerns associated with the use of food waste as animal feed, necessitating strict guidelines and monitoring. Despite the challenges, upcycling food waste via livestock provides a promising solution to food waste management issues. It provides a win-win solution for both the environment and economy, presenting a promising way forward for the future of agriculture by minimizing food waste, promoting sustainability in the food industry, and offering a new source of animal feed. This study argues that upcycling food waste through livestock farming has significant potential for minimizing food waste, promoting sustainability in the food industry, and providing a new source of animal feed. It provides a win-win solution for both the environment and economy, representing a promising way forward for the future of agriculture.

Keywords: animal feed; environmental impacts; food waste upcycling; sustainability; sustainable agriculture; waste food management

Received: 22 Jul 2025. Received in revised form: 08 Sep 2025. Accepted: 17 Sep 2025. Published online: 24 Sep 2025.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

Introduction

The majority of food waste consists of edible foods intended for the use of humans, but were discarded, deemed unfit, or consumed by pests. It includes the food material parts and edible or appealing products that can be used (Parfitt *et al.*, 2010, Foresight, 2011). Each country has a different amount and makeup of food waste. In the harvest phase after the harvesting and processing phases of the supply chain of food, Underdeveloped nations are responsible for 44 percent of the world's food waste. By contrast, industrialized nations like those in North America, Europe, South Korea, Oceania, China, and Japan are largely accountable for approximately 56 percent of food wastage, of which about 40 percent occurs during the pre-consumer as well as post-consumer stages (Ashraf *et al.*, 2012; Lipinski *et al.*, 2013; Ozturk *et al.*, 2011, 2019, 2022). Depending on which stage it happens in the food supply chain, food waste and food loss might be further subdivided. Food loss is the term for food waste that happens at the early phases of the food supply chain, such as during production, transportation, processing, and storage. Lower returns are found in the value chain at these phases. Food waste refers to the wastage of food that occurs throughout the supply chain, particularly during the retail and final stages of consumption. At this stage in the chain, the food waste indicates more opportunity for value development (Gustavsson *et al.*, 2011, Bond *et al.*, 2013, FAO, 2019a). There are two main sites that food waste usually comes from: homes and commercial spaces like restaurants. Food waste can have serious negative effects on human health and is a major environmental issue (Blair and Sobal, 2006; Bond *et al.*, 2013). Food loss and food waste are the reasons for the emission of greenhouse gases and have a detrimental effect on natural resources. The hike in food prices and the global rise in food insecurity serve as more evidence of the carelessness in food waste handling and the shortcomings of the current food system. Upcycling food waste is a novel strategy to address food waste by converting materials that would otherwise be thrown away into products with added value known as upcycled food (Aschemann-Witzel *et al.*, 2023). Feeding livestock provides an opportunity to recycle food waste and its nutrients. Due to the innate capacity of livestock animals to digest a variety of biomass, there is a chance to maximize the use of industrial, urban, and agricultural byproducts. We can efficiently produce more food while lessening the demand for resources, minimizing the negative impacts of waste on the environment, and easing the burden of climate change by rerouting these materials to cattle. The capacity of cattle to transform these resources into valuable animal products offers a workable way to provide food sustainably (Dou, 2021). This chapter presents a compelling argument that raising livestock for upcycling food waste holds significant promise in reducing food waste, promoting sustainability in the food sector, and providing an alternative source of animal feed. It offers a win-win solution for the economy and ecology and shows that agriculture has a bright future ahead.

Types of Food Waste

The FAO Food Balance Sheet lists 100 food groups, and there are differences in the types, forms, sources, and nutritional characteristics of food waste. Food waste's economic worth is determined by its energy, amino acid, protein, and phosphorus content. All of these are costly elements of animal diets. Based on source, nature, empirical uses, and suitability for feeding to animals, food waste is divided into four categories.

Ex-food waste

This type of food waste is often referred to as "off-spec" food, which describes produced food items that were pulled from the supply chain due to logistical issues like incorrect labelling or packaging, or because they did not meet brand requirements for consistency, appearance, or product specifications (Vandermeersch *et al.*, 2014). Ex-foods include surplus bakery goods, salty snacks, and confections high in sugar. Ex-foods are nutritionally similar to cereal grains, while certain products have higher fat content because they contain butter, margarine, or vegetable oil. There is a range of 25 to 73 percent starch concentration and 11.0 to 19.0 MJ kg^{-1}

digestible energy content. For safe, reliable, and simple mixes, they may need to be dried and heat treated, but otherwise they are dry and require little processing (Pinotti *et al.*, 2021).

Fruit and vegetables waste

Vegetables and fruits have a high wastage percentage among all classes of food. Approximately 50 percent of the global food waste is associated with vegetables and fruits (Wang *et al.*, 2023), with a high proportion of 61 percent happening in China (Xue *et al.*, 2021). The residues left from harvesting, packaging, processing, and handling are discarded according to business protocols dictated by the customers. Discards generated before consumption by humans offer a lucky chance for upcycling into animal feed due to their large quantity, predictable output, source separation, and targeted collection. But upcycling the discards of vegetables and fruit is limited by their high content of moisture, making them prone to spoilage. Drying can increase the time of storage and maintain the nutritional profile, but the costs and greenhouse gas emissions make it prohibitively expensive to use. Co-ensiling the crop residues or dry hay with fresh fruit can produce quality feeds. Solid-state fermentation employing bacteria or fungi can preserve perishable biomass for animal feeding. Wetness makes long-distance transportation expensive, making animal feeding limited to nearby farms. Innovative, low-carbon drying methods could enhance animal-based upcycling (Nayan *et al.*, 2020; Dou *et al.*, 2022).

Unsellable in the market

The market serves as a conduit between consumers and the food production and provision sectors. Unsold foods are routinely declared as leftovers, such as bakery products, fresh produce, meats, and other foods from animal sources that are approaching or exceeding "best-before" or "use-by" dates on the labels of products, even though they do not indicate any concerns about food safety (Ruppenthal and Horoś, 2021, Mijares *et al.*, 2021). This type of wasted food is most likely more common in developed countries as compared to developing countries (Jinno *et al.*, 2018). According to a study by Jinno *et al.* (2018), the materials and foods left unsold in grocery stores in the US consist of almost 75 percent vegetables and fruits, 5 percent bakery items, and 20 percent meats and foods from animal sources. These materials can be a great source of amino acids, phosphorus, and energy for pigs (Fung *et al.*, 2019a). (2019b) found that food waste from supermarkets that is thermally treated, including fruits, dairy, vegetables, meat, and bakery leftovers, has metabolizable energy more than corn (Shurson *et al.*, 2022). Recommend limiting diet inclusion to less than 10% to minimize overfeeding and high excretion. Proper treatment before feeding is crucial for animal health and consumer trust.

Leftover food from a consumer

Similar to non-point sources, post-consumer waste of food is produced in many homes, restaurants, and food service facilities. Even more complicated is post-consumer food waste, which includes any food-associated material that was once cooked or raw, edible or inedible, whole or in parts, and plant- or animal-based. A study reviewed 150 studies on the chemical and physical characteristics of food leftover or food waste from schools, services, and households, as well as samples taken from municipal solid waste streams. The study found significant differences in DM, pH, lipids, fiber, ash, and total N in food waste sources, with food services having higher lipid concentrations. The nutrient composition was extremely variable, with DM, pH, crude protein, and carbohydrate concentrations varying (Dou and Toth, 2021). The high degree of variability is not unexpected as several studies have demonstrated the effect of consumer behaviour and sociodemographic factors on the composition of household food waste (Patetta *et al.*, 2019; Shaw, 2021).

Economic, Environmental, and Social Consequences of Food Waste

Food waste, no doubt, is a significant social issue that has an adverse effect on consumer welfare, the ecosystem, the environment, and the security of food. In addition to the fact that approximately 1 billion people worldwide suffer from malnourishment, one-third of all edible food products that are for human consumption are wasted or lost annually during transportation. The amount of food wasted at the consumer stage in industrialized parts of the world is almost equal to the total amount of food present in sub-Saharan Africa, with per capita waste in these countries ranging from 95 to 115 kg annually. Furthermore, avoidable food waste has a detrimental impact on the environment, with China and the US accounting for the third-highest global carbon footprint. Food waste occurs throughout the food supply chain, but for several reasons, cutting it at the consumer or household level is prioritized. First, in developed nations, consumer food waste accounts for most of the food waste. Second, the food resource usage and environmental impact peak after it has been delivered to the customer and may be prepared at home. Third, household food waste mostly ends up in the garbage, adding to costs and having an adverse effect on the ecosystem. In contrast, a significant portion of food lost during the supply chain earlier is at least utilized, such as to feed different animals (Van Doorn, 2016).

The European Union wastes about 88 million tons of food each year, causing significant environmental impacts. A study reveals that food waste adds to 15-16 percent of the entire impact of whole food supply chain. Food that comes from animals is the main source that has different environmental impacts during the primary production step. During the production process, greenhouse gas emissions are the primary cause of nearly 75 percent of all food waste-associated effects on global warming (Scherhaufer *et al.*, 2018). An estimated 35 percent of food that is bought to be consumed at home is wasted. Given that one-third of global greenhouse gases are produced by the food industry, the environmental effects are the most significant. There are more nuanced social and economic repercussions. According to U. S. data, families lose hundreds of dollars annually due to food waste, and over-consumption increases costs and restricts access (Tadigadapa, 2022).

Addressing Global Crises of Food Waste

The increase in waste is a major issue faced by the current food systems. Large amounts of food loss and food waste, as well as the unsustainable use of natural resources, are indicators of inefficiencies in food systems (Messner *et al.*, 2021). Around one third of the food prepared for human consumption is wasted or lost worldwide, which is equal to approximately 1.3. billion tons of food annually (Gustavsson *et al.*, 2011). Understanding the reasons behind consumer-generated food waste will be more helpful for prevention because the majority of food waste happens at the household stage (Aydin and Yildirim, 2021). Food wastes and food losses are indirectly associated with the several environmental effects including deforestation, soil erosion, greenhouse gas emissions, and air and water pollution, which arise during the preparatory steps of food preparation and production, food storage, its transportation, and the management of waste (Mourad, 2016). This is because food production is notably resource intensive. Governments, corporations, NGOs, academics, and the public are all beginning to recognize food waste as a pressing issue due to the growing environmental and economic issues. As a result, there is significant data on the amounts of food lost or wasted and the emissions related to it in the whole food production to consumption process (Edjabou *et al.*, 2016). Alarming data show that food waste is a serious issue for society, the economy, and the ecosystem. The retail to consumption level of food waste generated in 2019 amounted to approximately 931 million tonnes, with households accounting for 61% of the waste, food services contributing 26% and the retail sector contributing 13 percent (Varghese *et al.*, 2021). About 8-10 percent of greenhouse gas emissions worldwide are caused by food waste (Mbow *et al.*, 2019). Food waste is regarded as a paradoxical issue (Richards *et al.*, 2021). Huge amounts of food are lost or wasted, where millions of people continue to experience food insecurity (Chaboud and Daviron, 2017; Papargyropoulou *et al.*, 2022). To make the necessary enhancement in food supply, feasible food systems must be diverted towards sustainability (Richards and Hamilton, 2018). Certain objectives are set in order to achieve this, including notable decreases in food loss and waste as well as improved resource utilization effectiveness (WHO, 2021). The academic community, NGOs, and government have shown concerns and are paying serious attention to food waste because of the growing financial and ecosystem loss it causes, which is pushing policymakers to take preventive action.

Concept of Food Waste Upcycling

Fortunately, food waste is a problem that is recognized globally. Increasingly, public-private partnerships and value chains are implementing initiatives to share data and expertise on reducing food waste. While food waste is a complicated problem that requires a wide range of solutions. Repurposed food is an innovative idea for creating plans and policies to reduce food waste. Trend reports indicate a huge potential market for the term, which is becoming more and more popular in the food industry (Forbes, 2021). Upcycled food introduces upcycling, a fundamental idea of the circular economy to the food industry. It is in keeping with the movement in policy to support closing the loop in food and agriculture among other major industries (Aldaco *et al.*, 2020). Upcycling is a term that is becoming more and more popular as a trend in green consumer behaviour (Adiguzel and Donato, 2021; Aschemann-Witzel *et al.*, 2023). Concerns about the environment, climate alteration, and the willingness to incorporate sustainable actions into diets and food choices are growing. About 78% Europeans believe that climate change is a major issue (Bonev *et al.*, 2022). Expectedly, recycled food holds significant potential for the agriculture and food sectors' sustainable transition. In light of this sustainable shift in food production and consumption, greater diversity is required. Upcycling needs to be defined precisely, and its dynamic nature must be recognized. Two distinct product categories surface in the market: one addresses symptoms but not the underlying causes, providing a valuable intermediate solution, while the other concentrates on the core causes of food waste and sustainability problems, providing a significant long-term impact (Aschemann-Witzel *et al.*, 2023).

Upcycling Potential of Livestock Animals

Most of the recently published research on using food waste as feed livestock animals comes from Taiwanese, South American, South Korean, Indian, and Japanese nations. While tests on poultry beef and dairy cattle Paek small ruminants and other animal species have also been conducted pig feeding is the focus of most of the studies (Angulo *et al.*, 2012). Animals have long been fed food scraps as part of a common practice. According to a study a number of significant Australian retailers provided farmers with about 40000 MT of food as feed (Al-Tulaihan *et al.*, 2004). In the UK, 2.2 MT of food by-products were converted to animal feed in 2010 (Parfitt *et al.*, 2010). Approximately, 1.6 MT of food waste was upcycled to animal feed in the US where 84-86% of waste from the processing and manufacturing sector was converted to either land applications or animal feed (Alliance, 2016).

Animals raised for livestock are essential in repurposing food scraps into valuable feed which promotes resource efficiency and sustainability. Different livestock species have the capacity to make efficient use of various kinds of food waste. Cattle and other ruminant animals can make good use of high-dietary-fiber plant-based food waste. This means that these animals can eat unsalable fruits and vegetables which are high in fiber and can provide them with energy (Nath *et al.*, 2023a). It is especially easy for pigs to turn food scraps into productive feed ingredients. According to research, the value of feeding of several food waste sources is on par with or higher than that of conventional pig ingredients like corn and soybean meal. An environmentally friendly and long-lasting solution to food waste is provided by recycling important nutrients from food waste into the diets of pigs. These creatures can break down different biomass materials such as food scraps. Particularly pigs and ruminants livestock animals have a great deal of potential to turn food waste into useful feed supporting resource efficiency and sustainable farming methods (Nath *et al.*, 2023a).

Role of animals in food waste upcycling

The highest priority in the food retrieval hierarchy is still preventing food waste from happening. This is the leading way to mitigate food waste (Van Bemmel and Parizeau, 2020). Due to the fact that large amounts of food waste are still produced. Societies cannot only focus on preventing waste they also need to advance in tandem with bettering food waste management in order to meet a number of sustainability goals. While anaerobic digestion and composting have received a lot of attention and are being used more frequently as food waste treatment options, upcycling to animal feed is higher in the hierarchy of food waste recovery. By capturing part of the nitrogen and carbon in stable materials and recycling them back into the soil, composting helps to improve soil health and reduce the need for fertilizer. Using multifunctional additives, modeling emissions control, and AI-based process control techniques, food waste composting efficiency can be increased (Li *et al.*, 2013).

Biogas is a renewable energy source produced by anaerobic digestion and digestate has properties that are similar to those of compost that are beneficial to the soil (Ozturk, 2014; 2017; Ren *et al.*, 2018). Instead of recycling nutrients back into the soil, which is the base level of system of food production, through anaerobic digestion or composting, the use of a variety of food waste sources to make animal feed is a better idea. This enables the upcycling of lipids, protein, minerals, and carbohydrates via animals to make nutrient-rich food for humans (Eastham and Creedon, 2023). The procedure of repurposing food waste into feed for animals is unmatched by any other method. This minimizes the requirement for traditional feedstuffs like grains and oilseed meals which has a knock-on effect of saving land and fertilizer as well as preventing the loss of phosphorus and nitrogen, and other resources (Nath *et al.*, 2023b). But not every food scrap can be used to make animal feed. High-quality materials with modest amounts of protein and energy with very low risks of feed safety can be treated by thermal treatment and are suitable for converting to feed for animals, whereas poor quality materials or materials with more feed safety risks should be treated by anaerobic digestion or composting.

Livestock animals have traditionally served as biological processors, converting unwanted or inedible food ingredients into eggs, milk, meat, etc. Modern treatment techniques can aid in the transformation of food waste into the feed products that are safe, wholesome, and enhanced in value. One workable way to tackle waste management, resource conservation, food security, pollution, and climate change mitigation at the same time is to recover consumption-stage food waste for feeding animals (Dou *et al.*, 2018). A range of feed sources obtained from nearby crop processing is commonly used in animal diets in place of some cereal grain. When wheat is ground into flour, a mixture of by-products known as bran and germ is created, which can be fed to cattle as wheat middling. This is also true of major crops such as soybeans, sunflowers, and oats whose hulls are frequently removed during the processing stage and added as a source of fiber to ruminant diets. Cattle diets can benefit from the utilization of potato processed by-products as well as other fruit and vegetable by-products. They must, however, be used immediately or treated further (such as ensiling) due to their high moisture content to prevent spoiling. In response to growing consumer demand for innovative goods like meat alternatives, it is anticipated that the variety and quantity of by-products in animal diets would increase as commodity fractionation for inclusion in meals increases. South Korea and Japan, which have been leaders in this field divert up to 60 percent of their everyday food waste to feed animals (Nguyen *et al.*, 2017). More specifically, a range of microbes present in the rumen and intestine, up to a lesser extent, can effectively break down plant fiber that is edible to humans, as well as plant byproducts. This enables the host to produce protein of high quality that contains essential fatty acids and amino acids (Matthews *et al.*, 2019).

Amount of food waste put to use as ingredients in animal feed

Worldwide, yearly 6 billion tons of feed are taken by food-producing livestock animals, of which about 72 percent is composed of roughages that are consumed by livestock such as goats, sheep, and cattle. Of 1.57 billion tons of , oilseed meal, grain by-products, and grains consumed, 65 percent are fed to poultry and swine (Mottet *et al.*, 2017). Considering this perspective, globally above 1.3 billion tons of consumable food material go to rubbish each year. This amount is 3 million tons which is more than the number of oilseed meals and cereal grains by-products consumed by pigs and poultry both. Furthermore, global animal production and meat-processing industries annually produce approximately 60 million tons of animal by-products (Hamilton, 2004). Since swine and poultry cannot effectively utilize the fiber in roughages and need diet that is higher in energy and nutrients than those for livestock. There is a great chance to recycle nutrients and energy from different sources of food waste into feed for animals. A larger percentage of food rubbish could be turned into animal feed which would relieve a lot of pressure on the water use and land for agriculture and reduce reliance on the production of crops for animal feed worldwide. A study showed that if the European Union adopt centralized and regulates systems to cautiously recycle the waste from food into feed to be consumed by animals, just like those which are successfully being used in South Korea and Japan, this would end up in a 21.5 percent reduction in land used for European pork production (Zu Ermgassen *et al.*, 2016). Moreover 8, 8 million tons of edible grains that are currently given to pigs to eat could be replaced if 39 percent of the food waste generated in Europe were used to make feed for pigs. This is equal to 70. 3 million tons of cereal that European citizens consume each year (Shurson, 2020). These conservative estimates explicitly show the substantial potential to enhance energy, phosphorus and nitrogen recovery by redirecting these priceless resources towards feed in the food animal production systems.

Benefits of Food Waste Upcycling

Increasing populations and hiking incomes in developing economies are expected to be the main drivers of the 60-70 percent predicted global hike in animal-sourced food by 2050 (FAO, 2019b). Together with the growing demand for food derived from animals comes the competition for scarce resources between fuel, food, and feed, as well as the pressing need to cut greenhouse gas emissions and develop more circular food systems and economies. Because locally it is a non-competing sourced nutritional resource with minimal environmental impact, upcycling the waste of food to animal feed is a great way to have the most significant impact on achieving sustainability and food security. Animals raised for meat, milk, and eggs can be fed food waste sources that include food that is edible but uneaten as well as food that is unpalatable, inedible, or that is unfit for consumption by humans (Sandström *et al.*, 2022, van Zanten, 2022).

There are several advantages to upcycling waste of food into animal feed, including resource efficiency and positive effects on the environment. Reusing food waste as livestock feed minimizes the amount of food waste that would otherwise end up in landfills, which helps create a more circular food system, and it also lessens the effects on the ecosystem of producing feed crops. In addition to lowering greenhouse gas emissions and improving resource use efficiency, this practice can increase the world's food supply and decrease food competition for resources. Using food waste in animal diets helps to address issues with food security, waste management resources, and the environment. Livestock can act as up-cyclers, converting edible materials into quality protein such as milk, eggs, and meat. This can help to address the issues associated with waste management, food security, resource conservation, and environmental sustainability. That is why they are a crucial component of the strategy to cut down on food waste and loss (Dou *et al.*, 2018). It is also possible for farmers to save money by turning food waste into animal feed which can also free up land that would have been used to grow feed crops and lower methane emissions from decaying food waste (Sandström *et al.*, 2022). Global animal production of food contributes 14.5 percent (about 7.1 gigatons of CO_2 equivalent) of greenhouse gas emissions annually, with the high amount from beef i.e., 35.3 percent, cattle i.e., 30.1 percent, poultry (8.7 percent), and swine (9.5 percent). The production stage, processing, and transportation of feed account for roughly 46.7 percent of the greenhouse gas emissions linked to global food production for animals. Enteric methane emissions from livestock account for about 39.1 percent of the emissions, while N_2O and methane emissions from manure storage account for roughly 9.5 percent. Since the highest amount of greenhouse gas release in the animal food sectors comes from feed production, processing, and transportation, using feed ingredients with lower environmental impact offers the best chance of drastically reducing greenhouse gas emissions (Gerber *et al.*, 2013). All things considered, turning food waste into livestock feed offers a viable solution that is advantageous to the environment and the food production chain.

Challenges and Solutions Associated with Livestock Upcycling

Utilizing food waste and by-products in animal production poses several challenges despite their widespread availability. However, these issues can be handled with the right management and policies.

Logistics of collection and distribution

The most practical solution is to dispose of consumer food waste in landfills. However there are challenges worldwide regarding the effective and economical collection and distribution of this waste (Dou *et al.*, 2018). Long-distance waste material transportation however presents logistical challenges in both metropolitan districts with their wide dispersion and rural areas with their small towns and isolated farmsteads. While consumers prefer to buy locally grown food, there may not be many options available to minimize food waste in the area, other than utilizing it as a substrate for the production of biogas or composting. Designing effective and efficient strategies that lessen food loss and waste throughout the food supply chain requires a methodical approach to food waste accounting. Luckily, the amount of food waste estimated during production and processing is simpler than estimated for the home and food sectors because of regulated processes that yield known-quantity byproducts. Due to the diverse range of consumer purchasing and consumption habits, defining the vast array of food waste originating from homes, businesses, and food services is much more challenging (Caldeira *et al.*, 2019).

Environmental impact

Numerous life cycle assessments (LCAs) have been done out in the past ten years to compare the environmental effects of using livestock feed versus the conventional disposal methods (landfill anaerobic digestion and composting) for food waste and loss. Yet one of the flaws with a number of these assessments has been the endpoint effects' inclusion without taking into account upstream effects along the food chain, such as fertilizer, water, land use, and energy, in addition to greenhouse gas and other gases like ammonia liberations (Dou *et al.*, 2018). A hybridized life cycle assessment (LCA) discovered that wet processing, which is more environmentally friendly than composting and anaerobic digestion reduces the environmental impact of turning municipal waste into feed for pig production (Salemdeeb *et al.*, 2017). In South Korea, for example, food waste needs to be dried and processed in centralized facilities, which requires energy. But because it contains less water and spoils less easily once the waste is produced, it can be transported over longer distances at a fair price. While it breaks down more quickly and is more expensive to transport, wet food waste does not emit greenhouse gases when used locally, unless it is dried and transported over long distances.

Economic viability

The logistics of gathering, moving, and processing food waste and by-products for use in animal diets may prove to be unaffordable, particularly when considering high-moisture food waste and by-products. Animal diets can profit financially from using byproducts and food waste, especially for diets that are high in moisture. By-products are more readily available to farms in Canada for free when compared to cereal grains and protein supplements which reduces feed costs and increases the amount of feed that is fed to animals. Large-scale food waste diversion to livestock food requires correctly identifying sources of food waste in the food supply chain quantifying waste and coordinating. Canadian distributors and processors of animal feed are constrained by financial constraints (MacRae *et al.*, 2016; Gooch *et al.*, 2019). For food waste recycling process to be viable on a commercial scale economic analysis utilizing return on investment metrics are essential.

Byproducts and food waste can become more popular of there are incentives, especially in retail. Processing and manufacturing sector (Caldeira *et al.*, 2020).

Regulatory restrictions

Regulations also limit what food waste and byproducts can Be used in animal diets. The Feed Acts permit the use of a variety of bakery wastes and processed by-products as feed, however various less volume and unique by-products related to innovative processing techniques and alterations in consumer requirements are not covered at this time. For example, the extraction of hemp oil yields by-products which contain 32 percent crude protein, such hulls and meal which are substantial sources of fiber and protein but are currently not allowed in diets. The growing demand from consumers for innovative products like quinoa has resulted in wastes and byproducts that have sufficient nutritional value to take the place of cereal grains, but these are often not allowed to be used in animal diets. Other cases use is governed by existing regulations which either forbid or restrict use. To prevent prions which are suspected to be there in certain risk materials from entering food chain and causing bovine spongiform encephalopathy, for example the stringent Enhanced Feed Ban restricts the recycling of meat and bone meals. Regulations that are supported by research could address the sustainability and economic viability of food production by making food waste and loss at the processing, retail, and consumer levels more easily accessible and by permitting the safe expansion of by-product use in proportion to the growth of commodity production. Evaluation of the quality of the nutrients

Comparing animal feed to conventional ways of disposing of waste like anaerobic digestion landfills and composting life cycle assessments (LCAs) have been used to evaluate the ecosystem effects of each. These analysis however, frequently ignore upstream effects on the food web, including those related to water, land usage, fertilizer, energy, greenhouse gas (GHG), and emission of ammonia. According to a hybridized life cycle assessment, using municipal waste as pig feed lessened the environmental impact (Shahin and Symons, 2011). It is necessary to compare NIRS spectra with traditional laboratory analysis of the feeds to develop trustworthy calibration equations for each by-product before using them on the farm. Other fast screening techniques, for instance, flow-injection mass spectrometry, can be utilized to identify contaminants. Still, their high equipment costs and operational complexity would limit their applicability to distribution centres that handle food waste and byproduct processing. However, a prompt and right assessment of the nutritional profiles of food waste and by-products is required if they are to be used in precision livestock feeding systems (Dou *et al.*, 2018).

Feed safety concerns

The health of humans, animals, and the environment must not be jeopardized when food that fails to meet human quality standards is diverted to landfills. Herbicides, heavy metals, and mycotoxins are among the contaminants found in food waste and byproducts. Food waste and fruit and vegetable leftovers with high moisture encourage the growth of bacteria and fungi which may result in the production of toxins. Commercial composting facilities employ a range of techniques such as density separation vacuuming and manual removal to get rid of impurities like plastic glass metal and stone (Levis *et al.*, 2010). Labor and sophisticated equipment are therefore needed to part away the usable food waste from packaging waste and outside contaminants in order to divert this food waste to animal food (Truong *et al.*, 2019).

Food wastes have been stabilized by a variety of preservation methods including heat sterilization and heat sterilization along with drying to 80-95 percent dry matter ensiling alone or after heat treatment without or with the addition of fermentation aids (bacterial enzymes or acids) and enzymatic treatment (Dou *et al.*, 2018). These ways, however, can significantly increase the cost of their use and are usually carried out at an industrial scale that is centralized making them difficult for smaller stakeholders to implement. Advanced low-energy and low-cost processing techniques based on biotechnological and physicochemical techniques have been developed in the European Union to process tubers, fruit, cereals, dairy wastes, and vegetables waste into bulk feed and to create specific functional feed additives like immune-stimulating protein hydrolysates, protein hydrolysates, fiber having prebiotic qualities, and antioxidants to improve oxidation (Petrusán *et al.*, 2016).

More recently Californian growing pigs were fed enzymatically treated leftovers from supermarket food i.e., fruit, vegetables, meat, and dairy items (Jinno *et al.*, 2018). The amount of nutrition from these wastes was equivalent to the nutrition in typical corn-soybean diet however, because of the high-water content of the feed the pig's intake was decreased resulting in less weight gain. Therefore, for these food wastes to be adopted their prices need to be set such that their cost of gain stays at least same or lower than that of standard diets.

Rules and potential biosafety risks related to repurposing food waste into animal feed

For many centuries animals particularly, pigs have been fed various types of cooked or uncooked food waste referred to as swill or garbage in numerous countries. Nevertheless, during the last several decades certain disease outbreaks have happened in a few nations leading to differing biosecurity viewpoints and laws for turning waste food into animal food among nations. Taiwan, South Korea, Thailand, and Japan are among the nations that have proactively considered the environmental and nutritional advantages of recycling a significant amount of food waste into food or feed for animals. These nations have developed the necessary infrastructure and regulations to achieve this while minimizing the risks associated with biosafety (Westendorf, 2000). Government policies in Japan that prioritized recycling food waste into feed for animals over other disposal ways were first put into place in 2001 and then revised in 2007 (Takata *et al.*, 2012). Approximately, in Japan, 40 percent of waste food originates at pre-consumer stages such as wholesale, food manufacturing, and grocery stores, and a smaller portion comes from post-consumer sources like households and restaurants. This food waste is then processed thermally and recycled into animal food which is branded as "Eco Feed" (Liu *et al.*, 2016). In a similar vein South Korea has put policies, procedures, and facilities in place to turn a sizable amount of food waste into safe animal feed. South Korea forbade the disposal of food waste in landfills in 2005. Instead, approximately 45 percent of the waste is repurposed for animal consumption, but 10% is disposed of by anaerobic digestion process, co-digestion with sewage sludge and vermi composting, and 45% is composted (Kim *et al.*, 2011; Dou *et al.*, 2018). As evidenced that the successful development and implementation of appropriate rules and regulations and plans have been implemented to make sure thermal treatment, transportation, and storage of processed or upcycled food waste to lessen its biosafety risks as an ingredient of animal feed. Both South Korea and Japan have shown that repurposing a significant portion of house food waste into feed can be achieved sustainably (Zu Ermgassen *et al.*, 2016).

Food Waste Upcycling to Achieve Sustainability

By reusing food waste produced during the pre-harvest to consumer stage and post-consumer levels of supply chains, food waste up-cycling has high potential to positively add to achieving the UN Sustainable Development Goals of careful usage and production, minimizing the climate alteration effects, and improving quality of life on land and enhancing life below water. Despite strong evidence and motivation, these laws and policies require comprehensive changes to facilitate the recovery, recycling, and re-purposing of more valuable nutrients from various food waste streams into animal feed. Governments could offer financial support, incentives, or one-time subsidies to entrepreneurs who develop the innovative infrastructure necessary for collecting, supplying sufficient capacity, and utilizing state-of-the-art thermal processing tools to ensure the biosafety of dehydrated waste streams. Additionally, they could establish channels of distribution to connect these supplies with commercial animal feed producers. It is possible to identify high-risk food waste sources that could be contaminated with disease-causing biological species and redirect them toward other beneficial processes, such as recycling through composting, biofuels production, and biogas, to prevent the spread of potential diseases. Extra Life Cycle Analysis is required for different dehydrated waste sources and by-products of livestock animals' by-products, which animal nutritionists can utilize while creating eco-nutrition programs for feeding animals that produce food. The global feed industry is shifting towards re-purposing and utilizing feed ingredients from waste, which have an acceptable nutritional profile and a reduced environmental impact.

Further research on animal nutrition is, however, desperately needed to create more reliable and thorough databases on digestible nutrient composition as well as precise prediction equations for different food waste sources used in the production of complete animal feeds that are both economical and nutritionally sound. This will help animal nutritionists fully account for the economic and nutritional value of sources of food waste in their formulations. To reduce the possibility of prion and pathogen transmission via repurposed food waste utilized as animal feed, new risk assessments and comprehensive bio-security protocols based on best biosafety practices, particularly for pathogens and viruses, should be carried out (Shurson, 2020).

Present and future trends

There will be a 70 percent increase in demand for animal protein by 2050. Concurrently, member nations of the United Nations (UN) have committed to cutting food waste in half by the year 2030. Furthermore, even in the event that the dietary modifications suggested by the UN Intergovernmental Panel on climate alterations are implemented, more efficient methods of producing food and animal feed will be needed to ensure a more sustainable food supply in the future. Nowadays, most developed nations' regulatory frameworks either restrict the kinds of waste that can be utilized as animal feed or outright forbid feeding food waste to them. The waste from food service establishments and retail, however, can be safely and effectively used in commercial production establishments. Based on liquid and dry feeding systems, the Japanese have established a profitable industry re-purposing food waste into feed for pigs that is supported and encouraged by national policy. With this feeding method, they have created licensed Eco feed-branded products and have not allowed emergency animal diseases to have a detrimental impact on the pork industry. A plan to address food safety and biosecurity concerns must be developed and implemented if other nations are to invest in and develop industries that convert food waste into livestock feed. To evaluate the industry's profitability and estimate the possible investment needed for new infrastructure for feed production, storage, and collection, a regional techno-economic analysis is necessary. To encourage producers and the livestock industry to actively participate in driving change, legislation grounded in rigorous scientific research will also be necessary.

Conclusions

Nowadays, more than one-third of the world's grain production is consumed by livestock animals. But livestock animals, including insects, may serve as effective bio-processors to turn the inevitable waste of food into functional animal protein. A circular food system would fulfil the growing requirements for animal feed while also alleviating the detrimental environmental effects of intensive livestock production and food waste sent to landfills. To prevent adverse outcomes for animal welfare, health, biosecurity, food safety, economy, market access, and food insecurity, it will be essential to ensure that feed safety is properly regulated upon the establishment of a food waste to livestock feed industry to achieve sustainability goals.

Authors' Contributions

Conceptualization: MO, AG, IEY; Data curation: IS, VA, BTU; Investigation: AG, IEY; Methodology: MO, VA, BTU; Project administration: AG, IEY; Resources: IS, VA, BTU; Supervision: AG, IEY; Validation: MO, IEY, VA; Roles/Writing - original draft: MO, AG, IEY, VA; and Writing - review & editing: AG, IEY.

All authors read and approved the final manuscript.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Adiguzel F, Donato C (2021). Proud to be sustainable: Upcycled versus recycled luxury products. Journal of Business Research 130:137-146. *https://doi.org/10.1016/j.jbusres.2021.03.033*

Al-Tulaihan AA, Najib H, Al-Eid SM (2004). The nutritional evaluation of locally produced dried bakery waste (DBW) in the broiler diets. Pakistan Journal of Nutrition 3:294-299. *https://doi.org/10.3923/pjn.2004.294.299*

Aldaco R, Hoehn D, Laso J, Margallo M, Ruiz-Salmón J, Cristobal J, … Batlle-Bayer L (2020). Food waste management during the COVID-19 outbreak: a holistic climate, economic and nutritional approach. Science of the Total Environment 742:140524. *https://doi.org/10.1016/j.scitotenv.2020.140524*

Alliance FWR (2016). Analysis of US food waste among food manufacturers, retailers, and restaurants. Food Marketing Institute, the Grocery Manufacturers Association & the National Restaurant Association, Arlington, USA. Retrieved 2025 August 12 from *https://www.foodwastealliance.org/wp-content/uploads/2020/05/FWRA-Food-Waste-Survey-2016-Report_Final.pdf*

Ambuko JL, Masakhwe SM, Amwoka E, Mujuka E, Fabi C (2025). Food loss and waste data gaps in fruit and vegetable value chains: a review of the literature. Frontiers in Horticulture 4:1529040. *https://doi.org/10.3389/fhort.2025.1529040*

Angulo J, Mahecha L, Yepes SA, Yepes AM, Bustamante G, Jaramillo H, Valencia E, Villamil T, Gallo J (2012). Nutritional evaluation of fruit and vegetable waste as feedstuff for diets of lactating Holstein cows. Journal of Environmental Management 95:S210-S214. *https://doi.org/10.1016/j.jenvman.2011.06.050*

Aschemann-Witzel J, Asioli D, Banovic M, Perito MA, Peschel AO, Stancu V (2023). Defining upcycled food: The dual role of upcycling in reducing food loss and waste. Trends in Food Science & Technology 132:132-137. *https://doi.org/10.1016/j.tifs.2023.01.001*

Ashraf M, Ozturk M, Ahmad MSAF, Aksoy A (2012). Crop production for agricultural improvement. Springer Dordrecht. *https://doi.org/10.1007/978-94-007-4116-4*

Aydin AE, Yildirim P (2021). Understanding food waste behavior: The role of morals, habits and knowledge. Journal of Cleaner Production 280:124250. *https://doi.org/10.1016/j.jclepro.2020.124250*

Blair D, Sobal J (2006). Luxus consumption: Wasting food resources through overeating. Agriculture and Human Values 23:63-74. *https://doi.org/10.1007/s10460-004-5869-4*

Bond M, Meacham T, Bhunnoo R, Benton T (2013). Food waste within global food systems. Global Food Security Swindon UK. Retrieved 2025 July 03 from *www.foodsecurity.ac.uk*

Bonev P, Gorkun-Voevoda L, Knaus M (2022). The effect of environmental policies on intrinsic motivation: evidence from the Eurobarometer surveys. In: Beiträge zur Jahrestagung des Vereins für Socialpolitik 2022: Big Data in Economics, ZBW - Leibniz Information Centre for Economics, Kiel, Hamburg

Caldeira C, De Laurentiis V, Corrado S, Van Holsteijn F, Sala S (2019). Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. Resources, Conservation and Recycling 149:479-488. *https://doi.org/10.1016/j.resconrec.2019.06.011*

Caldeira C, Vlysidis A, Fiore G, De Laurentiis V, Vignali G, Sala S (2020). Sustainability of food waste biorefinery: A review on valorisation pathways, techno-economic constraints, and environmental assessment. Bioresource Technology 312:123575. *https://doi.org/10.1016/j.biortech.2020.123575*

Carpentieri S, Soltanipour F, Ferrari G, Pataro G, Donsì F (2021). Emerging green techniques for the extraction of antioxidants from agri-food by-products as promising ingredients for the food industry. Antioxidants 10(9):1417. *https://doi.org/10.3390/antiox10091417*

Chaboud G, Daviron B (2017). Food losses and waste: Navigating the inconsistencies. Global Food Security 12:1-7. *https://doi.org/10.1016/j.gfs.2016.11.004*

De B, Das RC (2025). Examining whether developed or developing nations make more food waste: extracts from export–import data on food products. Quality & Quantity 1-37. *https://doi.org/10.1007/s11135-025-02129-3*

Dou Z (2021). Leveraging livestock to promote a circular food system. Frontiers of Agricultural Science and Engineering 8:188-192. *https://doi.org/10.15302/j-fase-2020370*

Dou Z, Toth JD (2021). Global primary data on consumer food waste: Rate and characteristics-A review. Resources, Conservation and Recycling 168:105332. *https://doi.org/10.1016/j.resconrec.2020.105332baker*

Dou Z, Toth JD, Pitta DW, Bender JS, Hennessy ML, Vecchiarelli B, … Baker LD (2022). Proof of concept for developing novel feeds for cattle from wasted food and crop biomass to enhance agri-food system efficiency. Scientific reports 12:13630. *https://doi.org/10.1038/s41598-022-17812-w*

Dou Z, Toth JD, Westendorf ML (2018). Food waste for livestock feeding: Feasibility, safety, and sustainability implications. Global food security 17:154-161. *https://doi.org/10.1016/j.gfs.2017.12.003*

Eastham J, Creedon A (2023). Food losses, food waste, and beyond in food supply chains: Retaining optimum nutrient density. Food Frontiers 4:971-979. *https://doi.org/10.1002/fft2.271*

Eche V, Emenike CU, Rupasinghe HV (2025). Nutritional Value of brewer's spent grain and consumer acceptance of its value-added food products. Foods 14(16):2900. *https://doi.org/10.3390/foods14162900*

Edjabou ME, Petersen C, Scheutz C, Astrup TF (2016). Food waste from Danish households: Generation and composition. Waste management 52:256-268. *https://doi.org/10.1016/j.wasman.2016.03.032*

FAO E (2019a). Moving forward on food loss and waste reduction. FAO Rome, Italy.

FAO I (2019b). The state of food and agriculture 2019. Moving forward on food loss and waste reduction. FAO, Rome 2-13.

Forbes H (2021). Food waste index report 2021. Retrieved 2025 July 02 from *https://www.unep.org/resources/report/unep-food-waste-index-report-2021*

Foresight U (2011). The future of food and farming. Final Project Report, London, The Government Office for Science.

Fung L, Urriola PE, Baker L, Shurson GC (2019a). Estimated energy and nutrient composition of different sources of food waste and their potential for use in sustainable swine feeding programs. Translational Animal Science 3:359-368. *https://doi.org/10.1093/tas/txy099*

Fung L, Urriola PE, Shurson GC (2019b). Energy, amino acid, and phosphorus digestibility and energy prediction of thermally processed food waste sources for swine. Translational Animal Science 3:676-691. *https://doi.org/10.1093/tas/txz028*

Gaur M, Yadav S, Soni A, Tomar D, Jangra A, Joia S, … Trajkovska Petkoska A (2025). Quinoa (*Chenopodium quinoa* Willd): nutritional profile, health benefits, and sustainability considerations. Discover Food 5(1):172. *https://doi.org/10.1007/s44187-025-00470-y*

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G (2013). Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO). *http://www.fao.org/docrep/018/i3437e/i3437e00.htm*

Gooch M, Bucknell D, Laplain D, Dent B, Whitehead P, Felfel A, Nikkel L, Maguire M (2019). The avoidable crisis of food waste: Technical report. Value Chain Management International and Second Harvest, Ontario Canada. Retrieved 2025 July 02 from *https://vcm-international.com/wp-content/uploads/2019/01/The-Avoidable-Crisis-of-Food-Waste-NR-January-17-2019.pdf*

Gustavsson J, Cederberg C, Sonesson U, Van Otterdijk R, Meybeck A (2011). Global food losses and food waste. FAO Rome 1-37. Retrieved 2025 July 02 from *https://www.fao.org/4/mb060e/mb060e00.pdf*

Hamilton C (2004). Real and perceived issues involving animal proteins. Protein sources for the animal feed industry. In: FAO Expert Consultation and Workshop. Bangkok Thailand 29 April-3 May 2002, 2004. Food and Agriculture Organization of the United Nations (FAO) pp 255-276.

Imazaki PH, Lewandowski C, Magana ML, Rohmer M, Bailly JD, David L (2025). Development and validation of an escape game for food safety education: amifying the management of a food-borne health alert. Journal of Veterinary Medical Education e20240151. *https://doi.org/10.3138/jvme-2024-0151*

Isaac-Bamgboye FJ, Onyeaka H, Isaac-Bamgboye IT, Chukwugozie DC, Afolayan M (2025). Upcycling technologies for food waste management: safety, limitations, and current trends. Green Chemistry Letters and Reviews 18(1):2533894. *https://doi.org/10.1080/17518253.2025.2533894*

Jinno C, He Y, Morash D, Mcnamara E, Zicari S, King A, Stein HH, Liu Y (2018). Enzymatic digestion turns food waste into feed for growing pigs. Animal Feed Science and Technology 242:48-58. *https://doi.org/10.1016/j.anifeedsci.2018.05.006*

Kazemi M (2025). Recycling agricultural waste: sustainable solutions for enhancing livestock nutrition. Veterinary Medicine and Science 11(3):e70321. *https://doi.org/10.1002/vms3.70321*

Kim MH, Song YE, Song HB, Kim JW, Hwang SJ (2011). Evaluation of food waste disposal options by LCC analysis from the perspective of global warming: Jungnang case, South Korea. Waste Management 31:2112-2120. *https://doi.org/10.1016/j.wasman.2011.04.019*

Lestari TD, Khairullah AR, Utama S, Mulyati S, Hernawati T, Damayanti R, … Lisnanti EF (2025). Bovine spongiform encephalopathy: A review of current knowledge and challenges. Open Veterinary Journal 15(1):54. *https://doi.org/10.5455/ovj.2025.v15.i1.5*

Levis JW, Barlaz MA, Themelis NJ, Ulloa P (2010). Assessment of the state of food waste treatment in the United States and Canada. Waste management 30:1486-1494. *https://doi.org/10.1016/j.wasman.2010.01.031*

Li Z, Lu H, Ren L, He L (2013). Experimental and modeling approaches for food waste composting: A review. Chemosphere 93:1247-1257. *https://doi.org/10.1016/j.chemosphere.2013.06.064*

Lipinski B, Hanson C, Waite R, Searchinger T, Lomax J (2013). Reducing food loss and waste. Working paper, installment 2 of creating a sustainable food future. World Resources Institute, Washington, DC.

Liu C, Hotta Y, Santo A, Hengesbaugh M, Watabe A, Totoki Y, Allen D, Bengtsson M (2016). Food waste in Japan: Trends, current practices and key challenges. Journal of Cleaner Production 133:557-564. *https://doi.org/10.1016/j.jclepro.2016.06.026*

MacRae R, Siu A, Kohn M, Matsubuchi-Shaw M, Mccallum D, Cervantes TH, Perreault D (2016). Making better use of what we have: Strategies to minimize food waste and resource inefficiency in Canada. Canadian Food Studies/La Revue canadienne des études sur l'alimentation 3:145-215. *https://doi.org/10.15353/cfs-rcea.v3i2.143*

Matthews C, Crispie F, Lewis E, Reid M, O'toole PW, Cotter PD (2019). The rumen microbiome: a crucial consideration when optimising milk and meat production and nitrogen utilisation efficiency. Gut Microbes 10:115-132. *https://doi.org/10.1080/19490976.2018.1505176*

Mbow C, Rosenzweig CE, Barioni LG, Benton TG, Herrero M, Krishnapillai M, … Xu I (2019). Food security. Retrieved in 2025 June 01 from *https://www.ipcc.ch/site/assets/uploads/2019/11/08_Chapter-5.pdf*

Messner R, Johnson H, Richards C (2021). From surplus-to-waste: A study of systemic overproduction, surplus and food waste in horticultural supply chains. Journal of Cleaner Production 278:123952. *https://doi.org/10.1016/j.jclepro.2020.123952*

Mijares V, Alcivar J, Palacios C (2021). Food waste and its association with diet quality of foods purchased in South Florida. Nutrients 13:2535. *https://doi.org/10.3390/nu13082535*

Mottet A, De Haan C, Falcucci A, Tempio G, Opio C, Gerber P (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. Global food security 14:1-8. *https://doi.org/10.1016/j.gfs.2017.01.001*

Mourad M (2016). Recycling, recovering and preventing "food waste": Competing solutions for food systems sustainability in the United States and France. Journal of Cleaner Production 126:461-477. *https://doi.org/10.1016/j.jclepro.2016.03.084*

Nath PC, Ojha A, Debnath S, Sharma M, Nayak PK, Sridhar K, Inbaraj BS (2023a). Valorization of Food Waste as Animal Feed: A Step towards Sustainable Food Waste Management and Circular Bioeconomy. Animals (Basel) 13(8):1366. *https://doi.org/10.3390/ani13081366*

Nath PC, Ojha A, Debnath S, Sharma M, Nayak PK, Sridhar K, Inbaraj BS (2023b). Valorization of food waste as animal feed: a step towards sustainable food waste management and circular bioeconomy. Animals 13:1366. *https://doi.org/10.3390/ani13081366*

Nayan N, Sonnenberg AS, Hendriks WH, Cone JW (2020). Prospects and feasibility of fungal pretreatment of agricultural biomass for ruminant feeding. Animal Feed Science and Technology 268:114577. *https://doi.org/10.1016/j.anifeedsci.2020.114577*

Nguyen DD, Chang SW, Cha JH, Jeong SY, Yoon YS, Lee SJ, Tran MC, Ngo HH (2017). Dry semi-continuous anaerobic digestion of food waste in the mesophilic and thermophilic modes: New aspects of sustainable management and energy recovery in South Korea. Energy Conversion And Management 135:445-452. *https://doi.org/10.1016/j.enconman.2016.12.030*

Operato L, Panzeri A, Masoero G, Gallo A, Gomes L, Hamd W (2025). Food packaging use and post-consumer plastic waste management: a comprehensive review. Frontiers in Food Science and Technology 5:1520532. *https://doi.org/10.3389/frfst.2025.1520532*

Ozturk M, Mermut A, Celik A (2011). Urbanisation, land use, land degradation and environment. Daya Publishing House, India p 445.

Ozturk M (2014). Biomass/bioenergy-prospects and challenges. Green infrastructure & sustainable societies/cities. Ege University, Izmir, Turkey.

Ozturk M, Saba N, Altay V, Iqbal R, Hakeem KR, Jawaid M, Ibrahim FH (2017). Biomass and bioenergy: An overview of the development potential in Turkey and Malaysia. Renewable and Sustainable Energy Reviews 79:1285-1302. *https://doi.org/10.1016/j.rser.2017.05.111*

Ozturk M, Hakeem KR, Ashraf M, Ahmad MSA (2019). Crop production technologies for sustainable use and conservation- physiological and molecular advances. apple Academic Press CRC Press p 457.

Ozturk M, Akram NA, Turkyilmaz BU, Ashraf M (2022). Introduction and application of organic fertilizers as protectors of our environment. Cambridge Scholars Press UK pp1-514.

Papargyropoulou E, Fearnyough K, Spring C, Antal L (2022). The future of surplus food redistribution in the UK: Reimagining a 'win-win'scenario. Food Policy 108:102230. *https://doi.org/10.1016/j.foodpol.2022.102230*

Parfitt J, Barthel M, Macnaughton S (2010). Food waste within food supply chains: quantification and potential for change to 2050. Philosophical Transactions Of The Royal Society B: Biological Sciences 365:3065-3081. *https://doi.org/10.1098/rstb.2010.0126*

Patetta MA, Pedraza LS, Popkin BM (2019). Improvements in the nutritional quality of US young adults based on food sources and socioeconomic status between 1989-1991 and 2011-2014. Nutrition Journal 18:1-11. *https://doi.org/10.1186/s12937-019-0460-4*

Petrusán JI, Rawel H, Huschek G (2016). Protein-rich vegetal sources and trends in human nutrition: A review. Current Topics in Peptide & Protein Research 17:1-19.

Pinotti L, Luciano A, Ottoboni M, Manoni M, Ferrari L, Marchis D, Tretola M (2021). Recycling food leftovers in feed as opportunity to increase the sustainability of livestock production. Journal of Cleaner Production 294:126290. *https://doi.org/10.1016/j.jclepro.2021.126290*

Ren Y, Yu M, Wu C, Wang Q, Gao M, Huang Q, Liu Y (2018). A comprehensive review on food waste anaerobic digestion: Research updates and tendencies. Bioresource Technology 247:1069-1076. *https://doi.org/10.1016/j.biortech.2017.09.109*

Richards C, Hurst B, Messner R, O'connor G (2021). The paradoxes of food waste reduction in the horticultural supply chain. Industrial Marketing Management 93:482-491. *https://doi.org/10.1016/j.indmarman.2020.12.002*

Richards T J, Hamilton SF (2018). Food waste in the sharing economy. Food Policy 75:109-123. *https://doi.org/10.1016/j.foodpol.2018.01.008*

Ruppenthal T, Horoś IK (2021). Avoidance of food waste from a grocery retail store owner's perspective. Sustainability 13(2):550. *https://doi.org/10.3390/su13020550*

Salemdeeb R, Zu Ermgassen EK, Kim MH, Balmford A, Al-Tabbaa A (2017). Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. Journal of cleaner production 140:871-880. *https://doi.org/10.1016/j.jclepro.2016.05.049*

Sandstrom V, Chrysafi A, Lamminen M, Troell M, Jalava M, Piipponen J, Siebert S, Van Hal O, Virkki V, Kummu M (2022). Food system by-products upcycled in livestock and aquaculture feeds can increase global food supply. Nature Food 3:729-740. *https://doi.org/10.1038/s43016-022-00589-6*

Scherhaufer S, Moates G, Hartikainen H, Waldron K, Obersteiner G (2018). Environmental impacts of food waste in Europe. Waste Management 77:98-113. *https://doi.org/10.1016/j.wasman.2018.04.038*

Shahin MA, Symons SJ (2011). Detection of Fusarium damaged kernels in Canada Western Red Spring wheat using visible/near-infrared hyperspectral imaging and principal component analysis. Computers and Electronics in Agriculture 75:107-112. *https://doi.org/10.1016/j.compag.2010.10.004*

Shaw PJ (2021). Avoidable Household food waste: Diagnosing the links between causes and composition. Recycling 6:80. *https://doi.org/10.3390/recycling6040080*

Shurson GC (2020). "What a Waste" - Can we improve sustainability of food animal production systems by recycling food waste streams into animal feed in an era of health, climate, and economic crises? Sustainability 12:7071. *https://doi.org/10.3390/su12177071*

Shurson GC, Palowski A, Van De Ligt JL, Schroeder DC, Balestreri C, Urriola PE, Sampedro F (2022). New perspectives for evaluating relative risks of African swine fever virus contamination in global feed ingredient supply chains. Transboundary and Emerging Diseases 69:31-56. *https://doi.org/10.1111/tbed.14174*

Srivastava A, Pandey S, Shahwal R, Sur A (2025). Recycling of waste into useful materials and their energy applications. In: Microbial niche nexus sustaining environmental biological wastewater and water-energy-environment nexus . Springer Nature Switzerland pp. 251-296.

Tadigadapa A (2022). Smart containers for food storage in refrigerators. IEEE Potentials 41:29-34. *https://doi.org/10.1109/mpot.2021.3090575*

Takata M, Fukushima K, Kino-Kimata N, Nagao N, Niwa C, Toda T (2012). The effects of recycling loops in food waste management in Japan: based on the environmental and economic evaluation of food recycling. Science of the total Environment 432:309-317. *https://doi.org/10.1016/j.scitotenv.2012.05.049*

Truong L, Morash D, Liu Y, King A (2019). Food waste in animal feed with a focus on use for broilers. International Journal of Recycling of Organic Waste in Agriculture 8:417-429. *https://doi.org/10.1007/s40093-019-0276-4*

Van Bemmel A, Parizeau K (2020). Is it food or is it waste? The materiality and relational agency of food waste across the value chain. Journal of Cultural Economy 13:207-220. *https://doi.org/10.1080/17530350.2019.1684339*

Van Doorn J (2016). Commentary: Why do we waste so much food? A research agenda. Journal of the Association for Consumer Research 1:53-56.

Van Zanten HH (2022). Upcycled non-competing feedstuff. Nature Food 3:681-681. *https://doi.org/10.1038/s43016-022-00590-z*

Vandermeersch T, Alvarenga R, Ragaert P, Dewulf J (2014). Environmental sustainability assessment of food waste valorization options. Resources, Conservation and Recycling 87:57-64. *https://doi.org/10.1016/j.resconrec.2014.03.008*

Varghese C, Pathak D, Varde AS (2021). SeVa: a food donation app for smart living. In: 2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC) IEEE pp 0408-0413.

Wadhwa M, Bakshi MPS (2013). Utilization of fruit and vegetable wastes as livestock feed and as substrates for generation of other value-added products. RAP publication 4:67.

Wang X, Dou Z, Feng S, Zhang Y, Ma L, Zou C, Bai Z, Lakshmanan P, Shi X,... Chen X (2023). Global food nutrients analysis reveals alarming gaps and daunting challenges. Nature Food 4:1007-1017. *https://doi.org/10.1038/s43016-023-00851-5*

WHO (2021). The State of Food Security and Nutrition in the World 2021: Transforming food systems for food security, improved nutrition and affordable healthy diets for all, Food & Agriculture Org.

Westendorf M (2000). Food waste as animal feed: An introduction, Food Waste to Animal Feed. Iowa State University Press, Ames, Iowa, USA.

Xue L, Liu X, Lu S, Cheng G, Hu Y, Liu J, Dou Z, Cheng S, Liu G (2021). China's food loss and waste embodies increasing environmental impacts. Nature Food 2:519-528. *https://doi.org/10.1038/s43016-021-00317-6*

Zu Ermgassen EK, Phalan B, Green RE, Balmford A (2016). Reducing the land use of EU pork production: where there's swill, there'sa way. Food policy 58:35-48. *https://doi.org/10.1016/j.foodpol.2015.11.001*