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REVIEW PAPER ON UPCYCLING OF FOODS: A SUSTAINABLE APPROACH TO REDUCING FOOD WASTE AND PROMOTING CIRCULAR ECONOMY

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Abstract

Food waste generation across the global food supply chain poses significant environmental, economic, and social challenges. Food upcycling has emerged as a promising and sustainable strategy to reduce food loss by transforming surplus and by-product materials into value-added products within a circular economy framework. This review critically examines the concept of food upcycling, distinguishing it from related practices such as reuse and recycling. Global trends in food waste generation across agricultural, industrial, retail, and household sectors are discussed to highlight the magnitude of the problem. The review systematically examines various categories of food waste and their potential for valorisation into functional food ingredients, nutraceuticals, and other high-value products. Conventional and emerging processing technologies, including drying, fermentation, extrusion, pulsed electric field processing, and three-dimensional food printing, are evaluated for their effectiveness in enhancing resource efficiency and preserving bioactive compounds. A case study on the upcycling of orange juice processing by-products is presented to demonstrate practical industrial implementation. In addition, it also analyses the regulatory frameworks, certification standards, consumer perception, and market trends. Environmental and economic impacts of food upcycling are assessed in relation to sustainability goals and circular economy principles. Finally, key challenges, research gaps, and future prospects are identified, emphasizing the role of food upcycling in achieving sustainable food systems and global development targets.

Keywords: Food upcycling; Food waste valorization; Circular economy; Sustainable food systems; Consumer acceptance; Bioactive compounds

I. Introduction

Food loss and waste have emerged as critical global challenges affecting food security, environmental sustainability, and economic stability. Rapid population growth, urbanization, and changes in consumption patterns have intensified pressure on food systems, resulting in substantial quantities of edible food being discarded at different stages of the supply chain (FAO, 2013; Abiad & Meho, 2018). These losses undermine food availability while simultaneously contributing to inefficient use of natural resources, including land, water, energy, and labour (Parfitt et al., 2010). Sustainable food system development increasingly emphasizes strategies that minimize waste generation and improve resource efficiency. Among these strategies, food upcycling has gained significant attention as an approach aligned with sustainability and circular economy principles (Papargyropoulou et al., 2014; Aschemann-Witzel et al., 2023). Food upcycling refers to the transformation of surplus food, by-products, or underutilized materials into new products of higher value while maintaining their suitability for human consumption. Unlike traditional waste management practices that focus primarily on disposal or low-value recovery, upcycling prioritizes value addition and extended material use (Kim, 2023).

Sustainability is commonly assessed through three interrelated dimensions: environmental, economic, and social. Food upcycling has the potential to address all three pillars simultaneously. Environmentally, it reduces landfill disposal and greenhouse gas emissions associated with food degradation (Scherhaufer et al., 2018). Economically, it offers opportunities for cost reduction, value creation, and innovation within the food industry (Lehn & Schmidt, 2023). From a social perspective, upcycling may enhance food availability and support ethical consumption; however, consumer acceptance and trust remain decisive factors influencing market success (Aschemann-Witzel et al., 2023).

Despite its potential, the implementation of food upcycling faces several limitations, including technological constraints, variability in waste composition, regulatory uncertainty, and negative consumer perceptions related to safety and quality (Socas-Rodríguez et al., 2021; Nikhil Swaraj et al., 2025). Existing research often focuses on isolated technologies or individual case studies, while integrated reviews addressing technological, regulatory, economic, and consumer aspects remain limited. This highlights the need for a comprehensive assessment of food upcycling within a circular economy framework.

Therefore, this review aims to critically evaluate food upcycling as a sustainable approach to reducing food waste and promoting circular economy principles. The paper synthesises current literature on food waste sources, upcycling technologies, regulatory and certification frameworks, consumer perception, and market trends. Environmental and economic impacts are also discussed, along with key challenges and future research directions, to support the development of resilient and sustainable food systems.

II. Methodology of Literature Review

A narrative literature review methodology was adopted to evaluate recent developments in food upcycling and its role in sustainable food systems. Scientific literature was collected from multiple databases, including Scopus, ScienceDirect, PubMed, Web of Science, and Google Scholar, to ensure comprehensive coverage of peer-reviewed research. In addition, reports from authoritative international organizations such as the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP) were consulted to obtain global statistics and policy-related information.

Relevant keywords and search terms such as food upcycling, food waste valorisation, by-product utilisation, circular economy in food systems, sustainable food processing, and consumer acceptance of upcycled foods were used individually and in combination. The search primarily focused on studies published between 2010 and 2025, with particular emphasis on recent literature from the last decade to capture current trends and technological advancements. Inclusion criteria comprised peer-reviewed journal articles, review papers, and authoritative reports that addressed food waste generation, upcycling technologies, nutritional and functional aspects, regulatory considerations, consumer perception, and environmental or economic impacts. Studies unrelated to food systems, non-English publications, and articles lacking scientific relevance were excluded from the the selected literature was systematically analysed and synthesised to identify key themes, technological approaches, benefits, limitations, and research gaps in food upcycling. This integrative approach enabled a comprehensive understanding of food upcycling within the framework of sustainability and circular economy principles.

III. Overview of Food Waste and Loss:

Food loss and food waste are among the most demanding issues. In recent years, both governmental and non-governmental organisations have highlighted the problem of discarded or unused food and its impact on food security, environmental sustainability, and the planet (Abiad & Meho, 2018). Approximately one-third of all edible food that is accepted for human consumption is lost or wasted worldwide each year, totalling around 1.3 billion tons. This food waste occurs at various stages of the food supply chain, from the initial stages of farming to the final point of consumption in households. In medium- and high-income nations, a significant portion of food that remains fit for human consumption is discarded. This issue arises from various factors, including consumer behaviour, retail practices, and supply chain inefficiencies. (FAO 2013, 2013)

Below (Table 1), which shares the global estimates of food waste generated at various sectors according to (Food Waste Index Report 2024, 2024). These results reveal that 1.05 billion tonnes of food were wasted across three key sectors, amounting to 132 kilograms per person each year. About 60% of this total is attributed to households, 28% to the food service industry, and 12% to the retail sector.

Table 1: Global Estimation of Food Waste

Sectors	Household	Food Services	Retail	Total
2022 Total (million Tonnes)	631	290	131	1,052
Global Average (kg/capital /year)	79	36	17	132

source: (Food Waste Index Report 2024, 2024)

IV. Sources of Food Waste

A major concern in the global food system is the generation of food waste, which primarily arises from four key sources such as agricultural, industrial, retail, and household sectors. In the agricultural sector, the residues like shells, husks, seeds, and flowers were found (Khaksar et al., 2022). Moving to the industrial sector, waste includes vegetable-based materials such as rice bran, wheat bran, soybean seeds, olive pomace, tomato skin, and orange peel, and animal-based waste like sheep visceral mass, bovine blood, and shrimp and crab shells. In the retail industry, significant food waste is caused by factors such as overstocking, strict aesthetic standards, damaged packaging, improper storage and handling, and unsold prepared or perishable foods (V et al., 2014). Finally, in households, the main contributors to food waste are spoiled or mouldy food, items past their best-before or use-by dates, plate leftovers, over-prepared meals, food no longer desired, and food suspected to be unsafe for consumption (Silvennoinen et al., 2014).

V. Impact of Food Waste on Environment and Economy

Food that is produced but not eaten creates many environmental problems. Studies shows that about 7% of global greenhouse gas emissions come from food waste in landfills. If this food waste were composted properly, it would be less damaging to the environment (Seberini, 2020). Avoidable losses throughout the food supply chain leads to unnecessary environmental effects due to excessive upstream production and processing. When food is thrown into landfills, it breaks down and releases methane, a greenhouse gas that leads to global warming (Scherhaufer et al., 2018).

VI. Concept of Upcycling in the Food Industry

Upcycling in the food industry is using unused material or leftover materials to create new or valuable products. One effective approach to handle this surplus is by redistributing it to communities facing food poverty (Papargyropoulou et al., 2014). Agro-food by-products and waste often contain functional and bioactive compounds, which can be easily used to redevelop the food products that contain essential nutrients and supplements for nourishment, distributed to the entire supply chain (Difonzo et al., 2022). This process can also lower carbon emissions, reduce land and water use, and, through economies of scale, support economic feasibility, as cost–benefit outcomes may differ across various upcycled foods (Thorsen et al., 2024).

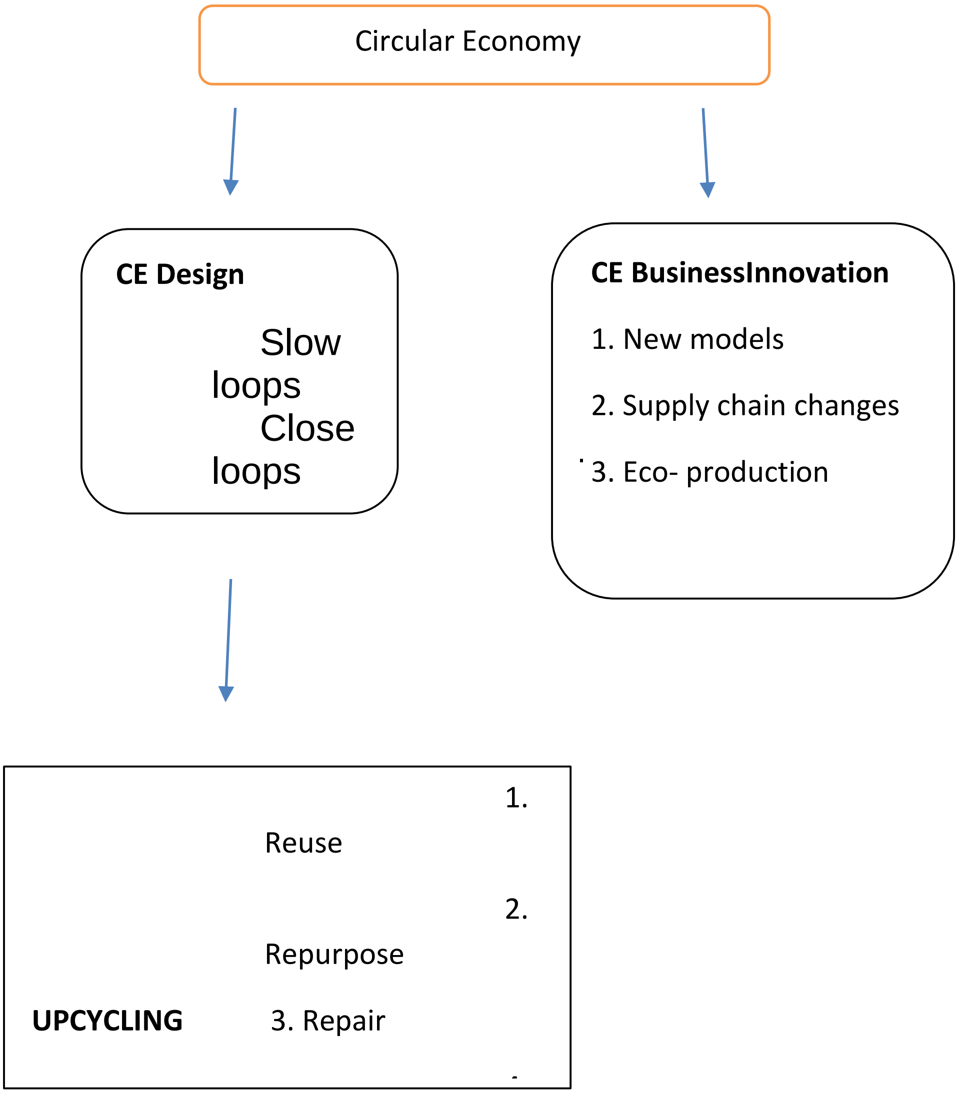
VII. Difference between Reusing, Recycling, and Upcycling

Reuse mainly focuses on promoting environmental sustainability by utilising, or more accurately, using a product again in its original form. (Badalamenti et al., 2022). For instance, Mahato et al. (2017) discussed citrus waste, which is prominent in providing bioactive compounds such as flavonoids, anthocyanins, and also species belonging to the Citrus genus are known for their secretion of essential oils, which are widely utilised as flavouring agents in beverages, soaps, cosmetics, and household products (Adenaike & Abakpa, 2021). Recycling involves using waste materials as an ingredient, where food waste (FW) can be used as a feedstock for animal feed, or converted into bio-fertiliser and biogas. For an environmental perspective, anaerobic processes are recommended for treating food waste due to their low emission of gases (Dung et al., 2014).Using this process can significantly lower greenhouse gas (GHG) emissions compared to other methods. The compost obtained through recycling acts as a better fertiliser for crops due to its higher nutrient availability, and can replace mineral fertilisers (Weiland, 2010). Upcycling involves repurposing products or materials that are no longer in use or are nearing disposal by repairing or remanufacturing them to create items of higher value (Singh et al., 2019). When it comes to food, upcycling refers to transforming surplus or imperfect food into new, value-added food products, thus contributing to waste reduction and delivering beneficial products to society (Kim, 2023). Using items of good quality, such as damaged potatoes, that are not sold commercially, can also be considered as upcycling of goods (Aschemann-Witzel, Asioli, Banovic, Perito, & Peschel, 2023).

VIII. Role of Upcycling in the Circular Economy

The main goal of economic activities in a closed-loop system is to resource, produce, consume, and regenerate resources, where all materials and energy are utilised efficiently and continuously within a sustainable economic cycle, thereby minimising the negative impact on the natural environment (Bi et al., 2006).

Figure 1: Upcycling in the Circular Economy



Sung (2023) explained that upcycling involves reuse, repair, repurpose, refurbish, and redesign to extend product life and reduce waste. Unlike recycling, which can lower quality, upcycling increases material value. In the Circular Economy, it helps slow, narrow, and close material flows. It also supports circular design and business models for sustainable production. With supportive policies and regulations, upcycling is a key step in moving from a linear to a circular economy.

Table: 2 Types of Food Waste Suitable for Upcycling

Category	Common Waste Type	Upcycling Application
Fruits and Vegetables	leaves, stems, roots, tubers, seeds, pomace (Panouillé et al., 2007)	Antioxidant, Polyphenols, lipoid content (Kalogeropoulos et al., 2012)
Dairy Products	whey, whey permeates (Kolev Slavov, 2017)	lactose and minerals animal feeds, protein content. (Menchik et al., 2019)
Cereals and Grains	Straw, dust, germ, bran, brewer spent grain. (Danciu et al., 2023)	phenolic compounds, flavonoids, glucans and pigments. (Pauline et al., 2020)
Seafood and meat by-products	head, bodies, shells and tails. (Tarafdar & Biswas, 2013) organs, fat or lard, skin, feet, abdominal and intestinal contents, bone and blood. (Jayathilakan et al., 2012)	Hypocholesterolemic, calcium-binding, immunostimulatory. (Harnedy & FitzGerald, 2012) Bio preservation, Antimicrobial (Sanchez-Reinoso et al., 2024)
Spent Grain and Coffee Ground	Spent grain Coffee ground	proteins, dietary fibres, antioxidants, and bakery products. (Pongsiriyakul et al., 2024)

IX. Methods and Technologies for Food Upcycling

Drying is one of the oldest, most common techniques to reduce spoilage, which involves the use of heat to evaporate liquid from a solid, semi-solid, or liquid material, turning it into a solid product (Mujumdar & Devahastin, 2000). Where the selection of an appropriate drying method depends on the specific characteristics of the product and various other factors (V. Changrue et al., 2006). The most commonly used dryers are solar tunnel drying, hot air drying and dehumidified air drying ((Sankalpa et al., 2017). Another method, Grinding, is a key step in reducing the size of materials and is widely used in the food industry. For example, in orange peel processing, different grinding methods are used, such as hammer mill grinding at ambient temperature, hammer mill grinding with water cooling, and conventional hammer milling have been utilised for effective particle size reduction (Jung et al., 2018), (Sankalpa et al., 2017). On the other hand, to reduce the size of the materials, different forces are produced to provide specific shapes and sizes to the products (Jung et al., 2018). Lastly, Extrusion processing is a method in which moistened, expandable starchy and protein-rich food materials are plasticised and forced through a die using moisture, heat, pressure, and mechanical shear. This process worked better for apple pomace extraction, as it was able to retain around 80–90% of polyphenols, which is much higher compared to other mixtures (Maurya & Said, 2014) .

Fermentation and bioconversion are the most prominent technologies in food upcycling, offering sustainable solutions to convert industrial wastes into high-value compounds. Fermentation has been widely utilised to extract bioactive compounds from these wastes (Lemes et al., 2022). For instance, a study demonstrated that a culture medium containing coffee husks yielded the highest in production of total carotenoids, as well as carotenoids extracted from coffee pulp exhibited the strongest antioxidant and antimicrobial activities (Moreira et al., 2018). Among the fermentation techniques, submerged fermentation is the most commonly employed worldwide for producing microbial biomass and valuable metabolites. This method provides several advantages, like low risk of contamination, compact and sealed systems, convenience for monitoring and automation, lower employee costs and the flexibility to use various biological agents such as bacteria, yeasts, moulds, microalgae, plant cells, and animal cells (Sánchez et al., 2015). Bioconversion refers to, the use of biochemical energy, stored in biomass, to produce higher-value products through microbial or enzymatic processes. It is one of the promising alternatives for the disposal and valorisation of biomass, depending on the residue type. In the case of lignocellulosic biomass (LB), bioconversion typically involves three main stages, namely, pretreatment, saccharification, and fermentation (Malacara-Becerra et al., 2022).

Călinoiu et al. (2017) demonstrated that thermal processing can also enhance the extraction of phenolic compounds from fruit waste, leading to increased phenolic content in the treated samples. Thermal processing is the most widely used method for preserving food and extending shelf life across various food products (Awuah et al., 2007). It involves heating food primarily to prevent harmful or spoilage-causing microorganisms and to inactivate enzymes, thereby preventing browning caused by polyphenol oxidases and minimizing flavour changes due to lipase and proteolytic activity (M. Shafiur Rahman, 2007). In the dairy industry, pasteurization method is used, such as HTST (high temperature short time) and LTLT (low temperature long time) (Papargyropoulou et al., 2014) for treating milk in case of animal by-products, pasteurization at 70°C for 1 hour resulted in a fourfold increase in potential methane yield compared to untreated samples, indicating that pasteurization before digestion can enhance both sanitation and the efficiency of degradability and energy recovery (Edström et al., 2003).

The food processing and manufacturing industry continually produces food losses and food waste throughout the entire production timeline line (Girotto et al., 2015). Various wastes and by-products from the food industry can be incorporated into food product formulations, but consumers reject them, as they are made from waste. To address these perceptions, food scientists have developed several strategies that balance nutrition, resource efficiency, and sustainable food processing; by this acceptance can be improved. In which 3D food printing technology is an emerging area with providing important benefits (Jagadiswaran et al., 2021). (3D) food printing involves building structures layer by layer using various techniques, including the extrusion-based printing of food inks. In recent times, 3D food printing (3DFP) has gained significant attention in both commercial and academic fields, as it utilises 3D printing technology to produce food products that are customised in both composition and appearance (Digital Gastronomy, 2022). Jagadiswaran et al. (2021) investigated the use of food industry waste streams, where 3D printing was applied to produce cookies made from broken wheat flour incorporated with grape pomace powder.

Long extraction time and more usage of solvent are the major drawbacks of conventional techniques (Luque De Castro & Garcõ Âa-Ayuso, 1998). To overcome these limitations, innovative and advanced extraction methods referred to as non-conventional methods have been developed (Azmir et al., 2013). Among them, pulsed electric field (PEF) requires less energy, making it cost-effective. Importantly, it does not increase the temperature, which allows for the extraction of valuable compounds, particularly those that are heat-sensitive. Corrales et al. (2008) adopted different techniques to extract bioactive compounds like anthocyanins from grape by-products and observed that PEF resulted in better extraction of anthocyanin monoglucosides. The application of these innovative processing technologies can minimize food processing waste and support the production of natural, high-value products, thereby promoting sustainability and fulfilment of the consumer's desires.

X. Upcycled Food Products

Table 3. Examples of Upcycled Food Products Commercially Available in the Market

Company	Type of Waste Utilized	Form of Product	Product Examples
Octonuts	Almond oil production by-products	Produces plant-based protein powder	Roasted Cashew Butter, Almond Protein Powder
Pluck Tea	Excess and irregular tea components	Develops artisan teas using upcycled ingredients	Canadian Maple tea, Chai spice tea
Barnana	Surplus bananas and plantains	Converts fruit waste into dried snack products	Cassava Chips, Dipped Bites
Rind Snacks	Peels and skins of fruits	Dehydrates fruit rinds into crisp snacks	Cocoa Berry Remix, Apple Chips
Harmless Harvest	Coconut meat left after juice extraction	Makes dairy-free yogurt alternatives	Flavoured coconut yogurts
Chix Soup Co	Chicken parts (bones, feet) & leftover vegetables	Makes broth from unused poultry parts and upcycled vegetables	Broth varieties with different spice blends
Uglies Kettle Chips	Imperfect potatoes from farming	Turns blemished potatoes into kettle-cooked snacks	Potato chips in assorted Flavours

source: (Where Food Comes From, 2025)

XI. Nutritional and functional benefits of upcycled food

Upcycled food items, which are obtained from agricultural and industrial residues, provide valuable nutritional and functional benefits that support a healthier and more eco-friendly food system (Dongo, 2025) . Producers of upcycled foods have taken into account different aspects, such as the nutritional qualities of the raw material, and verified if the final product meets all the nutritional benefits. So, that product can be sold with fixed advantages. (Thorsen et al., 2022). For example, grape pomace contains high levels of dietary fibre, minerals, proteins, and beneficial fat components that are often lost in conventional food processing (Yu & Ahmedna, 2013). From a functional perspective, Fernandes et al. (2025) reported that grape stems serve as a rich source of amino acids and bioactive compounds like selenium, tryptophan, proanthocyanidins, phenolic acids, flavonoids, and anthocyanins. Moreover, modern extraction methods are used to efficiently obtain bioactive compounds from the food waste and are also used in different food products. (Dongo, 2025).

XII. Case Study of Successful Upcycling Initiatives

Talens et al. (2021) investigated the potential of the recovery of beneficial compounds, including dietary fiber, polyphenols, and carotenoids, from the by-products of orange processing, such as peels, pulp, and seeds. The study employed a combination of hot air and microwave drying methods to produce a fibre-rich material comparable in quality to commercially available dietary fibres. The process was implemented within the capacity unit of the production line, where waste generated from the primary processing stage was effectively repurposed as raw material for a secondary production line. This integrated system not only optimises resource utilisation but is also helpful in the consistent supply of raw materials, as it is one of the major challenges in the commercialisation of upcycled food products. Therefore, the process represented a sustainable and innovative approach for the valorization of citrus by-products, enabling their transformation into high-value food ingredients.

XIII. Regulatory and Certification Aspects

In upcycled foods (UF), having clear and proper regulations is very important to handle harmful substances. Since they use by-products from the food industry, they must be carefully checked before approval. Even though general food regulations exist, UF requires more specific and stricter rules from the authorities (Nikhil Swaraj et al., 2025). For example, Food Standards Australia New Zealand has created rules to check raw materials and make sure food suppliers follow the Food Standards Code and the Imported Food Control Act (Zealand, 2005). A study from Sweden by Moshtaghian et al. (2023) showed that as age increases, people give more attention to food safety, with older individuals showing more concern than younger ones. To make production easier and improve consumer trust, clear regulations and proper certification systems are necessary (Kim, 2023).

Certification standards that also provide strict rules for upcycled foods. The classified products must contain Upcycled Certified Ingredients (95%), Upcycled Certified Products (10%), and Upcycled Minimal Content Products (less than 10%) (Where Food Comes From, 2025).

XIV. Consumer Perception and Market Trends

Upcycled food contributes to the reduction of food waste, but its success depends on consumer acceptance. It is essential to understand how consumers accept these food products (Bhatt et al., 2021). Lu et al. (2024) identified three categories of key factors influencing consumer acceptance of upcycled food, such as sociodemographic characteristics, psychological characteristics and product characteristics. Studies show that younger individuals with stronger environmental concern accept upcycled foods (Aschemann-Witzel, Asioli, Banovic, Perito, & Peschel, 2023). Psychographic characteristic means fear of trying different foods, which raises concerns about the quality and safety of those products (Pliner & Hobden, 1992) ,(Lu et al., 2024) . To increase consumer trust, researchers should focus more on enhancing the sensory properties of upcycled foods and clearly presenting the ingredient list and use of food components, as this can improve consumer acceptance (Aschemann-Witzel, Asioli, Banovic, Perito, & Peschel, 2023).

In other advertising, they use vital marketing tools and different strategies to encourage customers to buy new products. (Krishnan & Jain, 2006). Ma et al. (2024) identified four categories in their coding system that can enhance consumer acceptance, which include raising awareness about food waste and educating consumers, offering products with appealing flavours, using certification to establish trust in the product, and communicating benefits related to sustainability, health, and the economy.

Despite having its sustainability benefits, many producers are hesitant to food upcycling due to limited consumer acceptance. Surveys with undergraduates showed that without sustainability information, they preferred conventional products, but adding sustainability claims increased interest in upcycled foods. (Ghazanfar et al., 2022). In the case of Ethical, in which it drivers of food purchasing, such as environmental concerns, social responsibility, and animal welfare, can be presented together under a unified sustainability framework, enabling marketers and communicators to guide consumer choices without treating these aspects separately (Bhatt et al., 2021).

XV. Economic and Environmental Impact:

Upcycling, which means turning waste materials into valuable new products, is a sustainable method that helps to reduce environmental problems and also increases economic benefits (Jeon, 2023). Identifying the best way to upcycle food waste is important to support sustainability. This study develops an eco-friendly upcycling method through enzymatic hydrolysis, which changes food waste into high-value products like organic acids, bioethanol, and bioactive peptides. The research mainly looks at the cost-effectiveness of each process. (Ghinea et al., 2025). Cost-effectiveness means how much a food product costs and whether its quality matches the price or gives good value (Jeon, 2023). In one of the experiments, it was found that the final result of the bioactive peptide has given the highest cost benefits, while the organic acids are obtained at a lower cost. effective (Ghinea et al., 2025).

FAO states that the overall food wastage has a major effect on natural resources (FAO 2013, 2013). Considering the avoided environmental damage, it is important to understand that using upcycled ingredients can greatly reduce environmental impact and support sustainability (Thorsen et al., 2024). For example, in one of the research projects, it is shown that converting broccoli waste into powder can help environmental sustainability. This result is clearly seen when the powder is used instead of imported broccoli powder, which usually carries a higher environmental load. On the other hand, using the same powder as a replacement for wheat flour results in a smaller environmental benefit, as wheat has less carbon emissions (Rao et al., 2021). Food waste in the food processing and manufacturing sector occurs mostly due to poor transportation, contamination, food quality loss, and unsuitable storage (Parfitt et al., 2010). The best way to handle food waste is through proper management, where upcycling is more effective than other methods (Dou et al., 2024).

Upcycling involves improving the value of ingredients that would otherwise go to waste (Aschemann-Witzel, Asioli, Banovic, Perito, & Peschel, 2023). To align with global sustainability efforts outlined in the 2030 Agenda, the Sustainable Development Goals (SDGs) were established. One of these goals, SDG 2.1, aims to eliminate hunger by guaranteeing access to adequate, nutritious, and safe food, especially and easily provided for low-income populations. Another key target, SDG 12.3, focuses on minimizing food loss and waste throughout various points in the supply chain. Taking into consideration these goals can aid in efficient and responsible food use at multiple levels (United Nations, 2017).

XVI. Challenges and Future Prospects:

There is a lack of knowledge in realising the gap in upcycling across the broader economy. According to Sung K. et al. (2017) several challenges that can be taken into consideration. These include technological barriers such as the time-intensive nature of upcycling, inconsistent product quality, and the difficulty of working with damaged materials. Additionally, logistical challenges like material storage, high rental costs, and sourcing a consistent supply of usable waste also pose limitations. To overcome these barriers, the development of innovative technologies and more efficient logistics systems is an essential step toward achieving sustainability (Balu et al., 2022).

A food waste upcycling strategy must obtain effective policies and regulations (Mlambo et al., 2023). However, in many cases, analysing outcomes is a challenging task due to the lack of specific legislation and regulatory frameworks that ensure the safety and suitability of new products for consumers. Because the absence of regulation poses a risk to the vaporization of many potentially valuable by-products (Socas-Rodríguez et al., 2021).Although the study by Dou et al. (2024)primarily focuses on the use of food waste in animal feed, it also says that several issues related to policy gaps and regulatory barriers in upcycling, such as the lack of in-depth knowledge on food waste, the absence of a systematic categorisation of waste streams based on their suitability, and legislative obstacles that hinder large-scale processing. Furthermore, (Dou et al., 2024) it emphasizes the need for additional empirical data to achieve legitimacy, social acceptance, and practical implementation, along with cost-effective and efficient upcycling strategies that can support a more sustainable condition.

The potential for scaling up upcycling initiatives depends on three main factors: education and communication to raise awareness of upcycling benefits, particularly through social media, then financial support through loans or funding to help businesses expand and network building by connecting with retailers to demonstrate sustainability advantages and encourage broader adoption. However, commercialisation remains a major challenge. For innovations in order to succeed in both developed and underdeveloped countries, it is essential to focus on data as well as technology. In these modern markets, smallholder farmers face difficulties in commercializing of products while ensuring food security is maintained throughout the supply chain. (Sung K. et al., 2017; Abeysiriwardana & Jayasinghe-Mudalige, 2025; Mutea et al., 2025).

In Future research, it should investigate how factors such as age, cultural background, and personal habits shape individuals' perceptions of upcycled foods. It is equally important to study how elements like diet, lifestyle, and technology use interact to influence consumer choices across different regions and generations. Researchers should also outline how diverse demographic groups react to the upcycling approaches, such as education, advocacy, and emotional messaging and examine the psychological effects of these strategies on consumer behaviour and their role in encouraging sustainable food practices. Moreover, exploring which platforms foster the most peer engagement, particularly in social media, is crucial for designing campaigns that can effectively reach a wide audience (Zhang et al., 2021) .

XVII. Conclusion

A large amount of food is wasted globally, and this loss affects both supply chains and the environment (Dou et al., 2024).Various food upcycling initiatives emphasize the need for policy support and the implementation of cost-effective strategies to achieve sustainability (Mlambo et al., 2023). Consumer trust in upcycled products increases when they are produced through sustainable methods, contribute to food waste reduction, remain affordable, and are promoted with effective marketing approaches (Mori & Seo, 2025). Evidence from the Cluj-Napoca project shows that upcycling can significantly lower carbon footprints through vendor collaborations and the use of some apps that can track emissions while fostering environmental awareness among consumers (Villacorta et al., 2024) Additionally, investigating new supply chain models and collaboration and innovation, along with AI-assisted technologies, can also play a vital role in lowering the energy demand of food waste pretreatment (Romsdal et al., 2024), (Lee et al., 2024) Lastly, Policy-relevant sustainability assessments should be carried out to support large-scale adoption (Chen et al., 2025).

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