revista principia

ISSN 2447-9187

https://doi.org/10.18265/2447-9187a2024id8436

ORIGINAL ARTICLE

SUBMITTED April 4, 2024
APPROVED May 25, 2024
PUBLISHED ONLINE June 6, 2024
FINAL FORMATTED VERSION July 2, 2025
ASSOCIATE EDITOR
Profa. Dra. Poliana Sousa Epaminondas Lima

Closing the loop: sustainable approaches for managing and recovering food industry residues

Lethicya Lucas Pires da Silva [1] *
Shannon Perrone [2]
Carolina Leandra Fantt de Sousa e Reis [3]
Tainá Francisca Cordeiro de Souza [4]
Tatianne Ferreira de Oliveira [5]
Julião Pereira [6]

[1] lethicyapires@discente.ufg.br
[2] shannon@discente.ufg.br
[3] carolina.fantt@discente.ufg.br
[4] tainafcs@discente.ufg.br
[5] tatianne_ferreira_oliveira@ufg.br
[6] racalele@ufg.br

School of Agronomy, Federal University of Goiás (UFG), Goiânia, Goiás, Brazil

* *Corresponding author.*

ABSTRACT: Food waste management is an increasingly critical global issue, driven by the need to promote environmental sustainability, conserve resources, and mitigate global hunger. This study provides a theoretical analysis of the historical evolution of food waste management, examining its definition and international significance. Additionally, it critically evaluates the necessity of adopting sustainable approaches. The methodology involves a comprehensive literature review covering 2013 to 2023, utilizing keywords related to food waste, sustainability, and the circular economy. The databases consulted include Science Direct and MDPI. The findings indicate a shift from individual to institutional sources of food waste, highlighting the need for alternative management strategies. The environmental analysis underscores the negative impacts of conventional practices, while solutions such as food rescue, fermentation, and anaerobic digestion emerge as promising alternatives. Understanding consumer behavior is key, with smart labels introduced as potential tools to reduce food waste. The article also discusses the challenges and limitations of current food waste management practices, reinforcing the necessity of sustainable treatment methods. The study concludes by outlining future research directions, emphasizing the importance of understanding consumer behavior, investigating the potential of smart labels, and addressing existing knowledge gaps to foster a more sustainable and responsible approach to food consumption and waste management.

Keywords: barriers in food waste management; circular economy; food industry waste; food waste; sustainability.

Fechando o ciclo: abordagens sustentáveis para gerenciar e recuperar resíduos da indústria alimentícia

RESUMO: *A gestão de resíduos alimentares é uma questão global cada vez mais crítica, motivada pela necessidade de promover a sustentabilidade ambiental, conservar recursos e mitigar a fome global. Este estudo fornece uma análise teórica da evolução histórica da gestão de resíduos alimentares, examinando sua definição e importância internacional. Além disso, avalia criticamente* *a necessidade de adotar abordagens sustentáveis. A metodologia envolve uma revisão abrangente da literatura, cobrindo de 2013 a 2023, utilizando palavras-chave relacionadas ao desperdício de alimentos, à sustentabilidade e à economia circular. Os bancos de dados consultados incluem Science Direct e MDPI. As descobertas indicam uma mudança de fontes de desperdício individuais para institucionais, destacando a necessidade de abordagens alternativas de gestão. A análise ambiental ressalta os impactos negativos das práticas convencionais, enquanto soluções como resgate de alimentos, fermentação e digestão anaeróbica surgem como alternativas promissoras. Entender o comportamento do consumidor é um fator-chave, com rótulos inteligentes introduzidos como ferramentas potenciais para reduzir o desperdício alimentar. O artigo também discute os desafios e limitações das práticas atuais de gerenciamento de resíduos alimentares, reforçando a necessidade de métodos de tratamento sustentáveis. O estudo conclui delineando futuras direções de pesquisa, enfatizando a importância de entender o comportamento do consumidor, investigar o potencial de rótulos inteligentes e abordar lacunas de conhecimento existentes para promover uma abordagem mais sustentável e responsável ao consumo alimentar e à gestão de resíduos.*

Palavras-chave: *barreiras na gestão de resíduos alimentares; desperdício da indústria alimentícia; desperdício de alimentos; economia circular; sustentabilidade.*

1 Introduction

Food waste management has become increasingly critical in recent years due to concerns about environmental sustainability, resource conservation, and global food security. Although food waste is a global challenge, individual and industrial efforts are essential for developing effective solutions. In 2019, approximately 931 tons of food were discarded in landfills worldwide (UNEP, 2021), while nearly 1 billion people experienced hunger (WFP, 2019). Efficient management of agro-industrial waste is crucial for enhancing the food industry's sustainability (Serpa-Fajardo *et al*., 2022).

The definition of food loss and waste (FLW) remains inconsistent across the literature (Boiteau; Pingali, 2023). Some researchers in food science and nutrition argue that food is only considered wasted if it is still edible at the time of disposal, while others define waste as food that has transitioned from an edible to a non-edible state and is therefore unsuitable for consumption.

According to the Food and Agriculture Organization (FAO), food loss (FL) refers to a reduction in the weight (dry matter) or quality (nutritional value) of food originally intended for human consumption. In contrast, food waste (FW) is defined as food that remains suitable for human consumption but is discarded, whether due to spoilage or expiration. The FAO (FAO, 2013) further categorizes FL as occurring during the initial stages of the food supply chain (FSC), whereas FW pertains to losses at the final stage, primarily associated with retailer and consumer behavior (Ishangulyyev; Kim; Lee, 2019).

To ensure data consistency and reduce misinterpretations, the High-Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security recommends that all stakeholders, including governments, international organizations, the private sector, and civil society, establish a shared understanding, definition, and scope for FLW (HLPE, 2014). This recommendation highlights the issue's global significance.

The first documented report focusing on food waste by the American Public Health Association dates back to 1891, when it was noted that the city of Chicago incinerated 19.9 pounds of garbage per capita, while Washington D.C. collected 207 pounds per capita (Bovay; Zhang, 2020).

From an environmental perspective, food waste contributes to pollution at multiple levels throughout the food processing chain. In addition to greenhouse gas emissions generated across the supply chain, gases are released during food decomposition (FAO, 2019). When food waste is sent to landfills, it produces methane, a potent greenhouse gas. If FLW were treated as a country, it would be the third-largest emitter of greenhouse gases, accounting for approximately 3.3 gigatons of CO_2 equivalent per year (Lévesque; Perreault; Mikhaylin, 2023).

Moreover, the resources utilized in food production, such as water, land, and crops, are wasted when food is discarded. The subsequent loss of biodiversity caused by agricultural expansion represents another significant environmental consequence of excessive food waste. As the demand for food increases, additional resources are expended by corporations, governments, and consumers.

This article aims to conduct a bibliographical review, examining the consequences of food waste in the food industry, the role of the circular economy, sustainable approaches, societal behaviors, and governmental measures that can mitigate these impacts.

Sustainable approaches address the environmental challenges associated with inadequate food waste management and propose alternative solutions with reduced environmental impact, such as fermentation and anaerobic digestion. The discussion on challenges and limitations highlights the significant waste generated by industries, particularly dairy and meat processing facilities, and emphasizes the potential for repurposing by-products with added value. The circular economy promotes methods that align with the sustainable development goals, aiming to close the food chain loop. Furthermore, future strategies should focus on raising awareness and implementing campaigns that foster continuous improvements in food waste reduction.

2 Methods

The search strategy used to identify relevant literature involved utilizing essential keywords and terms to address the topic, including "food waste", "waste management in the food industry", "sustainability", "waste", "recycling of food waste", "recovery of waste in the food industry", and "circular economy". The selection criteria for articles included the analysis of abstracts, proficiency in the English language, and type of publication, focusing on peer-reviewed scientific articles of significant relevance to the study. Furthermore, the Boolean operators "AND" and "OR" were employed in combination with the keywords as part of the search strategy. Literature published outside the timeframe of 2013 to 2023, along with keywords unrelated to the subject, was excluded from the review. The Science Direct and MDPI databases were chosen due to their esteemed reputation, availability of relevant articles, and comprehensive coverage of related topics. Official documents providing global data on food rescue were also incorporated into the analysis.

3 Sustainable approaches for managing food industry residues

Over the last century, the focus of food waste management has shifted from individual households to institutions, commercial enterprises, and systemic approaches. As concerns regarding the environment and sustainability have intensified, institutions have increasingly begun to consider the environmental impact of food waste that occurs at the initial stages of the food supply chain due to financial and technological limitations in harvesting, storage, and refrigeration (Chen; Chaudhary; Mathys, 2020). Conversely, in higher-income countries, consumers predominantly generate food waste (UNEP, 2021).

Countries with a high gross domestic product (GDP) typically produce the largest quantities of food waste. In the United States, the Economic Research Service of the United States Department of Agriculture (USDA) estimated that 31% of food is lost or wasted at the retail and consumer levels, amounting to approximately 133 billion pounds of discarded food, valued at $161 billion annually (FSIS, 2016).

China, on the other hand, sees over 70% of its food waste originating from households and food service establishments, such as restaurants and cafeterias (Wang; Yang; Wang, 2022). Despite possessing only 7% of the world's arable land, China sustains 19% of the global population and contributes significantly to food waste, with an estimated 5.5 million tons of grain wasted annually at the household level and 10% originating from cafeterias (Wang; Yang; Wang, 2022). This scenario results in substantial costs associated with land, water, labor, and other resources required for food production, exacerbating environmental pollution (FAO, 2013). In response, China has launched initiatives such as the “Clean Your Plate” campaign and the “Anti-food Waste Law” to address pressing environmental, economic, and social concerns while raise awareness of food waste (Asefi *et al*., 2024; Wang; Yang; Wang, 2022).

Leftovers refer to food that remains after a meal, often consisting of previously prepared dishes or ingredients that were not fully utilized (Aloysius *et al*., 2023). When food waste is discarded in landfills, it contributes physical mass and alters its entire molecular composition. Fruits and vegetables frequently account for a significant portion of wasted food, despite containing bioactive compounds (Ray *et al*., 2023). For instance, discarded fruits may still retain polyphenols, vitamins, pigments, and fatty acids, with these components exhibiting bioactive properties such as anti-diabetic, antioxidant, anti-inflammatory, antimicrobial, anticancer, cardioprotective, and neuroprotective effects (Ray *et al*., 2023).

Conventional food waste management methods, such as landfilling and incineration, present environmental, social, and economic challenges (Xiong *et al*., 2019). Discarded food waste in landfills can emit harmful gases into the atmosphere, while incineration is energy-intensive and may produce highly toxic emissions, including dioxins (Palansooriya *et al*., 2023). While millions of people worldwide suffer from hunger, substantial amounts of food and their potential benefits are thrown away. Consequently, numerous researchers are critically examining alternative strategies for redistributing and reallocating food waste to those in need, starting with food rescue initiatives.

Food rescue, also known as food recovery or food redistribution, involves collecting and redirecting surplus food that would otherwise be wasted to individuals or organizations in need. These initiatives aim to prevent the disposal of edible food and ensure its safe and efficient redistribution to alleviate food insecurity and reduce food waste. The term “rescue” refers to food typically destined for landfill due to blemishes, expiration dates, packaging malfunctions, and other factors. One organization, in particular, focuses its food rescue efforts on fresh produce, including blemished items nearing the end of their marketability (Sewald; Kuo; Dansky, 2018).

Foods with imperfections or approaching the end of their shelf life are often overlooked and excluded from human consumption. This has led to the loss of over U$40 billion worth of food in the United States due to deviations from aesthetic standards and product category norms regarding shape, size, color, and texture (Mookerjee; Cornil; Hoegg, 2021). This represents a significant economic loss as well as the waste of edible food that remains fit for consumption. This category of food is referred to as rescue-based food (RBF), which consists entirely or partially of ingredients that are safe for human consumption and within expiration dates but are discarded due to aesthetic concerns or oversupply (De Visser-Amundson; Peloza; Kleijnen, 2021). RBF allows such food to be repurposed, re-entering the human food chain as a valuable product instead of being discarded (De Visser-Amundson; Peloza; Kleijnen, 2021).

Fermentation serves as an effective alternative for waste management compared to landfills and incineration. Of the hundreds of millions of tons of food waste generated annually, 40%-50% consists of fruits and vegetables (Sirohi *et al*., 2021). Compared to vegetable residues, fruit residues typically contain higher levels of saccharides and are suitable for developing various value-added products (Zhao *et al*., 2023). The primary waste produced by the fruit processing industry includes peels, pulp, seeds, and bagasse (Zhao *et al*., 2023). In some instances, discarded components like peels, seeds, and pulp have higher nutrient concentrations than the edible parts of the fruit. For example, pineapple peels contain great amounts of antioxidants, such as gallic and caffeic acid, compared to pulp or juice (Tanamool; Chantarangsee; Soemphol, 2020).

Another emerging method for alternative waste management is anaerobic digestion (AD), which repurposes food waste for renewable energy production, thereby promoting sustainability and reducing landfill disposal (Neri *et al*., 2023). This process is acknowledged as one of the most efficient technologies for transforming waste into fertilizers and biogas, which can be utilized for electricity generation or biofuel production within a circular economy framework (Tena; Perez; Solera, 2021a). Anaerobic digestion is a biochemical process facilitated by various microorganisms thriving in oxygen-free environments. It comprises four sequential stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Currently, there are three commercial-scale anaerobic digestion systems: single-stage systems, where waste bioconversion occurs within a single reactor; two-stage systems, where acidogenic and methanogenic processes are separated into distinct reactors; and temperature-phase anaerobic digestion (TPAD), which integrates a thermophilic pretreatment unit before mesophilic anaerobic digestion (Tena; Perez; Solera, 2021b).

In the Basque Country, various food industry by-products have been identified, including residues from potatoes, apples, grapes, bread waste, and coffee husks. As an alternative application, a study suggested repurposing these residues as raw materials for animal nutrition, provided they meet the required hygiene and sanitary standards for consumption (San Martin; Ramos; Zufía, 2016).

According to Beretta *et al*. (2013), some food waste can be avoided, such as losses due to overproduction, expiration dates, and inefficiencies in processing. Suggested practices for minimizing waste include redistributing or donating surplus food before it deteriorates, enhancing storage conditions, and adopting advanced food processing technologies. However, certain losses, such as food contamination, transport failures, and climate-related post-harvest losses, remain unavoidable.

To promote the utilization of industrial food waste, Cerón-Martínez *et al*. (2023) explored the use of pear guava (*Psidium guajava*) and Tommy Atkins mango (*Mangifera indica* L.) seeds, sourced in Colombia, to produce an oily extract with bioactive properties. The supercritical extraction method using carbon dioxide was employed in the process. The resulting extract exhibited antioxidant and anti-inflammatory properties, along with the potential to lower cholesterol levels in the human body. According to Gaharwar *et al*. (2023), another example of food waste reuse is the extraction of bioactive compounds from apple peels, which not only supports the circular economy but also provides health benefits due to its antioxidant activity attributed to polyphenol content.

Kiwi serves as an example of a fruit that generates substantial waste during both production and industrial processing. Discarding these residues leads to environmental impacts and the loss of kiwi-derived bioactive compounds, which possess antioxidant, anti-inflammatory, anti-tumor, and anti-microbial properties. These compounds have potential applications across various industries (Chamorro *et al*., 2022). Similarly, Weber, Trierweiler, and Trierweiler (2020) highlighted the potential of sweet potato waste for biorefinery applications, particularly for bioethanol and distilled beverages applications, contributing significantly to sustainable development and the circular economy. Additionally, the biorefinery sector enhances the economic viability of waste-utilization processes.

Reducing food waste requires consumer participation. One effective approach involves increasing consumer acceptance of aesthetically imperfect but otherwise safe and nutritious food. Reducing waste necessitates collective effort; while food donation programs are valuable, they have limitations, and additional measures are needed to address the issue comprehensively (Beretta *et al*., 2013).

The food sector must adopt more sustainable practices. Companies need to minimize waste, support environmental sustainability, and optimize resource availability. Environmental improvements require economic investment and time, but should be regarded as long-term commitments to sustainability (López-Cabarcos *et al*., 2024).

4 Challenges and limitations

The rapid change in lifestyle, combined with accelerated urbanization, have led to an increase in the production of diverse types of waste from the food industry, including fruits and vegetables, cereals, meat products, dairy products, poultry remains, eggs, seafood, kitchen waste, and agricultural waste (Arya *et al*., 2022). Aiming to contribute to the circular economy, Australia has launched a strategy that helps recover food waste, returning it to its life cycle. Talekar *et al*. (2023) highlight that biorefineries can be one of the ways to mitigate the impacts of waste and avoid the use of landfills and composting. Some challenges become evident for the use of biorefineries, such as the high moisture content of food. It is worth mentioning that sterilization and dehydration techniques can be used to facilitate the process. However, it is necessary to verify whether these methods are not minimizing important properties of food waste.

Another significant source of waste is the animal slaughter industry, which accounts for 49% of bovine remains, 47% of sheep and lambs, 44% of pig remains, and 37% of chicken remains, along with another 37% of inedible by-products. This leads to substantial amounts of waste that have considerable environmental impacts (Adhikari; Chae; Bressler, 2018). For instance, a 350 kg cow generates approximately 210 kg of waste, a 70 kg pig produces around 31.5 kg, and a 30 kg goat generates 18 kg of waste

(Chowdhury *et al*., 2022). The most commonly discarded parts in slaughterhouses include feathers, hair, skin, horns, hooves, bones, and deboning residues. Additionally, slaughterhouse wastewater can become contaminated with blood, proteins, lard, tallow, and other organic matter, necessitating proper disposal to prevent environmental damage. Some industries have adopted reuse strategies, such as processing these residues into animal feed or fertilizer (Yaakob *et al*., 2019).

Effective waste management is crucial and requires collaboration among all stakeholders involved in waste collection, including the general population and responsible authorities (Castiglione *et al*., 2023). Food waste generated in commercial settings can be categorized into two main types: waste from kitchens and back-office operations, including peels, shells, eggs, and packaging, and waste from front-office operations, such as leftover food on customer plates. While restaurants can control waste generation in kitchen operations, waste in the front office largely depends on consumer behavior. Proper management is essential, as some types of waste, such as those resulting from failures in the cold chain, can be minimized or prevented (Martin-Rios *et al*., 2018).

According to Rukikaire (2020), improper food waste disposal has severe environmental consequences, with landfill decomposition contributing to approximately 1.5 tons of carbon dioxide emissions annually. Innovation, technological advancements, and behavioral changes are among the key strategies for reducing food loss and waste (Rukikaire, 2020). Globally, between 4 and 11 million tons of dairy products are wasted annually (Usmani *et al*., 2022). The presence of lactose and proteins in milk adds value to dairy waste, as these components can be recovered and reintegrated into the food chain (Lappa *et al*., 2019).

Several measures can be taken to mitigate food loss and waste. These include the development of innovation platforms, government incentives to address food loss and foster supply chain collaboration, and technology and innovation training programs for small-scale producers, as well as revising excessively stringent food packaging regulations. Moreover, relaxing aesthetic standards for fruits and vegetables and enhancing redistribution systems to ensure that surplus food, when safe for consumption, reaches food banks are essential steps. Investments in infrastructure and logistics, especially in sustainable cold chain solutions, are also vital for food preservation (Rukikaire, 2020).

Food is a valuable source of nutrients, and waste discarded by industries could be repurposed for alternative applications through circular economy initiatives (Borrello *et al*., 2017). Embracing a responsible and sustainable approach throughout all stages of the food lifecycle can significantly reduce unnecessary waste. Universities, as centers of research and technological development, play a fundamental role in collaborating with industries to support waste reduction efforts (Rukikaire, 2020). High-quality university research serves as a critical foundation for scientific advancements and innovations, making academia a key pillar in waste analysis and management.

A lack of public awareness and ingrained cultural habits contribute to food waste on a global scale. To tackle this challenge, governments must implement public policies that encourage waste reduction and reuse. One strategy involves increased investment in research and adopting initiatives to educate the public on sustainable waste management practices (Champions 12.3, 2020). According to Champions 12.3 (2020), governments and companies must establish measurable goals for waste reduction, assess their losses, and develop targeted strategies to address this issue.

5 Circular economy and waste in the food industry

The circular economy is a production and consumption model that emphasizes sharing, recovering, and reusing materials over an extended period. Waste is repurposed and transformed into new resources for future activities, helping to reduce food waste in the industry (Acerbi *et al*., 2021). The three primary challenges associated with adopting circular economy principles in the agri-food supply chain are institutional, financial, and technological barriers (Mehmood *et al*., 2021). Most urban waste is improperly treated, posing potential environmental risks. This mismanagement can lead to air pollution, the spread of diseases, and negative effects on public health (Castiglione *et al*., 2023).

Short food supply chains are defined as marketing channels with minimal intermediaries, typically involving no more than one intermediary between the producer and the consumer (Unay-Gailhard; Bojnec, 2021). These chains facilitate interaction between rural and urban areas, aiming to achieve sustainability and food governance objectives (Reina-Usuga; De-Haro; Parra-Lopez, 2018). The sustainable objectives of the food supply chain are categorized into three dimensions: environmental, economic, and social (Kamble; Gunasekaran; Gawankar, 2020). Short food supply chains contribute to food waste reduction and support circular economy goals by decreasing the perishability rate of food, thus minimizing waste and preventing the disposal of non-standardized products (Kiss; Ruszkai; Takács-György, 2019). Within this system, producers utilize minimal or no packaging due to the nature of their economic and commercial activities. The volume of products sold is lower, and the purchasing process is more direct compared to large-scale supply chains (Kiss; Ruszkai; Takács-György, 2019).

To implement a circular economy across industries, two fundamental strategies can be applied: minimizing waste generating and managing waste sustainably. Waste recovery focuses on transforming waste into more useful products. Although landfilling, incineration, and composting are widely used waste treatment methods, they present limitations, such as strong odors, methane gas emissions, and slow degradation processes (Arancon *et al*., 2013).

The United Nations' 2030 Agenda serves as a global framework for promoting sustainable actions, intending to halve food waste through coordinated efforts by governments and corporations, particularly in countries experiencing slower progress toward sustainability targets. The feasibility of achieving these goals is evidenced by initiatives such as those in the United Kingdom, where per capita food waste was reduced by 27%, and various companies have successfully decreased waste by 25% (Champions 12.3, 2020).

The Sustainable Development Goals (SDGs), established by the United Nations in 2015, include at least 11 of the 17 goals directly linked to food. The first goals focus on "no poverty" and "zero hunger" (Hassoun *et al*., 2022). Effective waste management is crucial for alleviating poverty and achieving food security.

Technology acts as a critical tool in minimizing waste on a global scale. Blockchain technology, for instance, can be integrated into the circular economy to enhance waste management through traceability, enabling consumers to verify stored information regarding waste levels and associated incentives. Blockchain improves the monitoring of waste collection processes and optimizes urban waste management. Through this system, citizens submit data on discarded waste to waste collection operators, who then track landfill capacity and plan more efficient collection and transportation operations (Castiglione *et al*., 2023).

ISSN 2447-9187

6 Future research directions

Significant global progress has been made in food waste management in recent years. Governments, NGOs, businesses, and individuals have collaborated to seek and implement effective solutions. This progress has been notably enhanced by increased awareness and education regarding food waste and its impact on global systems. For instance, the United Nations' *Think*, *Eat*, *Save* campaign highlights that changing attitudes and behaviors related to food purchasing and consumption is a fundamental step toward successfully reducing and managing food waste more sustainably (UNEP, 2021).

Understanding consumer behavior is crucial for preventing food waste (Quested *et al*., 2013). The behaviors that lead consumers to contribute to household food waste are influenced by psychological, socio-cultural, and economic factors, including awareness, attitudes, cognitions, emotions, and contextual aspects such as available technologies (Vittuari *et al*., 2023). Addressing societal perceptions of food and resource utilization is essential for driving substantial changes in food waste management.

Bretter *et al*. (2023) found that individuals who perceive food waste as morally wrong are less likely to engage in such behavior. Additionally, each food category possesses attributes that influence individuals' decisions regarding sorting, preparation, storage, and disposal (Ananda; Karunasena; Pearson, 2022). Therefore, solutions such as smart labels could serve as a promising tool for reducing food waste generation.

Smart labels are app-based food labels that provide real-time information about specific products. In addition to basic nutritional data, these labels offer details about product origin, facilitate the rapid identification of items involved in food safety concerns or recalls, notify consumers, and provide up-to-date expiry information. Consistently updating consumers on product information, smart labels, and intelligent food packaging can enhance purchasing confidence and contribute to reducing food waste (Skinner, 2015).

Many consumers in the United States discard edible food due to misinterpretation of package date labels, often assuming that food is unsafe after the indicated date (Wilson *et al*., 2017). Conversely, consumers who purchase products nearing spoilage and consume them promptly help prevent waste at the retail level (Qi; Roe, 2016). In the United States, the largest share of food waste originates from households (37.2%), followed by consumer-facing businesses, including retailers (13.1%) and food service outlets (15.8%) This waste significantly impacts the environment, as food production requires substantial amounts of energy and water (EPA, 2020). Consequently, initiatives that incentivize consumers to purchase foods nearing expiration, along with food rescue programs, are effective strategies for mitigating household and retail food waste.

Another critical factor in the food industry is packaging, which serves to preserve and protect food while ensuring quality. Currently, there is a growing emphasis on incorporating environmentally beneficial materials into packaging. Biodegradable packaging presents an alternative to conventional packaging by utilizing polymers that naturally degrade, such as those derived from agricultural residues (Nath *et al*., 2023). Cassava peels and bagasse, for example, can serve as alternative sources of starch for the development of biodegradable packaging (Thuppahige *et al*., 2023).

7 Conclusions

Food waste poses a significant global challenge, especially within the food industry, where large quantities of waste are discarded. Throughout the food processing chain, various obstacles emerge that impede waste reduction; nonetheless, several strategies can be employed to address this issue. Effective waste management aims to close the loop by implementing measures that encourage a circular economy and prevent the loss of nutrient-rich food that remains fit for consumption.

Furthermore, adopting biodegradable packaging and converting waste into renewable energy are practices that enhance sustainability. In this context, future research must be carried out to significantly contribute to sustainable waste management strategies and promote social awareness, as closing the loop is a shared responsibility.

Financing

This research did not receive external funding.

Conflict of interests

The authors declare no conflict of interest.

Contributions to the article

SILVA, L. L. P.; PERRONE, S.; PEREIRA, J.: study/research design and conception; data analysis and/or interpretation; final revision with critical and intellectual contribution to the manuscript. **REIS, C. L. F. S.; SOUZA, T. F. C.; OLIVEIRA, T. F.:** final revision with critical and intellectual contribution to the manuscript. All authors participated in the writing, discussion, reading, and approval of the final version of the article.

References

ACERBI, F.; SASSANELLI, C.; TERZI, S.; TAISCH, M. A systematic literature review on data and information required for circular manufacturing strategies adoption. **Sustainability**, v. 13, n. 4, 2047, 2021. DOI: https://dx.doi.org/10.3390/su13042047.

ADHIKARI, B. B.; CHAE, M.; BRESSLER, D. C. Utilization of slaughterhouse waste in value-added applications: recent advances in the development of wood adhesives. **Polymers**, v. 10, n. 2, 176, 2018. DOI: https://dx.doi.org/10.3390/polym10020176.

ALOYSIUS, N.; ANANDA, J.; MITSIS, A.; PEARSON, D. Why people are bad at leftover food management? A systematic literature review and a framework to analyze household leftover food waste generation behavior. **Appetite**, v. 186, 106577, 2023. DOI: https://dx.doi.org/10.1016/j.appet.2023.106577.

ANANDA, J.; KARUNASENA, G. G.; PEARSON, D. Identifying interventions to reduce household food waste based on food categories. **Food Policy**, v. 111, 102324, 2022. DOI: https://doi.org/10.1016/j.foodpol.2022.102324.

ARANCON, R. A. D.; LIN, C. S. K.; CHAN, K. M.; KWAN, T. H.; LUQUE, R. Advances on waste valorization: new horizons for a more sustainable society. **Energy Science and Engineering**, v. 1, n. 2, p. 53-71, 2013. DOI: https://dx.doi.org/10.1002/ese3.9.

ARYA, P. S.; YAGNIK, S. M.; RAJPUT, K. N.; PANCHAL, R. R.; RAVAL, V. H. Valorization of agro-food wastes: ease of concomitant-enzymes production with application in food and biofuel industries. **Bioresource Technology**, v. 361, 127738, 2022. DOI: https://dx.doi.org/10.1016/j.biortech.2022.127738.

ASEFI, B.; MAENROUF, M. S.; NKINAHAMIRA, F.; XIAN, C. Y.; HAN, S. J.; WANG, P. Sustainable campus dining: evaluating food waste practices and awareness at Hainan Tropical Ocean University. **Sustainable Chemistry and Pharmacy**, v. 39, 101571, 2024. DOI: https://doi.org/10.1016/j.scp.2024.101571.

BERETTA, C.; STOESSEL, F.; BAIER, U.; HELLWEG, S. Quantifying food losses and the potential for reduction in Switzerland. **Waste Management**, v. 33, n. 3, p. 764-773, 2013. DOI: https://dx.doi.org/10.1016/j.wasman.2012.11.007.

BOITEAU, J. M.; PINGALI, P. Can we agree on a food loss and waste definition? An assessment of definitional elements for a globally applicable framework. **Global Food Security**, v. 37, 100677, 2023. DOI: https://dx.doi.org/10.1016/j.gfs.2023.100677.

BORRELLO, M.; CARACCIOLO, F.; LOMBARDI, A.; PASCUCCI, S.; CEMBALO, L. Consumers' perspective on circular economy strategy for reducing food waste. **Sustainability**, v. 9, n. 1, 141, 2017. DOI: https://doi.org/10.3390/su9010141.

BOVAY, J.; ZHANG, W. A century of profligacy? The measurement and evolution of food waste. **Agricultural and Resource Economics Review**, v. 49, n. 3, p. 375-409, 2020. DOI: https://doi.org/10.1017/age.2019.16.

BRETTER, C.; UNSWORTH, K. L.; KAPTAN, G.; RUSSELL, S. V. It is just wrong: moral foundations and food waste. **Journal of Environmental Psychology**, v. 88, 102021, 2023. DOI: https://doi.org/10.1016/j.jenvp.2023.102021.

CASTIGLIONE, A.; CIMMINO, L.; DI NARDO, M.; MURINO, T. A framework for achieving a circular economy using the blockchain technology in a sustainable waste management system. **Computers and Industrial Engineering**, v. 180, 109263, 2023. DOI: https://doi.org/10.1016/j.cie.2023.109263.

CERÓN-MARTÍNEZ, L. J.; HURTADO-BENAVIDES, A. M.; AYALA-APONTE, A.; SERNA-COCK, L.; TIRADO, D. F. Bioactive fractions isolated from by-products of the guava (*Psidium guajava*) and mango (*Mangifera indica* L.) agri-food industry. **Fluids**, v. 8, n. 9, p. 1-12, 2023. DOI: https://doi.org/10.3390/fluids8090256.

CHAMORRO, F.; CARPENA, M.; FRAGA-CORRAL, M.; ECHAVE, J.; RAJOKA, M. S. R.; BARBA, F. J.; CAO, H.; XIAO, J.; PRIETO, M. A.; SIMAL-GANDARA J. Valorization of kiwi agricultural waste and industry by-products by recovering bioactive compounds and applications as food additives: a circular economy model. **Food Chemistry**, v. 370, 131315, 2022. DOI: https://dx.doi.org/10.1016/j.foodchem.2021.131315.

CHAMPIONS 12.3. Call to global action on food loss and waste. **Champions 12.3**, Sept. 2020. Available at: https://champions123.org/publication/call-global-action-food-loss-and-waste. Accessed on: 4 Feb. 2024.

CHEN, C.; CHAUDHARY, A.; MATHYS, A. Nutritional and environmental losses embedded in global food waste. **Resources, Conservation & Recycling**, v. 160, 104912, 2020. DOI: https://dx.doi.org/10.1016/j.resconrec.2020.104912.

CHOWDHURY, M. W.; NABI, M. N.; AREFIN, M. A.; RASHID, F.; ISLAM, M. T.; GUDIMETLA, P.; MUYEEN, S. M. Recycling slaughterhouse wastes into potential energy and hydrogen sources: an approach for the future sustainable energy. **Bioresource Technology Reports**, v. 19, 101133, 2022. DOI: https://doi.org/10.1016/j.biteb.2022.101133.

DE VISSER-AMUNDSON, A.; PELOZA, J.; KLEIJNEN, M. How association with physical waste attenuates consumer preferences for rescue-based food. **Journal of Marketing Research**, v. 58, n. 5, p. 870-887, 2021. DOI: https://doi.org/10.1177/00222437211031243.

EPA – U.S. ENVIRONMENTAL PROTECTION AGENCY. **2018 wasted food report**: Estimates of generation and management of wasted food in the United States in 2018. Washington, D.C.: EPA, 2020. Available at: https://19january2021snapshot.epa.gov/sites/static/files/2020-11/documents/2018_wasted_food_report-11-9-20_final_.pdf. Accessed on: 12 Feb. 2024.

FAO – FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. **Food wastage footprint**: Impacts on natural resources. Summary Report. Rome: FAO, 2013. Available at: https://www.fao.org/4/i3347e/i3347e.pdf. Accessed on: 4 May 2024.

FAO – FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. **The state of food and agriculture**: Moving forward on food loss and waste reduction. Rome: FAO, 2019. Available at: https://www.fao.org/3/ca6030en/ca6030en.pdf. Accessed on: 4 Feb. 2024.

FSIS – FOOD SAFETY AND INSPECTION SERVICE. USDA revises guidance on date labeling to reduce food waste. **United States Department of Agriculture**, Washington D.C., 14 Dec. 2016. Available at: https://www.fsis.usda.gov/news-events/news-press-releases/usda-revises-guidance-date-labeling-reduce-food-waste. Accessed on: 14 May 2024.

GAHARWAR, S. S.; KUMAR, A.; RATHOD, K. S.; SHINDE, S. V. Valorization of *Malus domestica* L. (apple) peels: a case study of circular bioeconomy. **Sustainable Chemistry and Pharmacy**, v. 36, 101301, 2023. DOI: https://doi.org/10.1016/j.scp.2023.101301.

HASSOUN, A.; PRIETO, M. A.; CARPENA, M.; BOUZEMBRAK, Y.; MARVIN, H. J. P.; PALLARÉS, N.; BARBA, F. J.; BANGAR, S. P.; CHAUDHARY, V.; IBRAHIM, S.; BONO, G. Exploring the role of green and Industry 4.0 technologies in achieving sustainable development goals in food sectors. **Food Research International**, v. 162, Part B, 112068, 2022. DOI: https://doi.org/10.1016/j.foodres.2022.112068.

HLPE – HIGH LEVEL PANEL OF EXPERTS. **Food losses and waste in the context of sustainable food systems**: A report by the high level panel of experts on food security and nutrition of the Committee on World Food Security. Rome: HLPE, 2014. Available at: https://www.fao.org/3/i3901e/i3901e.pdf. Accessed on: 12 Feb. 2024.

ISHANGULYYEV, R.; KIM, S.; LEE, S. H. Understanding food loss and waste: why are we losing and wasting food? **Foods**, v. 8, n. 8, 297, 2019. DOI: https://dx.doi.org/10.3390/foods8080297.

KAMBLE, S. S.; GUNASEKARAN, A.; GAWANKAR, S. A. Achieving sustainable performance in a data-driven agriculture supply chain: a review for research and applications. **International Journal of Production Economics**, v. 219, p. 179-194, 2020. DOI: https://doi.org/10.1016/j.ijpe.2019.05.022.

KISS, K.; RUSZKAI, C.; TAKÁCS-GYÖRGY, K. Examination of short supply chains based on circular economy and sustainability aspects. **Resources**, v. 8, n. 4, 161, 2019. DOI: https://doi.org/10.3390/resources8040161.

LAPPA, I. K.; PAPADAKI, A.; KACHRIMANIDOU, V.; TERPOU, A.; KOULOUGLIOTIS, D.; ERIOTOU, E.; KOPSAHELIS, N. Cheese whey processing: integrated biorefinery concepts and emerging food applications. **Foods**, v. 8, n. 8, 347, 2019. DOI: https://doi.org/10.3390/foods8080347.

LÉVESQUE, J.; PERREAULT, V.; MIKHAYLIN, S. Food waste environmental impact assessment as leverage to better guide restaurants toward improving their sustainability. **International Journal of Gastronomy and Food Science**, v. 33, 100742, 2023. DOI: https://doi.org/10.1016/j.ijgfs.2023.100742.

LÓPEZ-CABARCOS, M. Á.; PIÑEIRO-CHOUSA, J.; QUIÑOÁ-PIÑEIRO, L.; LÓPEZ-PÉREZ, M. L. Water and waste management strategies as drivers of the financial performance of food companies. **Technological Forecasting and Social Change**, v. 200, 123138, 2024. DOI: https://doi.org/10.1016/j.techfore.2023.123138.

MARTIN-RIOS, C.; DEMEN-MEIER, C.; GÖSSLING, S.; CORNUZ, C. Food waste management innovations in the foodservice industry. **Waste Management**, v. 79, p. 196-206, 2018. DOI: https://doi.org/10.1016/j.wasman.2018.07.033.

MEHMOOD, A.; AHMED, S.; VIZA, E.; BOGUSH, A.; AYYUB, R. M. Drivers and barriers towards circular economy in agri-food supply chain: a review. **Business Strategy and Development**, v. 4, n. 4, p. 465-481, 2021. DOI: https://doi.org/10.1002/bsd2.171.

MOOKERJEE, S.; CORNIL, Y.; HOEGG, J. From waste to taste: how “ugly” labels can increase purchase of unattractive produce. **Journal of Marketing**, v. 85, n. 3, p. 62-77, 2021. DOI: https://doi.org/10.1177/0022242920988656.

NATH, P. C.; SHARMA, R.; DEBNATH, S.; SHARMA, M.; INBARAJ, B. S.; DIKKALA, P. K.; NAYAK, P. K; SRIDHAR, K. Recent trends in polysaccharide-based biodegradable polymers for smart food packaging industry. **International Journal of**

Biological Macromolecules, v. 253, Part 8, 127524, 2023. DOI: https://doi.org/10.1016/j.ijbiomac.2023.127524.

NERI, A.; BERNARDI, B.; ZIMBALATTI, G.; BENALIA, S. An overview of anaerobic digestion of agricultural by-products and food waste for biomethane production. **Energies**, v. 16, n. 19, 6851, 2023. DOI: https://doi.org/10.3390/en16196851.

PALANSOORIYA, K. N.; DISSANAYAKE, P. D.; IGALAVITHANA, A. D.; TANG, R.; CAI, Y.; CHANG, S. X. Converting food waste into soil amendments for improving soil sustainability and crop productivity: a review. **Science of The Total Environment**, v. 881, 163311, 2023. DOI: https://doi.org/10.1016/j.scitotenv.2023.163311.

QI, D.; ROE, B. E. Household food waste: multivariate regression and principal components analyses of awareness and attitudes among U.S. consumers. **PLoS ONE**, v. 11, n. 7, e0159250, 2016. DOI: https://doi.org/10.1371/journal.pone.0159250.

QUESTED, T. E.; MARSH, E.; STUNELL, D.; PARRY, A. D. Spaghetti soup: the complex world of food waste behaviours. **Resources, Conservation and Recycling**, v. 79, p. 43-51, 2013. DOI: https://doi.org/10.1016/j.resconrec.2013.04.011.

RAY, A.; DUBEY, K. K.; MARATHE, S. J.; SINGHAL, R. Supercritical fluid extraction of bioactives from fruit waste and its therapeutic potential. **Food Bioscience**, v. 52, 102418, 2023. DOI: https://doi.org/10.1016/j.fbio.2023.102418.

REINA-USUGA, L.; DE-HARO, T.; PARRA-LÓPEZ, C. Territorial short food supply chains: conceptualization and characterization for the case of Córdoba, Spain. **ITEA – Información Técnica Económica Agraria**, v. 114, n. 2, p. 183-202, 2018. DOI: https://doi.org/10.12706/itea.2018.012.

RUKIKAIRE, K. Food loss and waste must be reduced for greater food security and environmental sustainability. **United Nations Environment Programme**, Rome, 2020. Available at: https://www.unep.org/news-and-stories/press-release/food-loss-and-waste-must-be-reduced-greater-food-security-and. Accessed on: 4 Feb. 2024.

SAN MARTIN, D.; RAMOS, S.; ZUFÍA, J. Valorisation of food waste to produce new raw materials for animal feed. **Food Chemistry**, v. 198, p. 68-74, 2016. DOI: https://doi.org/10.1016/j.foodchem.2015.11.035.

SERPA-FAJARDO, J. G.; HERNÁNDEZ-RAMOS, E. J.; FERNÁNDEZ-LAMBERT, G.; SANDOVAL-HERAZO, L. C.; ANDRADE-PIZZARRO, R. D. Post-industrial context of cassava bagasse and trend of studies towards a sustainable industry: a scoping review – Part I. **F1000 Research**, v. 11, 562, 2022. DOI: https://doi.org/10.12688/f1000research.110429.1.

SEWALD, C. A.; KUO, E. S.; DANSKY, H. Boulder food rescue: an innovative approach to reducing food waste and increasing food security. **American Journal of Preventive Medicine**, v. 54, n. 5, suppl. 2, p. S130-S132, 2018. DOI: https://doi.org/10.1016/j.amepre.2017.12.006.

SIROHI, R.; GAUR, V. K.; PANDEY, A. K; SIM, S. J.; KUMAR, S. Harnessing fruit waste for poly-3- hydroxybutyrate production: a review. **Bioresource Technology**, v. 326, 124734, 2021. DOI: https://doi.org/10.1016/j.biortech.2021.124734.

SKINNER, G. A. Smart labelling of foods and beverages. *In*: BERRYMAN, P. (ed.). **Advances in food and beverage labelling**: information and regulations. Sawston: Woodhead Publishing, 2015. p. 191-205. DOI: https://doi.org/10.1533/9781782420934.3.191.

TALEKAR, S.; EKANAYAKE, K.; HOLLAND, B.; BARROW, C. Food waste biorefinery towards circular economy in Australia. **Bioresource Technology**, v. 388, 129761, 2023. DOI: https://doi.org/10.1016/j.biortech.2023.129761.

TANAMOOL, V.; CHANTARANGSEE, M.; SOEMPHOL, W. Simultaneous vinegar fermentation from a pineapple by-product using the co-inoculation of yeast and thermotolerant acetic acid bacteria and their physiochemical properties. **3 Biotech**, v. 10, n. 3, 115, 2020. DOI: https://doi.org/10.1007/s13205-020-2119-4.

TENA, M.; PEREZ, M.; SOLERA, R. Benefits in the valorization of sewage sludge and wine vinasse via a two-stage acidogenic-thermophilic and methanogenic-mesophilic system based on the circular economy concept. **Fuel**, v. 296, 120654, 2021a. DOI: https://doi.org/10.1016/j.fuel.2021.120654.

TENA, M.; PEREZ, M.; SOLERA, R. Effect of hydraulic retention time on the methanogenic step of a two-stage anaerobic digestion system from sewage sludge and wine vinasse: microbial and kinetic evaluation. **Fuel**, v. 296, 120674, 2021b. DOI: https://doi.org/10.1016/j.fuel.2021.120674.

THUPPAHIGE, V. T. W.; MOGHADDAM, L.; WELSH, Z. G.; WANG, T.; KARIM, A. Investigation of critical properties of Cassava (*Manihot esculenta*) peel and bagasse as starch-rich fibrous agro-industrial wastes for biodegradable food packaging. **Food Chemistry**, v. 422, 136200, 2023. DOI: https://doi.org/10.1016/j.foodchem.2023.136200.

UNAY-GAILHARD, İ.; BOJNEC, Š. Gender and the environmental concerns of young farmers: do young women farmers make a difference on family farms? **Journal of Rural Studies**, v. 88, p. 71-82, 2021. DOI: https://doi.org/10.1016/j.jrurstud.2021.09.027.

UNEP – UNITED NATIONS ENVIRONMENT PROGRAMME. **UNEP Food Waste Index Report 2021**. Nairobi: United Nations Environment Programme, 2021. Available at: https://www.unep.org/resources/report/unep-food-waste-index-report-2021. Accessed on: 4 Feb. 2024.

USMANI, Z.; SHARMA, M.; GAFFEY, J. SHARMA, M.; DEWHURST, R. J.; MOREAU, B.; NEWBOLD, J.; CLARK, W.; THAKUR, V. K.; GUPTA, V. K. Valorization of dairy waste and by-products through microbial bioprocesses. **Bioresource Technology**, v. 346, 126444, 2022. DOI: https://doi.org/10.1016/j.biortech.2021.126444.

VITTUARI, M.; HERRERO, L. G.; MASOTTI, M.; IORI, E.; CALDEIRA, C.; QIAN, Z.; BRUNS, H.; VAN HERPEN, E.; OBERSTEINER, G.; KAPTAN, G.; LIU, G., MIKKELSEN, B. E.; SWANNELL, R.; KASZA, G.; NOHLEN, H.; SALA, S. How to reduce consumer food waste at household level: a literature review on drivers and levers for behavioural change. **Sustainable Production and Consumption**, v. 38, p. 104-114, 2023. DOI: https://doi.org/10.1016/j.spc.2023.03.023.

WANG, L.; YANG, Y.; WANG, G. The clean your plate campaign: resisting table food waste in an unstable world. **Sustainability**, v. 14, n. 8, 4699, 2022. DOI: https://doi.org/10.3390/su14084699.

WEBER, C. T.; TRIERWEILER, L. F.; TRIERWEILER, J. O. Food waste biorefinery advocating circular economy: bioethanol and distilled beverage from sweet potato. **Journal of Cleaner Production**, v. 268, 121788, 2020. DOI: https://doi.org/10.1016/j.jclepro.2020.121788.

WFP – WORLD FOOD PROGRAMME. **World hunger is still not going down after three years and obesity is still growing – UN report**. Rome: WFP, 2019. Available at: https://www.wfp.org/news/world-hunger-still-not-going-down-after-three-years-and-obesity-still-growing-un-report. Accessed on: 12 Feb. 2024.

WILSON, N. L. W.; RICKARD, B. J.; SAPUTO, R.; HO, S.-T. Food waste: the role of date labels, package size, and product category. **Food Quality and Preference**, v. 55, p. 35-44, 2017. DOI: https://doi.org/10.1016/j.foodqual.2016.08.004.

XIONG, X.; YU, I. K. M.; TSANG, D. C. W.; BOLAN, N. S.; OK, Y. S.; IGALAVITHANA, A. D.; KIRKHAM, M. B.; KIM, K.-H.; VIKRANT, K. Value-added chemicals from food supply chain wastes: state-of-the-art review and future prospects. **Chemical Engineering Journal**, v. 375, 121983, 2019. DOI: https://doi.org/10.1016/j.cej.2019.121983.

YAAKOB, M. A.; MOHAMED, R. M. S. R.; AL-GHEETHI, A.; TIEY, A.; KASSIM, A. H. M. Optimising of *Scenedesmus* sp. biomass production in chicken slaughterhouse wastewater using response surface methodology and potential utilisation as fish feeds. **Environmental Science and Pollution Research**, v. 26, p. 12089-12108, 2019. DOI: https://doi.org/10.1007/s11356-019-04633-0.

ZHAO, Z.; SUN, L.; SHA, Z.; CHU, C.; WANG, Q.; ZHOU, D.; WU, S. Valorisation of fresh waste grape through fermentation with different exogenous probiotic inoculants. **Heliyon**, v. 9, n. 6, e16650, 2023. DOI: https://doi.org/10.1016/j.heliyon.2023.e16650.