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A classification of food products to enhance circular economy and reduce waste: A systematic literature review

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ABSTRACT

Along food supply chains, one-third of global food production is wasted annually: circular economy can be applied to prevent and recover food waste. The literature has explored food waste from many perspectives; however, no attention has been devoted to understanding how the intrinsic characteristics of food products influence food waste generation and valorization. This study proposes a classification of food products based on circular economy principles derived from a systematic literature review. The classification sheds light on how the intrinsic variability of food products influences food waste generation and recovery along the supply chain. The characteristics that drive differences in terms of food waste are identified by defining two product groups for each step of the chain (primary production: plant origin and animal origin; manufacturing: minimally processed and processed; distribution: ambient temperature and controlled temperature; retail: short shelf life and long shelf life). This stresses the intertwining of food waste with supply chain operations. Moreover, within the same supply chain stage, food waste causes and circular economy actions vary greatly depending on the product characteristics. The review also reveals how the most relevant causes within each product category correspond to a high relevance of practices addressing these causes. The adopted perspective represents a novel contribution to knowledge, providing a clear discussion of the variability of food waste along the supply chain and unveiling aspects requiring further research. From a practical standpoint, the classification can empower food industry actors to develop circular economy actions through an appropriate understanding of product characteristics.

1. Introduction

Wasted food accounts for one-third of global food production, responsible for environmental, social, and economic impacts (FAO, 2019b). Along food supply chains (SCs), 14 % of food is lost from post-harvesting up to retailing (FAO, 2019b), while 17 % becomes waste at the retail stage or during consumption, either in households or in food service (UNEP, 2021). In this work, all these flows will be described with the term “food waste”, encompassing all the food discarded along the SC, from primary production to retail. Food waste (FW) is estimated to be responsible for 8 % of all greenhouse gas emissions, and its value accounts for $940 billion in economic losses. Moreover, wasted food threatens food security: more than 700 million people are undernourished, and growth in the global population will intensify this problem (FAO, 2023). Reducing FW would enhance food availability and reduce the exploitation of natural resources. Several international policies have been developed to address FW, such as the Sustainable Development Goals of the United Nations, in particular, goal 12.3 (United Nations, 2015), the European Farm to Fork Strategy (European Commission, 2020b), or the European Circular Economy Action Plan (European Commission, 2020a).

These policies exemplify the relevance of the problem and put forward circular economy (CE) to tackle FW. Many definitions have been provided for the CE concept (Kirchherr et al., 2023); this study will adopt the conceptualization offered by the Ellen MacArthur Foundation in 2012, which helped increase the popularity of the concept. The 2012 report defines CE as “*an industrial system that is restorative and regenerative by intention and design",* juxtaposed to the linear conceptualization of industrial systems (Ellen MacArthur Foundation, 2012). In a CE, “*waste is food*” from which further value can be extracted to reduce waste generation (Ellen MacArthur Foundation, 2012). Therefore, it is clear how the tenets of CE can be applied to the food sector to address FW through its prevention or valorization, fostering the sustainability of the food sector (Formentini et al., 2021; Latino et al., 2024).

Recognizing the multifaceted nature of CE, it becomes imperative to involve the entire food SC in addressing the root causes of FW, as sources

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of waste are found from farm to fork (FAO, 2019b; Principato et al., 2019). More than half of FW in Europe is generated in primary production, manufacturing, distribution, and retail (Caldeira et al., 2019). These value-adding activities of the SC will be the focus of this study, which will not include considerations on FW generated at the consumer level since it would require specifically investigating consumers' behavior and its implications (Stancu et al., 2016).

While the literature has extensively explored FW from diverse perspectives, there remains a gap concerning how the intrinsic characteristics of different food products influence FW generation and valorization (Chauhan, 2021; Viscardi et al., 2022; Ögel et al., 2023). Existing studies often focus on a specific food group and fail to assess the complexity arising from the wide variety of existing food products (Chauhan, 2021). Moreover, food SCs can embed different dynamics depending on the product, potentially posing further difficulties when introducing CE practices (Kazancoglu et al., 2021).

By delving into these overlooked aspects, this study seeks to pave the way for mainstreaming CE within the food industry, empowering food industry actors to effectively embed FW prevention and recovery practices into their operations through an appropriate understanding of product characteristics. This study will address this gap by exploring how the intrinsic characteristics of food products influence FW causes and the related CE practices for prevention and recovery. The present study is guided by the following research question: *How do product characteristics influence circular economy for food waste prevention and valorization along food supply chains?* To reach the set objective, this study will propose a classification of food products based on CE principles derived from a comprehensive literature review. This classification seeks to shed light on how the intrinsic variability of food products influences FW generation and recovery practices throughout the SC. Such insights are novel in literature and hold promise for facilitating the integration of CE practices within food companies, offering detailed guidelines for FW prevention and valorization.

2. Methodology

This study adopts a systematic literature review approach, which is a suitable methodology since it allows the classification of existing studies according to key themes (Seuring et al., 2005). Moreover, systematizing the existing body of knowledge on the CE of FW through the lens of food products can highlight understudied aspects and propose a way forward for the development of the field (Tranfield et al., 2003; Kraus et al., 2022). Understanding the state of the art of this field is also relevant in practical terms since an easily understandable synthesis of existing knowledge can inform actions (Denyer and Tranfield, 2009). To fulfill these objectives, the literature review followed the steps recommended by Denyer and Tranfield (2009): definition of the scope of the review, studies location, and consequent evaluation and selection, followed by their analysis and synthesis, to finally report and use the results, according to a conceptual framework.

2.1. Scope definition

From the presented research question (i.e., "*How do product*

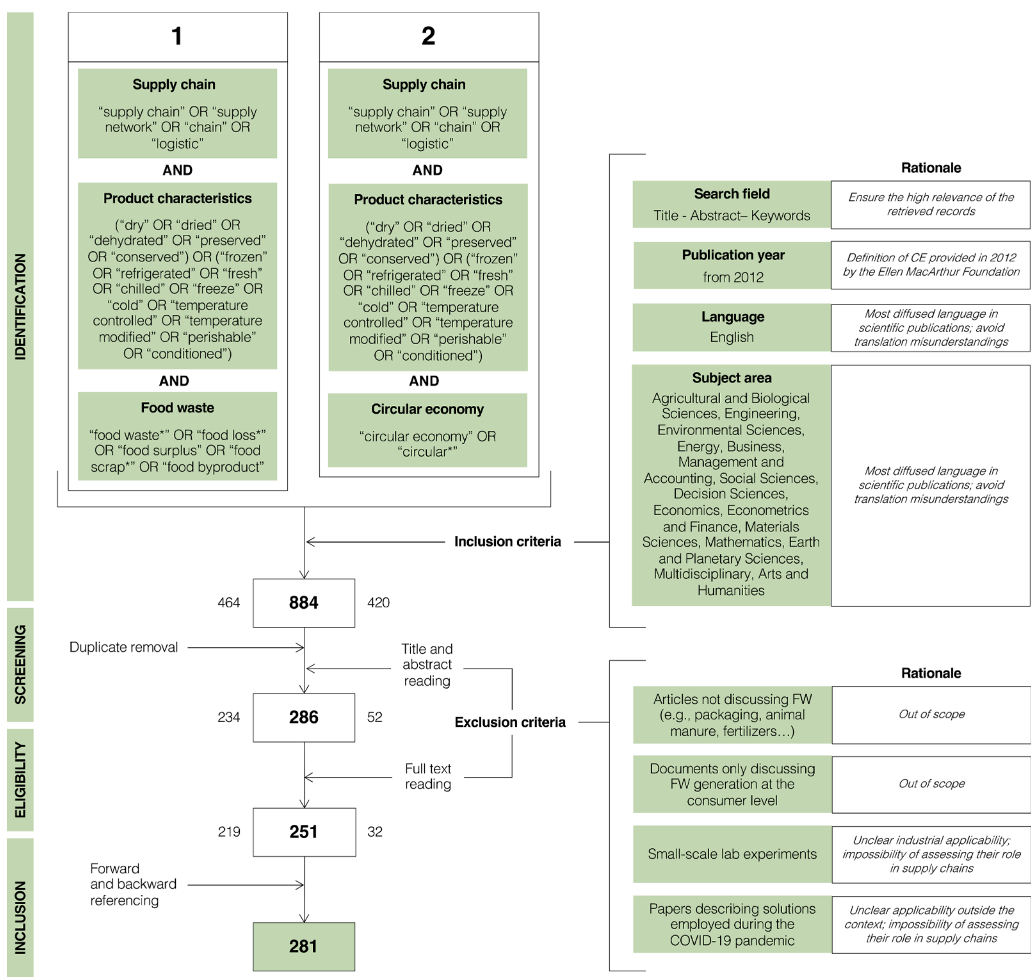

Fig. 1. PRISMA chart summarizing the systematic review of the literature, with details on the search strings and inclusion and exclusion criteria.

characteristics influence circular economy for food waste prevention and valorization along food supply chains?"), it is possible to identify four main elements: food waste, circular economy, product characteristics, and supply chains. Keywords were defined for each of these elements, as shown in Fig. 1. Regarding FW and SC, the chosen expressions were retrieved from literature to consider the multiple synonyms employed to describe these concepts (Chaboud, 2017). Only the term CE was selected for this topic to ensure consistency with the definition provided by the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2012). This implied not including keywords related to similar concepts (industrial ecology, R frameworks…), similar to what is done in most CE literature reviews (Ghisellini et al., 2016; De Angelis et al., 2018). The definition of the keywords regarding product characteristics required more consideration, as this element cannot introduce an a priori classification nor exclude certain food products from the analysis. A thorough consultation of the several available classifications of food products revealed their high granularity, fragmentation, and the non-existence of a unique categorization of food items. To overcome these limitations, the broad categorization presented by Bradford et al. (2018) is adopted. The author explains how food products require either a dry SC or a cold SC to be correctly preserved, distinguishing between products requiring controlled temperature or not. This perspective enables avoiding using more specific classifications that could introduce subjectivity in the search. Accordingly, keywords describing these different conditions were selected.

2.2. Studies location

The defined keywords were combined with Boolean operators to generate research strings (Fig. 1). Within each topic, the operator "OR" is used between the stated keywords; for product characteristics, the operator "OR" is used between the keywords describing the cold and dry chain. The topics "supply chain" and "product characteristics" are maintained in both strings, using the operator "AND", while the other areas are alternatively combined, generating two queries. This choice was guided by the need to include as many records as possible relevant to answering the research question (Denyer and Tranfield, 2009) since including both topics in a unique research string would have resulted in a much narrower set of retrieved articles. The search was conducted on the Scopus database. Scopus offers a more comprehensive journal coverage with respect to the Web of Science database in the fields of interest for the present research (Mongeon and Paul-Hus, 2016). These considerations are also valid for PubMed, which includes journals in the field of medicine and life sciences. Therefore, using the Scopus database could ensure a high relevance of the retrieved records.

2.3. Studies selection and evaluation

Inclusion criteria were employed during the document retrieval from the Scopus database and posed restrictions on the search field, publication year, language, and subject area (Fig. 1). The database search, conducted in December 2023, led to the identification of 884 articles. Well-defined exclusion criteria guided the selection of the articles to be included in the final sample. The definition of inclusion and exclusion criteria is crucial to ensure the review is based on high-quality evidence; therefore, their definition must be well-reasoned and justified, as detailed in Fig. 1 (Tranfield et al., 2003). For example, the choice of limiting the search to papers in English is related to its diffusion in scientific literature, as well-reputed scientific journals are edited in English. Hence, the language restriction is posed to ensure the quality of retrieved records. While potentially skewing the results of the review, all inclusion and exclusion criteria were carefully defined with the aim of guaranteeing high standards in the paper selection. The removal of duplicates and the title and abstract screening restricted the sample to 286 papers. These were further screened by means of full-text reading, narrowing the sample to 251 records. After defining the eligible articles, forward and backward referencing was employed to ensure the inclusion of all important publications. This systematic procedure, summarized in Fig. 1, led to the definition of a final sample of 281 records.

2.4. Studies analysis and synthesis

The analysis of the retrieved papers followed a qualitative approach, thanks to a thorough assessment of the content of each record. This procedure, which led to the proposal of a novel classification of food products, is summarized in Fig. 2 and described in greater detail below.

In the first cycle of coding, attribute coding was employed to gather, for each article, descriptive information regarding the discussed food products and SC stages (Saldaña, 2013).

The mapped causes and CE practices were further analyzed with a second cycle of coding. This further analysis aimed at grouping similar codes to create coherent and homogeneous categories, presented in the tables in Fig. 2 (Saldaña, 2013). Cause categories were derived following an inductive analysis of the coded causes. An abductive approach was followed for CE practices since the FW hierarchy inspired the created categories. The FW hierarchy is a conceptual framework ranking the strategies to prevent and manage FW from most to least preferred (Papargyropoulou et al., 2014; Teigiserova et al., 2020). At the top is prevention, followed by reuse for human or animal consumption. When not possible, the framework suggests either recycling, the extraction of nutrients, or the use for energy recovery. At the bottom is disposal, which should always be avoided (Papargyropoulou et al., 2014; Teigiserova et al., 2020). This framework has gained recognition by both academics and practitioners. Hence, following a similar structure in the coding can help fit this study in the broader discourse on this topic.

This two-step coding procedure enabled mapping the products discussed in relation to FW causes and CE practices along the whole SC. These data have been crucial for defining a classification of food products in light of CE. This framework was built through the inductive analysis of the retrieved information. An inductive approach is appropriate to build this novel classification, since many food product classifications are available (e.g., EFSA (2015); FAO (2019a)), but none specifically built for the purpose of isolating the elements that influence the generation of FW and its recovery. An inductive analysis is one where "*the researcher begins with an area of study and allows the theory to emerge from the data*" (Strauss and Corbin, 1990). Inductively analyzing results enables findings to arise from the data and not from expectations or pre-determined models (Thomas, 2006). The thorough analysis of papers led to the identification of the factors that mostly influence FW, as discussed in greater detail in the following paragraphs. These were then combined to build the final proposed classification. Developing a model or framework containing the main identified themes is a common output of inductive research (Thomas, 2006).

3. Results

3.1. The proposed classification of food products from a CE perspective

The first relevant element emerging from the inductive analysis is the relevance of the SC stage in defining food characteristics, since a characteristic can be relevant in certain SC stages and less important in others. As further detailed below, FW causes and CE practices strongly depend on the operations carried out at each stage of the SC. This evidence led to the inclusion of the SC aspect in the proposed classification. More specifically, the descriptive codes defined during coding were harmonized to fall within one of these four categories: *primary production, manufacturing, distribution*, and *retail*. These categories represent the simplest food SC, and several literature contributions suggest a similar grouping (e.g., Caldeira et al. (2019); FAO (2019b); Delgado et al. (2021)). *Primary production* includes harvesting, breeding, fishing, and related activities to procure raw materials, which are processed and packed during *manufacturing. Distribution* involves warehousing and

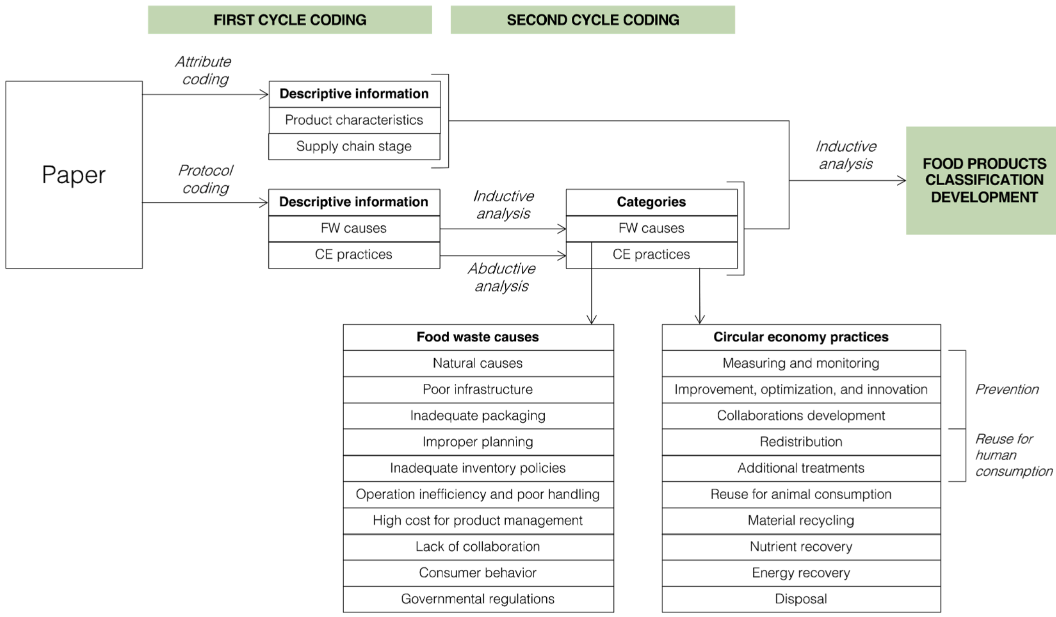

Fig. 2. Methodology summary and codes categories.

transportation activities, while *retail* considers the selling of food products (FAO, 2019b; Delgado et al., 2021). These categories constitute the first dimension of the proposed classification, as shown in Fig. 3.

The varying relevance of a certain characteristic along the SC prompted the definition of different characteristics for each SC stage. For primary production, the main differences arise between products of *plant origin* and *animal origin*; at manufacturing, *minimally processed* and *processed* foods strongly differ in terms of FW generation and management. During distribution, foods transported or stored at *ambient temperature* or *controlled temperature* present significant differences, while at the retailing stage, products with *short shelf life* or *long shelf life* are notably different (Fig. 3). To ensure the proper definition of boundaries for each category, scientific papers and international guidelines have been consulted. The *plant origin* category includes products based on fruit, vegetables, cereals, legumes, nuts, or seeds. Instead, *animal origin* products are those foods that contain dairy, meat, seafood, or eggs (Day et al., 2022). *Plant origin* products appear to be more subject to FW causes, and more CE practices are available for prevention and recovery. These mainly focus on improving crops and infrastructures and on the introduction of new technologies. Regarding the manufacturing stage, many food classifications exist that embed considerations on the level of product processing, often used in specific regions or countries (Moubarac et al., 2014). To ensure a broader generalizability, the NOVA classification system has been consulted, which has global validity for industrially produced food items (Monteiro et al., 2018, 2019). Following the NOVA food groups, the *minimally processed* category overlaps with “Unprocessed or minimally processed foods”, while the *processed* category contains “Processed culinary ingredients”, “Processed foods”, and “Ultra-processed foods” (Monteiro et al., 2018). The generation of FW for *minimally processed* items is mostly linked to the removal of inedible parts, which is less relevant for *processed* food. The prevention of FW regarding this latter category can, for example, be achieved through shelf-life extension, which is not available for *minimally processed* food. Regarding distribution, the *ambient temperature* category includes all those food items that do not require a modified temperature to be correctly preserved; on the other hand, *controlled temperature* groups all products conserved at a modified temperature with respect to the ambient one (exotic chilled, medium chill, cold chill, and frozen products) (Gustafsson et al., 2006). This characteristic makes these products more susceptible to the generation of FW. Accordingly, CE practices mostly focus on enhancing the reliability of the cold chain. At the retailing stage, the attention is put on the products’ shelf life, defined by the Codex Alimentarius as: “*The period during which the product maintains its microbiological safety and sensory qualities at a specific storage temperature*” (FAO, 1999). Perishable products, whose shelf life is defined by a “use by” date, fall within the *short shelf life* category, whereas food items labeled with a “best before date” are considered to belong to the *long shelf life* category (Priefer et al., 2016). This distinction underlines how *long shelf life* products are mainly recovered through donations, whereas CE practices for *short shelf life* ones focus on prevention practices.

The combination of the identified dimensions into the final proposed classification is shown in Fig. 4. The classification considers the SC stage and the product characteristics within each stage, leading to the definition of sixteen possible combinations, represented in the figure by different branches. These typologies arise since a product of *plant* or *animal origin* can be *processed* or *minimally processed*, then stored and transported at *ambient* or *controlled temperature*, and have a *long* or *short shelf life*. The combination of these characteristics can be employed to describe any food product while highlighting the characteristics that mostly influence the generation and recovery of FW.

To ensure each of these sixteen combinations represents an existing food product, the classification is validated by comparing it with the food classification proposed by the Codex Alimentarius. The Codex Alimentarius is supported by FAO and the World Health Organization and is a collection of internationally adopted food standards (FAO,

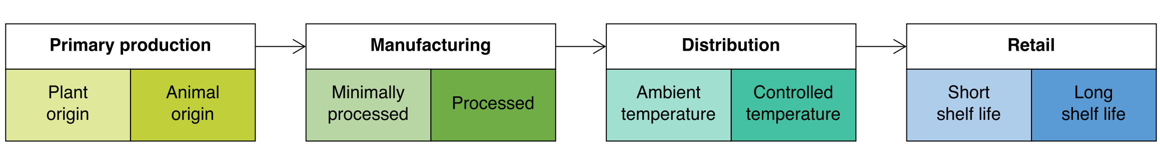

Fig. 3. Categories of food products identified for each SC category.

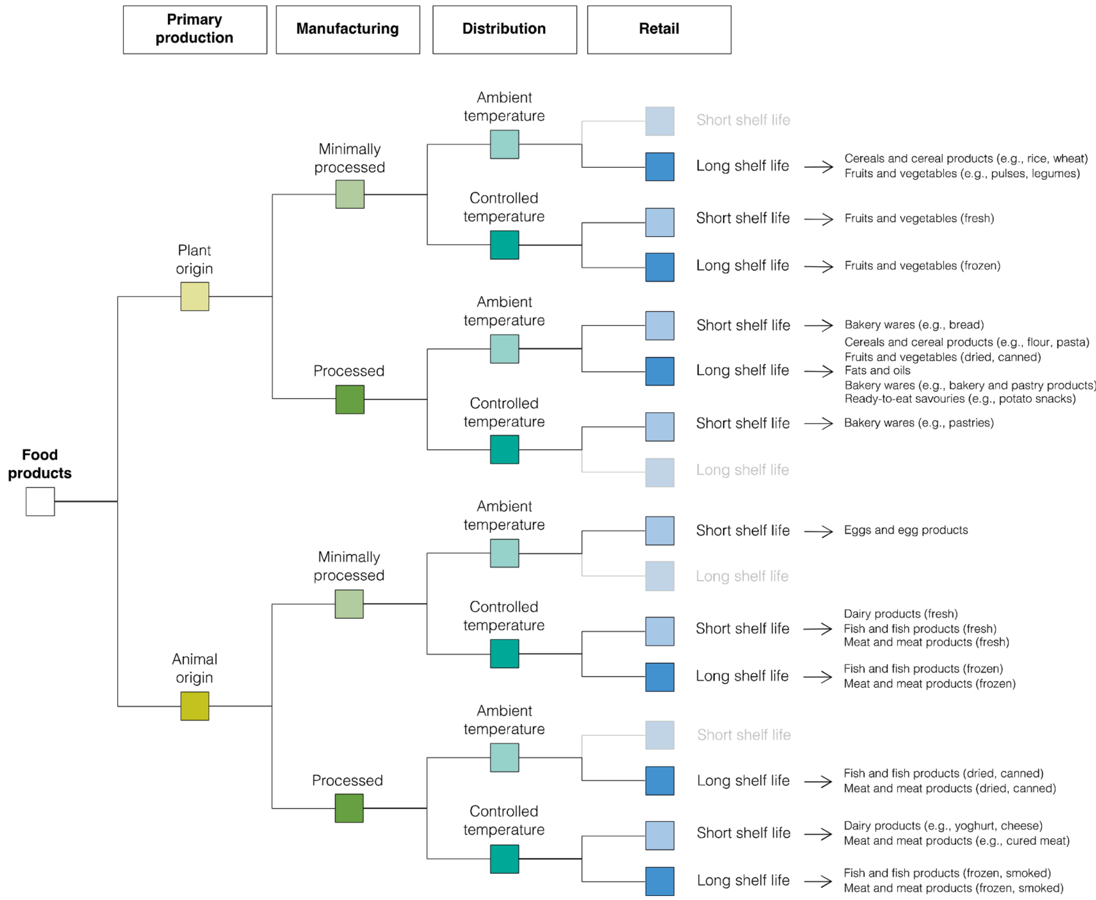

Fig. 4. Proposed classification of food products from a CE perspective. On the right, each branch is associated with one or more Codex Alimentarius categories: blurred branches do not represent any food product and are excluded from the framework.

2024). The Codex Alimentarius proposes a categorization of food products (FAO, 2019a), and each Codex category is associated with one or more of the branches of the developed classification. For example, frozen whole fish is of animal origin, minimally processed, distributed at a controlled temperature, and has a long shelf life. All Codex categories are portrayed in the classification, testifying its completeness and versatility in describing the wide variety of existing food products. During the analysis, four branches were not matched to any Codex category (blurred in Fig. 4); these are removed from the classification, resulting in twelve possible combinations.

3.2. Descriptive analysis

The developed classification framework is useful for describing the paper sample (Fig. 5). Starting from the SC stages considered in the papers, it is possible to note an almost equal distribution of documents across the four stages, with more attention devoted to distribution and retail. This finding can be enriched by assessing how many stages are considered in each paper. Most documents focus on the description of just one SC activity, with a very small portion of articles adopting a SC perspective and describing all stages.

On the other hand, Fig. 5 also reports the distribution of articles across the identified product categories. Products of *plant origin* are discussed far more than those of *animal origin*. Documents are more evenly distributed across the *minimally processed* and *processed* categories, while at the distribution stage, most papers focus on products requiring *controlled temperatures*. A skewed distribution is also found in the retail stage, where most documents discuss products with a *short shelf life*, and only a small portion focuses on those with a *long shelf life*.

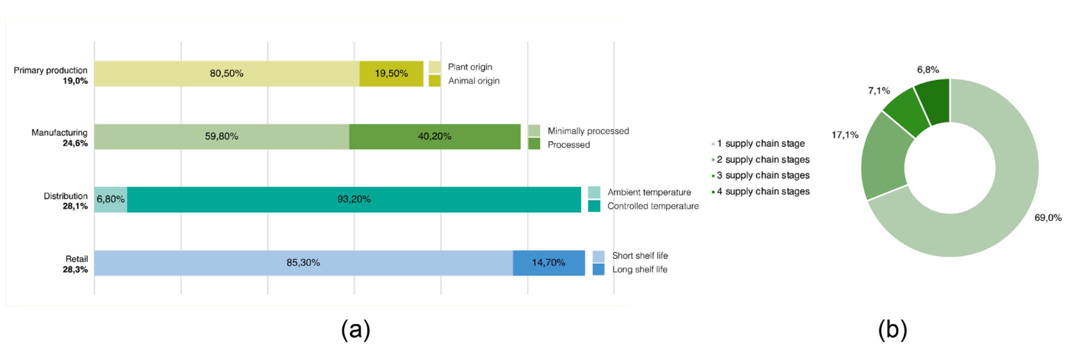

Fig. 5. Descriptive analysis of the paper sample: distribution across (a) SC stages and food categories and (b) number of considered SC stages.

3.3. Content analysis

3.3.1. Causes

Fig. 6 summarizes the identified FW causes with respect to the proposed product classification and their occurrence in the paper sample.

Natural causes are widely discussed and are found across the whole SC. At primary production, these are particularly relevant for products of *plant origin*, which can be subjected to damage due to weather conditions (precipitations, temperature) (Goffart et al., 2022; Rahman et al., 2022) or due to pest and fungus infestation and diseases (Bradford et al., 2018; Blanckenberg et al., 2021). These products can also be wasted if harvested when unripe or too mature (Cardoso et al., 2021; Santos, D., et al., 2022). *Animal origin* products are less affected by natural causes, which occur in the case of animal deaths or coincide with fish by-catches (Xue et al., 2019; Cooney et al., 2023). Natural causes are even more relevant during manufacturing due to the removal of inedible fractions or uncommonly eaten parts such as guts (Raak et al., 2017). Unexpectedly, *minimally processed* products are mostly affected by this cause, linked to the separation of inedible parts or the generation of scraps from cleaning and processing to obtain the target product (Akanbi et al., 2020; Skendi et al., 2020; Jones et al., 2021). These scraps can represent a significant portion of the raw material (25 %−70 %) depending on the considered food (Bandekar et al., 2022; Markowska et al., 2022; Hassoun et al., 2023). When operations are not optimized this share can increase due to the unintended removal of valuable portions of the product (Alao et al., 2017). *Processed* foodstuffs are less affected by this cause as *minimally processed* products are used as input in their manufacturing, leading to smaller quantities of by-products and greater variability in nature and composition (Esparza et al., 2020; Selvaggi et al., 2021; Gómez and Martinez, 2023). Natural causes also affect foodstuff during distribution activities, especially for goods requiring *controlled temperature*. This category of food products can be damaged if inadequate temperatures are used during storage and transportation, leading to modifications in the food matrix and the rapid growth of microorganisms (Duret et al., 2019; Hu et al., 2019; Turan and Ozturkoglu, 2022). Food can be damaged during storage due to the succession of seasons and temperature conditions (Badia-Melis et al., 2018; Mercier et al., 2018). Food products stored at *ambient temperature* are instead more susceptible to infestations and molds, especially in humid climates (Kostyukovsky et al., 2016; Bradford et al., 2018). Lastly, at the retail stage, loss of freshness is the main natural cause leading to the generation of FW, especially affecting *short shelf life* products. Contaminations and microorganism growth can enhance natural degradation due to sub-optimal environmental parameters (Trento et al., 2021; Silapeux et al., 2021).

Poor infrastructure can be a source of FW, especially downstream in the SC. At distribution, products requiring *controlled temperature* transportation are more affected by this FW cause, as the absence or inadequacy of cold transportation leads to deterioration (Raut et al., 2019; Kale et al., 2021; Thi et al., 2022). The use of conventional modes of transport with improvised cooling systems or refrigerated vehicles in poor conditions represents a cause of FW (Lipińska et al., 2019; Saengsathien et al., 2023). Similarly, facilities required to correctly store these products are often lacking or inappropriate in developing countries (Lima et al., 2022; Turan and Ozturkoglu, 2022). Moreover, even with adequate infrastructure, the inability to monitor temperatures during storage and distribution can cause FW (Badia-Melis et al., 2018; Shoji et al., 2022). The limited use of sensors or the lack of real-time measuring hampers the understanding of the real temperature distributions and the identification of weak points along the cold chain (Mangla et al., 2019; You et al., 2023). Products stored at *ambient temperature* are easier to manage but require facilities able to prevent exposure to sunlight and moisture, which are not always available in developing countries (Surucu-Balci and Tuna, 2021). Products may be transported using open vehicles, exposing them to light and heat (Gogo et al., 2017; Wigati et al., 2019). Similar conditions can cause FW for retailers, especially regarding products with a *short shelf life* (de Moraes et al., 2020; Ögel, Ecer and Özgöz, 2023).

Inadequate packaging is a cause of FW that is more relevant downstream in the SC. At the distribution stage, inappropriate and traditional packaging can cause a moisture content increase in *ambient temperature* goods, enabling fungal growth and insect damage (Bradford et al., 2018; Poudel et al., 2020). For food requiring *controlled temperature*, incorrect packaging design can cause slow and inefficient cooling, affecting the product quality over time (Wu et al., 2019). For both product categories, using packages of improper size or the absence of protective materials can lead to mechanical damage (Negi and Anand, 2019; Agnusdei et al., 2022). At the retail stage in developing countries, food with a *short shelf life* is likely to become waste if displayed in traditional containers that are unable to protect the product (Silapeux et al., 2021). In developed countries, the use of packaging prone to deformation constitutes a relevant cause of FW for both product categories.

Improper planning is especially relevant at the primary production stage for products of *plant origin*. Farmers often lack or cannot access market information, which usually leads to overproduction and the consequent wastage of products exceeding demand (Hernández-Cruz et al., 2021, 2022; Dong et al., 2022). Moreover, due to their low bargaining power, farmers attempt to manage risks by producing surplus quantities of fresh produce, which exceed demand and will consequently be wasted despite being edible (Ludwig-Ohm et al., 2019; Meagher et al., 2020). The concerns that lead to overproduction are related to the need to compensate for unexpected losses, ensure compliance with quality standards, and avoid contractual penalties (Raak et al., 2017). This cause gains relevance at the retailer stage for *short shelf life* products, in terms of overstocking due to the variability of consumers' purchasing habits, who can switch to substitute products or postpone the purchase (Weaver and Moon, 2018; Luiz Reni Trento et al., 2021). In this context, orders placed without decision support software can enhance the magnitude of this FW cause (Seubert et al., 2020).

At the distribution stage, **inadequate inventory policies** mainly cause FW for products stored at *controlled temperatures* due to poor inventory rotation and stock aging (Satiti and Rusdiansyah, 2018; Turan and Ozturkoglu, 2022). The First In, First Out (FIFO) policy is widely adopted in the management of stocks. However, it is often linked to FW generation since it does not consider the perishability of the product or its deterioration (Mendes et al., 2020; Akkaş and Honhon, 2022). At retailers, waste is generated for *short shelf life* products due to poor stock rotation, for example, by disregarding the FIFO principle (Buisman et al., 2019; Pikora et al., 2021). This condition can be exacerbated by overstocking, a commonly implemented practice to maintain high on-shelf availability and increase customer satisfaction (Akkaş, 2019; Riesenegger and Hübner, 2022).

FW related to **operation inefficiency and poor handling** is generated across the whole SC but is most relevant at the distribution stage. At primary production, products of *plant origin* are most affected by this cause, which is related to mechanical damage due to careless handling, often associated with the absence of skilled labor and adequate equipment, especially in developing countries (Gogo et al., 2017; Singh et al., 2023). Damaging products implies quality losses and potential safety concerns due to microorganism contamination (Tröger et al., 2020; Goffart et al., 2022). *Animal origin* products are threatened mainly by poor hygienic and sanitation practices (Sawaya, 2017). During manufacturing, both product categories appear equally affected by this cause: machine failures, blackouts, human errors, foreign body contaminations, and set-up mistakes influence FW generation, and its magnitude can be greater for *processed* products that undergo more manufacturing stages (Raak et al., 2017; Eičaitė et al., 2023; Facchini et al., 2023). Concerning distribution, *ambient* and *controlled temperature* products can both be subject to poor handling during picking and loading/unloading activities, possibly causing mechanical damage due to overloading and incorrect stacking (Tostivint et al., 2017;

	Primary production		Manufacturing		Distribution		Retail	
	Plant origin	Animal origin	Minimally processed	Processed	Ambient temperature	Controlled temperature	Short shelf life	Long shelf life
Natural causes	36	8	48	25	4	22	25	4
Poor infrastructures	8	4		3	3	36	16	4
Inadequate packaging	4		2	2	2	10	17	6
Improper planning	11	3		2		5	9	
Inadequate inventory policies				2	1	11	28	6
Operation inefficiency and poor handling	17	4	12	12	2	59	35	6
High cost for product management	2		2			8	2	
Lack of collaboration	4		2	1		9	6	
Consumer behavior	22	6	6	7		2	34	9
Governmental regulations	12					7	39	7

(a)

	Primary production		Manufacturing		Distribution		Retail	
	Plant origin	Animal origin	Minimally processed	Processed	Ambient temperature	Controlled temperature	Short shelf life	Long shelf life
Natural causes	• Incorrect harvesting time • Microbial growth, pests, diseases • Weather conditions	• By-catches • Diseases, deaths	• Raw material contamination (microbial) • Removal of edible and inedible portions during processing	• Removal of edible and inedible portions during processing	• Infestations, microbial growth • Weather conditions	• Inadequate temperatures • Infestations, microbial growth • Weather conditions	• Improper environmental conditions • Infestations, microbial growth • Weather conditions	• Infestation, microbial growth • Weather conditions
Poor infrastructures	• Inadequate post-harvest transportation and storage practices	• Inadequate storage practices		• Inadequate processing temperature monitoring	• Inadequate infrastructures (vehicles, storage facilities) • Poor road conditions	• Absent or inadequate cold chain infrastructures (vehicles, storage facilities) • Improper temperature measuring and monitoring • Non-optimal routing	• Inadequate infrastructures (storage facilities)	• Inadequate infrastructures (storage facilities)
Inadequate packaging	• Packaging unable to protect the products		• Defective packaging	• Defective packaging	• Improper packaging material	• Dirty packaging • Improper packaging material • Incorrect packaging design	• Improper packaging material • Packaging unable to protect the products	• Easily damageable packaging
Improper planning	• Lack of demand information • Overproduction	• Lack of demand information • Overproduction		• Lack of demand information • Overproduction		• Inaccurate demand forecasting • Overstocking	• Inaccurate demand forecasting and seasonality • Overstocking • Unsuccessful promotions	
Inadequate inventory policies				• Overstocking	• Inventory aging	• Inventory aging • Inventory policies independent from expiry dates • Poor inventory rotation	• Poor inventory rotation • Shelf overstocking	• Poor inventory rotation • Shelf overstocking
Operation inefficiency and poor handling	• Careless and improper handling (by staff) • Inappropriate equipment • Lack of skilled personnel	• Careless handling (by staff) • Poor hygienic conditions	• Inappropriate equipment • Machinery mistakes and failures • Personnel inaccuracy and mistakes • Product contamination (physical, biological)	• Inappropriate equipment • Machinery mistakes and failures • Personnel inaccuracy and mistakes • Product contamination (physical, biological)	• Careless handling (by staff) • Transportation delays	• Careless and improper handling (by staff) • Cold chain breaks • Improper temperature control or failures • Inadequate stacking and storage practices • Prolonged loading and unloading operations • Transportation delays	• Careless and improper handling (by staff and consumers) • Inadequate stacking and storage practices • Prolonged unloading operations • Temperature fluctuations and heterogeneity	• Careless and improper handling (by staff and consumers) • Inadequate stacking and storage practices
High cost for product management	• Low value of wasted produce with respect to recovery cost		• Low value of by-products with respect to recovery cost			• High cost of cold chain infrastructures	• High cost of cold chain infrastructures • Low value of wasted products with respect to recovery cost	
Lack of collaboration	• Absence of horizontal collaboration between farmers		• Retailer requirements on residual shelf life	• Retailer requirements on residual shelf life		• Lack of coordination between cold chain partners	• Enforcement of take-back agreements	
Consumer behavior	• Impossibility of selling visually imperfect products	• Impossibility of selling visually imperfect products	• Impossibility of selling visually imperfect products	• Impossibility of selling visually imperfect products		• Rejected deliveries due to small product defects	• Fastly evolving consumer preferences • Impossibility of selling visually imperfect or damaged products • Purchase of products with longer remaining shelf life	• Impossibility of selling damaged products
Governmental regulations	• Strict specifications on produce appearance					• Low enforcement of cold chain regulations	• Strict regulations on use-by dates • Strict specifications on product appearance	• Strict regulations on best-before dates

(b)

Fig. 6. FW causes according to the proposed product classification: (a) occurrence - the reported numbers refer to the number of papers mentioning the cause, (b) detail on FW causes.

Becerra-Sanchez and Taylor, 2021; Negi and Trivedi, 2021; Shewfelt and Prussia, 2021). Inefficiencies can also be related to long lead times, where transportation delays due to road traffic or prolonged unloading waiting times can cause a deterioration of the products, especially for *controlled temperature* transportation (Mercier et al., 2018; Mangla et al., 2019; Surucu-Balci and Tuna, 2021). Flight delays, long port waiting times, routing changes, and prolonged shipments can impact the journey duration of food products, with potentially detrimental consequences on their shelf life at delivery (Ndraha et al., 2020; Negi and Trivedi, 2021; Onwude et al., 2022). Additionally, *controlled temperature* products may be subject to temperature abuse (i.e., a deviation from the optimal storage temperature), which can cause food deterioration (Ndraha et al., 2018). Such events can be linked to refrigeration faults, wrong pallet positioning, or long loading/unloading operations leading to extended open-door time (Jedermann et al., 2014; Loisel et al., 2021; Steynberg et al., 2022). Similar conditions can be found at the retailer stage, where temperature abuse can be associated with a wrong product positioning or the penetration of ambient air in refrigerated shelves (Göransson et al., 2018; Ögel et al., 2023). Products characterized by both a *long* or *short shelf life* can be subject to damages due to inadequate or excessive handling by employees or customers (Liu et al., 2022; Mattsson and Williams, 2022).

High cost for product management is a cause of FW that is not widely discussed in the literature but can have implications in the development of CE. At primary production, this is found exclusively for *plant origin* products, especially in developing countries: low value produce and agricultural residues are often discarded because their recovery would be too expensive, despite being useful from a CE perspective (Wigati et al., 2019; Bolaji et al., 2021). Similarly, scraps derived from the manufacturing of *minimally processed* products can be discarded if market conditions make the recovery of such materials not economically sustainable (Bolaji et al., 2021; Selvaggi et al., 2021). During distribution, this cause of FW only emerged for *controlled temperature* products in developing countries. In this context, the cold chain is perceived as a cost rather than an added value for the product (Yan et al., 2021; Thi et al., 2022).

A **lack of collaboration** in the SC can lead to the generation of FW. In primary production, this is found for *plant origin* products and mainly relates to a lack of horizontal collaboration among farmers (Tröger et al., 2020; Esteso et al., 2022). This can lead to improper crop planning, often associated with overproduction, which becomes more prominent when farmers are also isolated from the downstream portion of the SC (Kumar et al., 2020; Herzberg et al., 2022). At the manufacturing stage, this cause is related to the relationship with retailers, which is not collaborative as the downstream actor is in a stronger bargaining position. Retailers often impose a "*Minimum Life on Receipt*", which is the minimum product's shelf life to deliver to the retailer, usually set at 2/3 of the shelf life (Santos et al., 2022). This rule applies to all products, meaning that *long shelf life* products cannot be placed on the market even years before expiration (De Boeck et al., 2017; Raak et al., 2017). The lack of collaboration among cold chain partners at the transportation stage can cause temperature abuse due to low coordination between transportation and warehousing activities (Onggo et al., 2019; Yan et al., 2021). Retailers often apply take-back agreements to products with *short shelf life*: with this practice, unsold expired items are returned to the supplier, who must take care of this FW (Trento et al., 2021). This practice entails a burden shift: waste generated by retailers is passed upstream, potentially hiding the true location of this FW hotspot (Eriksson et al., 2017).

Despite only retailers being in contact with final consumers, **consumer behavior** is a cause of FW that has effects even upstream in the SC. The consumption stage is beyond the scope of this paper; however, the produced food is destined for consumers, and their preferences and conduct influence the behavior of SC actors. This is found to be a relevant cause of FW generation, as waste is produced in an attempt to satisfy consumers' preferences. At the retailer output, consumers also directly influence FW generation due to behaviors adopted at the point of sale. Starting from primary production, *plant origin* products are subject to strict esthetic specifications imposed by other SC actors in response to consumers' preferences (Ludwig-Ohm et al., 2019; de Vasconcelos et al., 2021). Products are inspected at harvesting: if not compliant with color, shape, or size requirements, they are discarded (de Brito Nogueira et al., 2020; Ali et al., 2021). These requests are frequently associated with the willingness of retailers to present consumers with cosmetically perfect products since small defects could result in a missed sale (de Hooge et al., 2018). Similarly, manufacturers of both *minimally processed* and *processed* goods can incur product rejections if visual quality targets set by retailers are not met, for example, when a raw material variation leads to a different visual appearance (Raak et al., 2017; Eičaitė et al., 2023). This cause is extremely relevant for retailers: consumers first evaluate products' appearance, meaning damaged or imperfect products with both *short* and *long shelf life* are left on the shelves (I. Esparza et al., 2020; Somkun, 2020). An additional cause is found for *short shelf life* products at this stage, where consumers tend to select fresher products, leaving on the shelves those with a shorter residual shelf life (Akkaş and Honhon, 2022; Santos et al., 2022).

Governmental regulations are extremely relevant for *plant origin* products, which in developed countries are subject to standards regarding their appearance (Blanckenberg et al., 2022). In Europe, several regulations exist that specify cosmetic-centered criteria for commercializing agricultural products, leading to wasting malformed and undersized products with good nutritional characteristics (Blanke, 2015; Porter et al., 2018). Some of these criteria have been removed over the years, but strict cosmetic specifications are still enforced in the SC, as detailed above (de Hooge et al., 2018). Conversely, developing countries often do not have regulations regarding the distribution of *controlled temperature* food: the weak enforcement of the cold chain is a prime cause of FW in these contexts (Chauhan, 2021; Yan et al., 2021). At the retailer outlet, this cause is considerably relevant for *short shelf life* products, which may expire on the shelves and must be removed from the market (Sundgren, 2020; Lin and Januardi, 2023). Expired products constitute 15 % of the waste generated at this stage, and while this constitutes a matter of food safety, regulations on expiry dates are often perceived as strict (De Moraes et al., 2020; Santos et al., 2022).

3.3.2. CE practices

Fig. 7 summarizes the identified CE practices with respect to the proposed product classification and their occurrence in the paper sample.

Prevention practices include a broad set of actions, which have been grouped into three categories (i.e., "measuring and monitoring", "improvement, optimization and innovation", and "collaborations development"), discussed in greater detail in the following paragraphs. In general, it emerges how prevention strategies are mostly implemented at the distribution and retail stages for *controlled temperature* and *short shelf life* products. Other examples can be found all along the SC, especially for *plant origin* products at the harvesting stage.

Measuring and monitoring can be effective FW prevention practices, which may entail using digital technologies and 4.0 solutions to gather and analyze data. At harvesting, for *plant origin* products, these technologies can be employed to reduce overproduction by predicting crop yield and generating automated forecasting models, overall bridging the gap between farmers and the market (Majluf-Manzur et al., 2021; Hernández-Cruz et al., 2022). Such tools can also gather and analyze weather data, detect diseases, and determine optimal harvesting times (Villalobos et al., 2019; Pallathadka et al., 2022). For both *processed* and *minimally processed* goods, at the manufacturing stage, better measuring and monitoring FW can help determine where to intervene for its reduction (Eičaitė et al., 2023). When smart technologies are used, it is also possible to improve quality controls, automatically detect failures, provide real-time monitoring of products' condition, and generally improve operations (Tagarakis et al., 2021; Ramirez-Asis

		Primary production		Manufacturing		Distribution		Retail	
		Plant origin	Animal origin	Minimally processed	Processed	Ambient temperature	Controlled temperature	Short shelf life	Long shelf life
Prevention	Measuring and monitoring	9	1	7	4	2	70	17	1
	Improvement, optimization, and innovation	27	6	17	17	3	60	57	4
	Collaborations development	12		4	3		20	14	1
Reuse for human consumption	Redistribution	7	2	7	7	2	4	31	9
	Additional treatments	9	1	19	13		2	10	
	Reuse for animal consumption	16	3	28	17	1	2	15	4
	Material recycling	4	1	25	5				
	Nutrient recovery	15	2	17	11	1	2	9	2
	Energy recovery	6		23	11		1	8	2
	Disposal	6	3	11	6	3	7	16	3

(a)

		Primary production		Manufacturing		Distribution		Retail	
		Plant origin	Animal origin	Minimally processed	Processed	Ambient temperature	Controlled temperature	Short shelf life	Long shelf life
Prevention	Measuring and monitoring	• Digital and 4.0 technologies for disease detection, weather monitoring, optimized planning and harvesting, crop yield prediction	• 4.0 technologies for disease detection, weather monitoring, dietary strategies	• Digital and 4.0 technologies for temperature monitoring, automated failure detection and quality inspections • Waste flows measuring to set reduction targets	• Digital and 4.0 technologies for temperature and humidity monitoring, automated failure detection and quality inspections • Waste flows measuring to set reduction targets	• Electronic meters or indicator strips measuring humidity, moisture content, and temperature	• Digital and 4.0 technologies for temperature monitoring and management, quality prediction, cold chain interruption detection, gas concentration assessment, and product temperature and quality evolution simulation • Intelligent packaging and containers for dynamic expiry dates	• Digital and 4.0 technologies for temperature and humidity monitoring of displayed products, traceability, dynamic expiry dates and prices • Intelligent packaging for dynamic expiry dates and spoilage detection • Waste flows measuring	• Intelligent packaging for dynamic expiry dates
	Improvement, optimization, and innovation	• Crops biofortification • Farmers education and training • Improved infrastructures (post-harvest facilities, roads, transportation means) • Improved packaging for better protection and temperature control • Mechanization, new tools, technologies, and practices during harvesting • Sanitation and high hygiene standards	• Improved packaging for better protection and temperature control • New tools and technologies	• Improved packaging for optimized portions and shelf life extension • Optimization of planning, production, maintenance, and inventory management • Staff training	• Improved packaging for optimized portions • Location of plants near farms • New machinery and technologies • Optimization of planning, production, maintenance, and inventory management • Shelf life extension (new or additional ingredients, new processing techniques) • Staff training	• Improved packaging to prevent moisture infiltration and microbial growth	• Improved infrastructures (refrigerated facilities and vehicles, roads, new equipment) • Improved packaging for better protection and shelf life extension • Optimized storage (policies considering shelf life, dynamic shelf life prediction), transportation (distance, vehicle, outsourcing), and facility location • Staff training	• Adequate store density • Consumer education • Improved demand planning and ordering decisions • Improved infrastructures (enclosed, refrigerated display) • Improved packaging for shelf life extension • Optimized pricing policies (discounts for almost expired or ugly products, dynamic pricing based on residual shelf life) and storage (shelf space allocation, policies considering shelf life) • Staff training	• Improved packaging for shelf life extension and better product visibility
	Collaborations development	• Horizontal collaboration • Vertical collaboration (short supply chains)		• Vertical collaboration (flexible minimum life on receipt with retailers, contract farming with farmers)	• Vertical collaboration (flexible minimum life on receipt with retailers, contract farming with farmers)		• Horizontal collaboration (facilities sharing, optimized shipments) • Vertical collaboration (optimized shipments)	• Vertical collaboration (collaborative forecasting, data sharing on product shelf life, flexible minimum shelf life on receipt)	• Vertical collaboration (flexible minimum shelf life on receipt)
Reuse for human consumption	Redistribution	• Donation of surplus or ugly products	• Donation	• Donation of ugly, damaged, wrongly labeled, or almost expired products • Selling of surplus or almost expired products (to secondary markets or employees)	• Donation of ugly, damaged, wrongly labeled, or almost expired products • Selling of surplus or almost expired products (to secondary markets or employees)	• Donation of almost expired products	• Donation of almost expired products	• Donation of almost expired or surplus products • Selling of almost expired products (through online platforms)	• Donation of almost expired products
	Additional treatments	• Reprocessing (on-site or by manufacturing companies, cafes, and industrial kitchens)	• Self-consumption	• Remanufacturing (on-site or by other manufacturing companies) • Repacking wrongly labeled products	• Remanufacturing (on-site or by other manufacturing companies) • Repacking wrongly labeled products		• Remanufacturing rejected products • Repacking damaged products	• Remanufacturing (on-site or by manufacturing companies) • Repacking damaged products	
	Reuse for animal consumption	• Bedding (inedible waste) • Consumption without further processing • Feed production	• Consumption without further processing	• Bedding (inedible waste) • Consumption without further processing (by-products) • Feed production	• Consumption without further processing (by-products, defective products) • Feed production	• Feed production	• Feed production	• Consumption without further processing (unsold and expired products) • Feed production (unsold and expired products)	• Feed production (unsold and expired products)
	Material recycling	• Biopolymers production • Compounds extraction (vitamins)	• Soap production	• Biopolymers production • Compounds extraction (proteins, vitamins, fibers, fats, oils, enzymes, pigments)	• Compounds extraction (proteins, enzymes, vitamins)				
	Nutrient recovery	• Anaerobic digestion to obtain digestate • Fermentation or composting to obtain fertilizer	• Fermentation or composting to obtain fertilizer	• Anaerobic digestion to obtain digestate • Composting to obtain fertilizer	• Anaerobic digestion to obtain digestate • Composting or vermicomposting to obtain fertilizer	• Anaerobic digestion to obtain digestate • Composting to obtain fertilizer	• Anaerobic digestion to obtain digestate • Composting to obtain fertilizer	• Anaerobic digestion to obtain digestate • Composting to obtain fertilizer	• Anaerobic digestion to obtain digestate • Composting to obtain fertilizer
	Energy recovery	• Anaerobic digestion to obtain biogas • Biofuel production		• Anaerobic digestion to obtain biogas • Biofuel and solvent production • Incineration with recovery of heat and power	• Anaerobic digestion to obtain biogas • Biofuel production • Incineration with recovery of heat and power		• Anaerobic digestion to obtain biogas	• Anaerobic digestion to obtain biogas • Biofuel production • Incineration with recovery of heat and power	• Anaerobic digestion to obtain biogas
	Disposal	• Landfill of products unfit for sale	• Incineration of fish by-catches or dead animals	• Incineration without energy recovery of products contaminated with foreign bodies • Landfill	• Incineration without energy recovery of products contaminated with foreign bodies • Landfill	• Landfill of rotten or expired products	• Incineration without energy recovery of expired or rejected products • Landfill of expired or rejected products	• Incineration without energy recovery of damaged or expired products • Landfill of damaged, expired, or recalled products	• Landfill of recalled products

(b)

Fig. 7. CE practices according to the proposed product classification: (a) occurrence - the reported numbers refer to the number of papers mentioning the practice, (b) detail on CE practices.

et al., 2022; Hassoun et al., 2023). Measuring and monitoring practices are most relevant at the distribution stage for *controlled temperature* products, where several technologies can be employed to control products and environmental conditions. Temperature can be monitored in real time (with RFID tags, GPS systems, wireless sensor networks, IoT technologies, or intelligent containers), enabling to promptly solve criticalities and accurately predict products quality evolution, potentially leading to the introduction of dynamic expiration dates (Lorite et al., 2017; Villalobos et al., 2019; Chen et al., 2022). Data can also be collected through thermal imaging or by monitoring humidity and the concentration of gases such as oxygen, ethylene, and carbon dioxide (Lamberty and Kreyenschmidt, 2022; Zhu et al., 2022). The large amount of collected data can be employed to forecast and simulate the evolution of food characteristics to improve transportation and storage, preventing FW generation (do Nascimento Nunes et al., 2014; Wu et al., 2019; Kale et al., 2021; Chen et al., 2022). Simpler solutions are available for *ambient temperature* products, with electronic meters or indicator strips for measuring humidity and moisture content (Kostyukovsky et al., 2016; Bradford et al., 2018). Similar prevention solutions are found at the retailer stage, especially for *short shelf life* food, where intelligent packaging, RFID tags, and spoilage indicators can be employed to estimate the residual shelf life (Porat et al., 2018; De Moraes et al., 2020; Albrecht et al., 2021).

Improvement, optimization and innovation appear to be very relevant practices along the SC. At harvesting, this approach can help prevent the generation of FW through operation mechanization, optimized harvesting or fishing tools, the adoption of high hygiene standards, and an improved packaging design (Verghese et al., 2015; Becerra-Sanchez and Taylor, 2021; Goffart et al., 2022). Moreover, other key FW prevention practices are crop biofortification, which can be applied to *plant origin* products to enhance pest tolerance, and farmers' training and education (Kummu et al., 2012; Hewett, 2013). At manufacturing, these practices are very relevant for both *processed* and *minimally processed* goods: it is possible to reduce manufacturing by-products by optimizing and automating production lines (Xue et al., 2019; Goryńska-Goldmann et al., 2021). At this stage, it is also possible to introduce new technologies or ingredients aimed at extending the products' shelf life, often combined with improved packaging material and design (Verghese et al., 2015; Boz and Koelsch Sand, 2020; García-Hernández et al., 2023). At distribution, packaging improvement is relevant for both *ambient* and *controlled temperature* products. For the former, attention is devoted to adopting hermetic and moisture-proof bags (Bradford et al., 2018; Poudel et al., 2020). For the latter, the focus is on ensuring correct cooling through packaging design or altering gas composition in the package to extend shelf life (Jedermann et al., 2014; Falagán and Terry, 2018; Batziakas et al., 2020). Transportation of *controlled temperature* products can be improved to reduce FW to shorten transit times and by selecting proper vehicles (Chabada et al., 2014; Orjuela-Castro et al., 2019; Negi and Trivedi, 2021). During storage, the wastage of these products can be reduced by updating warehouses and adopting inventory policies that consider product shelf life or dynamic quality decay (Jedermann et al., 2017; Glew et al., 2021; Liu et al., 2022). Improving inventory management can also help reduce FW at the retailer stage, especially for food with a *short shelf life*. This prevention practice can entail selecting the appropriate shelf space for each product and ensuring stock rotation (Akkas et al., 2019; Mendes et al., 2020). Retailers can also leverage prices to prevent FW: promotions and discounts can be used to clear inventories, and the application of dynamic prices can encourage customers to buy products closer to expiration (a higher price is set for fresher food, which decreases as expiration approaches) (Kayikci et al., 2022; Riesenegger and Hübner, 2022; Lin and Januardi, 2023). Retailers can also educate customers on the theme of FW through awareness campaigns (Sundgren, 2020; Eičaitė et al., 2022).

At the harvesting stage, the **development** of horizontal and vertical **collaborations** emerged as relevant for *plant origin* products. Horizontal collaboration can aid planning through the sharing of market data and can also increase the farmers' bargaining power if cooperatives are established (Gokarn and Kuthambalayan, 2019; Ludwig-Ohm et al., 2019). Vertical collaboration allows farmers to engage with downstream actors of the SC, reducing market uncertainty and easing planning and pricing (Herzberg et al., 2022). This type of collaboration can also lead to the development of short SCs, where the elimination of intermediaries allows produce to reach the consumer in a shorter time, limiting FW hotspots (Meagher et al., 2020; Navarro-del Aguila and de Burgos-Jiménez, 2022). For manufacturers, developing collaborations with retailers can be relevant to make the required minimum life on receipt more flexible, reducing rejections and FW (Santos, M.J., et al., 2022). For the distribution of *controlled temperature* products, the creation of collaborative relationships can allow an efficient and effective movement of goods, reducing lead times and disruptions and, consequently, FW (Wickrama Gunaratne and Jayaratne, 2020; Yan et al., 2021; Saengsathien et al., 2023). At the retailer stage, collaborations with manufacturers can also lead to the establishment of collaborative forecasting practices, which can help reduce FW of *short shelf life* products through a more careful definition of safety stock level, avoiding overstocking (C.C. De Moraes et al., 2020; L.R. Trento et al., 2021). More generally, retailers can benefit from data sharing along the SC since punctual shelf life data can reduce product outdating (Ketzenberg et al., 2023).

Reuse for human consumption is widely adopted along the whole SC. *Plant origin* products with minor mechanical damage, produced in excess, or that do not comply with cosmetic standards can be **redistributed** through donations to charities (Meagher et al., 2020; Blanckenberg et al., 2022). This practice is also commonly employed by manufacturers, but additionally, sub-standard products can be sold at discounted prices to employees or through secondary markets (Kummu et al., 2012; Garrone et al., 2016; Al-Khateeb et al., 2021). Retailers mainly donate *short shelf life* items that remain unsold or are approaching the expiration date (Bilska et al., 2018; Lowrey et al., 2023). In some cases, food is even removed from the shelves a few days in advance since it is very unlikely for these products to be sold before their expiration (Sert et al., 2016). These items are also often sold at a discounted price through secondary channels or online platforms (Eičaitė et al., 2022; Riesenegger and Hübner, 2022).

Alternatively, damaged or out-of-spec food can be recovered by means of **additional treatments**. At harvesting, produce not suited for the fresh market can be destined to produce juices or jams, with processing occurring directly on the farm site or in alternative facilities (Blanke, 2015; Porter et al., 2018). For manufacturers, FW can be caused by wrong labeling, so additional treatments can be aimed at repacking such products (Jones et al., 2021). FW can also be recovered through remanufacturing into alternative finished goods, even by introducing new technologies and production lines to recover by-products on the production site (Skendi et al., 2020; Ncube et al., 2021; Facchini et al., 2023). This is sometimes possible also for retailers, which can process surplus food into a new format or unpack items and sell them in bulk (Goossens et al., 2019; Tröger et al., 2020; Van Bemmel and Parizeau, 2020).

Reuse for animal consumption is traditionally used at the harvesting stage for *plant origin* products to feed animals, produce feed, or as bedding material (Parmar et al., 2018; Gillman et al., 2019). *Animal origin* waste is also recovered in this manner, especially in the fishing industry, where bycatches can be turned into aquafeed products (Cooney et al., 2023). At the manufacturing stage, this practice is widely adopted, allowing the recovery of by-products from *minimally processed* food and finished *processed* goods (Goryńska-Goldmann et al., 2021; Paini et al., 2022). These products can be sent to feed producers or aquacultures and farms, or even to feed terrestrial invertebrates (Tedesco et al., 2019; Islam and Peñarubia, 2021; Facchini et al., 2023). At the retailer output, unsold and expired *short shelf life* items are often recovered as animal feed (C.C. De Moraes et al., 2020; Gómez and

Martinez, 2023; Ögel et al., 2023).

Material recycling emerges as a relevant recovery practice for *minimally processed* food, whose manufacturing by-products are sources of useful ingredients such as proteins, fibers, or vitamins that can be employed, for example, in the pharmaceutical and cosmetic industries (Augustin et al., 2016; Cardoso et al., 2021; Thakur et al., 2021). These materials can also be sources of biopolymers used to produce bioplastics (Esparza et al., 2020).

Nutrient recovery is more relevant at the initial stages of the SC. Both *plant* and *animal origin* products can be employed to produce liquid and solid soil amendments through fermentation or composting processes (Gillman, Campbell and Spang, 2019; Cooney et al., 2023). Anaerobic digestion is another relevant process that yields digestate, a form of fertilizer that can be used on cultivated fields (Kumngen et al., 2023). All these processes are also frequently applied to recover FW generated during manufacturing, aimed at producing fertilizers to give back to the soil some of the nutrients taken for cultivation (Vlajic et al., 2018; Dong et al., 2022; Paini et al., 2022).

Energy recovery is a widely adopted practice at the manufacturing stage, especially for *minimally processed* goods. Production by-products are excellent for producing biogas and biomethane through anaerobic digestion, as well as for the combined generation of heat and power (Chinnici et al., 2019; Sadhukhan et al., 2020). These materials can also be employed to produce biodiesel, other biofuels, and solvents (Paini et al., 2022).

4. Discussion

The presented results, together with the proposed classification of food products, highlight the interplay between food product characteristics and the generation and recovery of FW along the SC. The characteristics driving these differences vary along the SC, stressing how FW is strongly intertwined with specific SC operations.

As depicted in Figs. 6 and 7, the importance of different causes and management practices varies significantly along the SC. It is possible to observe how the main causes and practices are strictly linked with the operations carried out at each SC stage. For instance, during distribution, FW is more commonly generated due to "inefficiencies and poor handling" since these activities entail goods manipulation and often focus on optimization to obtain greater efficiency. Similarly, looking at CE practices, retailers rely on food redistribution far more than other SC actors since they handle finished products and are in direct contact with consumers. It can also be observed how the same cause or practice can take different connotations depending on the considered SC stage. The cause "lack of collaboration" is an example, as the type of collaboration (horizontal or vertical) and the actors involved widely change along the SC. Horizontal collaboration mainly regards farmers and logistics providers, who can build partnerships with their peers to reduce FW. The establishment of vertical collaborations is a practice found throughout the SC. This appears to be particularly relevant between manufacturers and retailers, as well as between farmers and retailers to create short SCs. Concerning FW management, the subject of "improvement, optimization, and innovation" actions shifts significantly depending on the considered SC stage. The FW prevention practices that fall within this category focus on the main activities, operations, and infrastructures that characterize each step of the chain. For instance, during distribution, attention is devoted to improving vehicles and logistics facilities. Instead, at the manufacturing stage, improvement practices have a greater focus on machinery.

The developed framework also highlights how FW causes and CE actions can vary greatly within the same SC stage, depending on the identified product characteristics. While similar operations are conducted at each stage, the intrinsic characteristics of food products significantly influence FW generation and management. For example, "natural causes" considerably vary depending on the considered product, as well as causes related to "poor infrastructures" and "operation inefficiency and poor handling". The differences between products are particularly evident in all those cases where, within the same SC stage, a cause is only found for one product type. This is less frequent when analyzing prevention and recovery practices. However, it is possible to note how the same CE action can take different connotations depending on the considered product type within the same SC stage, especially at higher tiers of the FW hierarchy. Moreover, some prevention and recovery strategies are only available for certain food products, for example, within "measuring and monitoring", "improvement, optimization, and innovation", or "reuse for human consumption" practices. Differences can also be observed in the occurrence of FW causes and the availability of CE practices across different product categories. For example, it is possible to note a discrepancy in the occurrence of "natural causes" for *plant* and *animal origin* products. Similarly, the extent of discussion in the scientific literature on CE practices varies between product categories. This is exemplified by "measuring and monitoring" practices implemented at the distribution stage, where *controlled temperature* products have been more broadly investigated in relation to this prevention strategy.

A further insight that can be derived from the comparison of Figs. 6 and 7 is the alignment between FW causes and recovery practices: it can be noted how the most relevant causes within each product category correspond to a high relevance of practices addressing these causes. For example, many solutions ("measuring and monitoring", "improvement, optimization, and innovation") have been proposed to prevent the generation of FW of *controlled temperature* goods due to "poor infrastructures" or "inefficiency and poor handling". At manufacturing, by-products and scraps constitute a significant portion of FW and the most common CE practices aim at their recovery ("reuse for animal consumption", "material recycling"). This finding sheds a positive light on the state of prevention and management of FW. Nevertheless, the SC stage and product characteristics can pose restrictions on the available CE practices. Despite these limitations, it is possible to effectively prevent and recover FW by developing tailored solutions that account for these specificities. However, Fig. 7 also highlights how many implemented practices are not found in the first tiers of the FW hierarchy, especially in primary production and manufacturing (Teigiserova et al., 2020). This partial misalignment with the FW hierarchy suggests the need to propose tailored solutions that are able to retain more value from these products.

4.1. Implications

From a theoretical standpoint, the proposal of a classification of food products in light of CE represents a novel contribution to knowledge. As detailed above, the proposed classification enables isolating the food characteristics that mostly influence the generation and recovery of FW at each SC stage. The variability of FW along the SC has been partially discussed in previous literature, but the developed framework allows this element to emerge more clearly (Canali et al., 2017; Magalhães et al., 2021). For instance, Canali et al. (2017) describe how FW generation and mitigation are contingent upon the considered activity and process within the SC. Magalhães et al. (2021) delineate more clearly such differences, which were mainly found between logistics and retail activities. This work instead adopts an overarching perspective on the food SC, broadening the scope of the analysis. Thanks to an in-depth analysis of the literature, this study elucidates in greater detail the variability of FW along food SCs, exposing the manifold connotations CE can have depending on the considered SC stage.

Furthermore, the findings presented in this work provide several insights into understanding the influence of product characteristics on FW and CE. Only a few literature contributions put forward this possible variability, which was discussed here in greater detail, and clearly defined thanks to the proposed classification (Chauhan, 2021; Ögel et al., 2023). Avoiding focusing on a single food category or product enriches the contribution of this work, as most studies have so far focused on one or a few food types (Chauhan, 2021; Viscardi et al., 2022). Overall, this study also enables systematizing the wide body of knowledge available on FW, unveiling those aspects requiring further research, as detailed below.

This work also has significant practical implications: the perspective adopted in this review, centered around food products, can be easily interpreted by food industry practitioners. Posing the food product at the core of the analysis can potentially simplify the understanding of challenges related to FW since every player in the SC has a great knowledge of the nature of its products. The findings of this work can also shed light on FW derived from those products that are less studied in the literature, thanks to the broad categories embedded in the proposed classification. Starting from food characteristics, the proposed classification can be employed as a map to navigate the most common FW generation hotspots and how to address them effectively throughout the whole SC, as the systematization of CE practices provided in this work can aid in understanding the most appropriate CE practices to be implemented. The overarching perspective on FW causes and CE practices adopted in this work can serve as a guide when dealing with FW, eventually raising awareness of the challenges faced in other SC stages and promoting a CE culture.

5. Concluding remarks, limits, and future research

The study presented in this work aimed to understand the influence of food product characteristics on CE for FW prevention and valorization along food SCs. The proposed classification of food products, based on a thorough analysis of the literature, clearly highlights how FW generation and prevention are strongly intertwined with SC operations. Within the same stage of the SC, the causes of FW and related CE practices significantly vary depending on the characteristics of the food product.

Despite the discussed implications, the main limitation of this work lies in the adoption of a systematic literature review methodology. While this approach is suitable for exploring this novel topic since it allows the classification of studies according to themes, a systematic review of the literature also embeds some constraints. The most relevant one is the impossibility of providing punctual details for each paper (Seuring et al., 2005), which could be associated with the loss of nuances of the many dynamics involved in the complex phenomenon of FW. The empirical analysis of multiple SCs could overcome this limitation, enabling the deepening and validation of the proposed classification. For instance, such empirical investigation could be conducted using a case study methodology to obtain a thick description of the phenomenon of interest (Eisenhardt, 1989). Conducting an empirical validation could also help overcome another limitation related to the uneven distribution of articles across different product categories, as shown in Fig. 5. While a lack of attention from academics can be a symptom of the low significance of a certain cause or CE practice, it is difficult to assess the real magnitude of these aspects. Nevertheless, this work clearly exposes those food categories that have been understudied, hopefully sparking future empirical research on these products. Moreover, this limitation could also be overcome by surveying a large sample of food firms along the whole SC, ensuring a balanced distribution of food product types. Such efforts could corroborate the proposed classification and potentially enrich it with more accurate considerations of the involved FW flows. Validating and refining the classification of food products presented in this work is also relevant to tackling possible research bias. The inductive analysis of the papers entails their interpretation, which is subject to the point of view of the researchers (Thomas, 2006). The protocols for paper selection and analysis have been defined with care to ensure standardization, therefore mitigating potential subjectivity. However, further studies on this topic could strengthen the findings of this work.

This work also underlines how most analyzed studies focus on just one SC stage, neglecting to consider the SC as a whole (Fig. 5). Future research should consider food SCs in their entirety to analyze FW from a broader perspective and highlight those mechanisms embedded in SCs of different products, which potentially lead to the generation of waste. For example, it could be interesting to explore the link between the identified product characteristics and their progression along the SC. A longitudinal SC study could possibly reveal cascading effects between product characteristics when going downstream the SC. For instance, if a specific cause differs for *minimally processed* goods of *animal* or *plant origin*, or if CE practices applied to *short shelf life* items change considering the degree of processing. Both qualitative and quantitative investigation methodologies appear suitable for exploring this aspect in greater detail.

The analysis of CE practices revealed a further possible research direction since it highlighted how many of the implemented practices are not the most preferred ones according to the FW hierarchy. Future research could focus on developing circular solutions to recover more value from FW flows while respecting the contingencies set by the food product characteristic and the SC stage. The conceptualization of food products in relation to CE presented in this paper can enable a more focused development of FW management practices, which exploit the inherent nature of food products to develop more effective CE solutions.

CRediT authorship contribution statement

Stella Viscardi: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Claudia Colicchia:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

Agnusdei, G.P., et al., 2022. Towards circular economy in the agrifood sector: water footprint assessment of food loss in the Italian fruit and vegetable supply chains. Ecol. Indic. 137 https://doi.org/10.1016/j.ecolind.2022.108781.

Akanbi T.O., Dare K.O. and Aryee A.N.A. (2020) High-value products from cereal, nuts, fruits, and vegetables wastes.

Akkas, A., Gaur, V., Simchi-Levi, D., 2019. Drivers of product expiration in consumer packaged goods retailing. Manag. Sci. 65 (5), 2179–2195. https://doi.org/10.1287/mnsc.2018.3051.

Akkaş, A., Honhon, D., 2022. Shipment policies for products with fixed shelf lives: impact on profits and waste. Manuf. Serv. Oper. Manag. 24 (3), 1611–1629. https://doi.org/10.1287/msom.2021.1018.

Akkaş, A., 2019. Shelf space selection to control product expiration. Prod. Oper. Manag. 28 (9), 2184–2201. https://doi.org/10.1111/poms.13034.

Al-Khateeb, S.A., et al., 2021. Battling food losses and waste in saudi arabia: mobilizing regional efforts and blending indigenous knowledge to address global food security challenges. Sustainability 13 (15). https://doi.org/10.3390/su13158402 (Switzerland)Available at:

Alao, B.O., et al., 2017. The potential of animal by-products in food systems: production, prospects and challenges. Sustainability 9 (7), 1089.

Albrecht, A., et al., 2021. A multi-model approach to implement a dynamic shelf life criterion in meat supply chains. Foods 10 (11). https://doi.org/10.3390/foods10112740.

Ali, A., et al., 2021. Economic and environmental consequences' of postharvest loss across food supply Chain in the developing countries. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2021.129146, 323. Available at:

Augustin, M.A., et al., 2016. Role of food processing in food and nutrition security. Trends Food Sci. Technol. 115–125. https://doi.org/10.1016/j.tifs.2016.08.005.

Badia-Melis, R., et al., 2018. New trends in cold chain monitoring applications - A review. Food Control 170–182. https://doi.org/10.1016/j.foodcont.2017.11.022.

Bandekar, P.A., et al., 2022. Cradle-to-grave life cycle assessment of production and consumption of pulses in the United States. J. Environ. Manag. 302 https://doi.org/10.1016/j.jenvman.2021.114062.

Batziakas, K.G., et al., 2020. Reducing postharvest losses of spinach stored at nonoptimum temperatures with the implementation of passive modified atmosphere packaging. HortScience 55 (3), 326–335. https://doi.org/10.21273/HORTSCI14732-19.

Becerra-Sanchez, F., Taylor, G., 2021. Reducing post-harvest losses and improving quality in sweet corn (Zea mays L.): challenges and solutions for less food waste and improved food security. Food and Energy Security. John Wiley and Sons Inc. https://doi.org/10.1002/fes3.277.

Bilska, B., Piecek, M., Kołozyn-Krajewska, D., 2018. A multifaceted evaluation of food waste in a polish supermarket-case study. Sustainability 10 (9). https://doi.org/10.3390/su10093175 (Switzerland)Available at:

Blanckenberg, A., Opara, U.L., Fawole, O.A., 2021. Postharvest losses in quantity and quality of table grape (Cv. crimson seedless) along the supply chain and associated economic, environmental and resource impacts. Sustainability 13 (8). https://doi.org/10.3390/su13084450 (Switzerland)Available at:

Blanckenberg, A., Fawole, O.A., Opara, U.L., 2022. Postharvest losses in quantity and quality of pear (cv. Packham's Triumph) along the supply chain and associated economic, environmental and resource impacts. Sustainability 14 (2). https://doi.org/10.3390/su14020603 (Switzerland)Available at:

Blanke, M., 2015. Challenges of reducing fresh produce waste in Europe—From farm to fork. Agriculture 5 (3), 389–399. https://doi.org/10.3390/agriculture5030389 (Switzerland)Available at:

Bolaji, I., et al., 2021. Multi-criteria decision analysis of agri-food waste as a feedstock for biopolymer production. Resour. Conserv. Recycl. 172 https://doi.org/10.1016/j.resconrec.2021.105671.

Boz, Z., Koelsch Sand, C., 2020. A systematic analysis of the overall nutritional contribution of food loss and waste in tomatoes, spinach, and kidney beans as a function of processing. J. Food Process. Eng. https://doi.org/10.1111/jfpe.13509.

Bradford, K.J., et al., 2018. The dry chain: reducing postharvest losses and improving food safety in humid climates. Trends Food Sci. Technol. 84–93. https://doi.org/10.1016/j.tifs.2017.11.002.

Buisman, M.E., Haijema, R., Bloemhof-Ruwaard, J.M., 2019. Discounting and dynamic shelf life to reduce fresh food waste at retailers. Int. J. Prod. Econ. 209, 274–284. https://doi.org/10.1016/j.ijpe.2017.07.016.

Caldeira, C., et al., 2019. Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. Resour. Conserv. Recycl. 149 (August 2018), 479–488. https://doi.org/10.1016/j.resconrec.2019.06.011.

Canali, M., et al., 2017. Food waste drivers in Europe, from identification to possible interventions. Sustainability 9 (1). https://doi.org/10.3390/su9010037 (Switzerland)Available at:

Cardoso, R.V.C., et al., 2021. A case study on surplus mushrooms production: extraction and recovery of vitamin d2. Agriculture 11 (7). https://doi.org/10.3390/agriculture11070579 (Switzerland)Available at:

Chabada L. et al. (2014) Logistical causes of food waste: a case study of a norwegian distribution chain of chilled food products.

Chaboud, G., 2017. Assessing food losses and waste with a methodological framework: insights from a case study. Resour. Conserv. Recycl. 125, 188–197. https://doi.org/10.1016/j.resconrec.2017.06.008.

Chauhan, C., et al., 2021. Food loss and waste in food supply chains. A systematic literature review and framework development approach. J. Clean. Prod. 295 https://doi.org/10.1016/j.jclepro.2021.126438.

Chen, Q., et al., 2022. Sustainable food cold chain logistics: from microenvironmental monitoring to global impact. Compr. Rev. Food Sci. Food Saf. 4189–4209. https://doi.org/10.1111/1541-4337.13014.

Chinnici, G., et al., 2019. A model of circular economy of citrus industry. In: Proceedings of the 19th International Multidisciplinary Scientific GeoConference SGEM 2019. https://doi.org/10.5593/sgem2019V/4.2.

Cooney, R., et al., 2023. A circular economy framework for seafood waste valorisation to meet challenges and opportunities for intensive production and sustainability. J. Clean. Prod. 392, 136283.

Day, L., Cakebread, J.A., Loveday, S.M., 2022. Food proteins from animals and plants: differences in the nutritional and functional properties. Trends in Food Science and Technology. Elsevier Ltd, pp. 428–442. https://doi.org/10.1016/j.tifs.2021.12.020.

de Brito Nogueira, T.B., et al., 2020. Fruits and vegetable-processing waste: a case study in two markets at Rio de Janeiro, RJ, Brazil. Environ.Sci. Pollut. Res. 27 (15), 18530–18540. https://doi.org/10.1007/s11356-020-08244-y.

de Hooge, I.E., van Dulm, E., van Trijp, H.C.M., 2018. Cosmetic specifications in the food waste issue: supply chain considerations and practices concerning suboptimal food products. J. Clean. Prod. 183, 698–709.

de Moraes, C.C., et al., 2020. Retail food waste: mapping causes and reduction practices. J. Clean. Prod. 256 https://doi.org/10.1016/j.jclepro.2020.120124.

de Vasconcelos, D.C., Viana, F.L.E., de Souza, A.L., 2021. Circular economy and sustainability in the fresh fruit supply chain: a study across Brazil and the UK. Lat. Am. Bus. Rev. 22 (4), 393–421. https://doi.org/10.1080/10978526.2021.1941070.

do Nascimento Nunes, M.C., et al., 2014. Improvement in fresh fruit and vegetable logistics quality: berry logistics field studies. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 372 (2017), 20130307.

De Angelis, R., Howard, M., Miemczyk, J., 2018. Supply chain management and the circular economy: towards the circular supply chain. Prod. Plan. Control 29 (6), 425–437. https://doi.org/10.1080/09537287.2018.1449244.

De Boeck, E., et al., 2017. Ensuring food safety in food donations: case study of the Belgian donation/acceptation chain. Food Res. Int. 100, 137–149. https://doi.org/10.1016/j.foodres.2017.08.046.

De Moraes, C.C., et al., 2020. Retail food waste: mapping causes and reduction practices. J. Clean. Prod. 256, 120124.

Delgado, L., Schuster, M., Torero, M., 2021. Quantity and quality food losses across the value Chain: a comparative analysis. Food Policy. https://doi.org/10.1016/j.foodpol.2020.101958, 98. Available at:

Denyer D. and Tranfield D. (2009) 'Producing a systematic review.'.

Dong, W., et al., 2022. A framework to quantify mass flow and assess food loss and waste in the US food supply chain. Commun. Earth Environ. 3 (1) https://doi.org/10.1038/s43247-022-00414-9.

Duret, S., et al., 2019. Combining Quantitative risk assessment of human health, food waste, and energy consumption: the next step in the development of the food cold chain? Risk Anal. 39 (4), 906–925. https://doi.org/10.1111/risa.13199.

EFSA (2015) The Food Classification and Description System FoodEx 2, EFSA Supporting Publications. Available at: 10.2903/sp.efsa.2015.EN-804.

Eisenhardt, K.M., 1989. Building theories from case study research. Acad. Manag. Rev. 14 (4), 532–550.

Eičaitė, O., et al., 2022. Food waste in the retail sector: a survey-based evidence from central and Eastern Europe. J. Retail. Consum. Serv. 69, 103116.

Eičaitė, O., et al., 2023. Exploring food loss in the food industry: a survey-based approach for Lithuania. J. Clean. Prod. 399, 136668.

Ellen MacArthur Foundation (2012) Towards the circular economy.

Eriksson, M., et al., 2017. Take-back agreements in the perspective of food waste generation at the supplier-retailer interface. Resour. Conserv. Recycl. 122, 83–93. https://doi.org/10.1016/j.resconrec.2017.02.006.

Esparza, I., et al., 2020a. Fruit and vegetable waste management: conventional and emerging approaches. J. Environ. Manag. https://doi.org/10.1016/j.jenvman.2020.110510.

Esparza, I., et al., 2020b. Fruit and vegetable waste management: conventional and emerging approaches. J. Environ. Manag. 265 https://doi.org/10.1016/j.jenvman.2020.110510.

Esteso, A., et al., 2022. Optimization model to support sustainable crop planning for reducing unfairness among farmers. Cent. Eur. J. Oper. Res. 30 (3), 1101–1127. https://doi.org/10.1007/s10100-021-00751-8.

European Commission (2020a) A New Circular Economy Action Plan. Available at: https://www.un.org/sustainabledevelopment/sustainable-consumption-production/.

European Commission (2020b) Farm to fork strategy, DG SANTE/Unit 'Food Information and composition, Food waste, (DG SANTE/Unit 'Food information and composition, food waste'), p. 23. Available at: https://ec.europa.eu/food/sites/food/files/safety/docs/f2f_action-plan_2020_strategy-info_en.pdf.

FAO, 1999. Code of Hygienic Practice For Refrigerated Packaged Foods with Extended Shelf Life, CXC 46-1999. FAO.

FAO, 2019a. General Standard for Food Additives, Codex Stan 192-1995. FAO. http://www.fao.org/food/foodsafetyquality/scientificadvice/jecfa/jecfa-additives/en/.

FAO, 2019b. The State of Food and Agriculture 2019. Moving forward On Food Loss and Waste Reduction. FAO. Rome [Preprint].

FAO, 2023. The State of Food Security and Nutrition in the World, The State of Food Security and Nutrition in the World 2023. FAO. https://doi.org/10.4060/cc3017en.

FAO, 2024. About Codex Alimentarius. FAO.

Facchini, F., et al., 2023. Agri-food loss and waste management: win-win strategies for edible discarded fruits and vegetables sustainable reuse. Innov. Food Sci. Emerg. Technol. 83, 103235.

Falagán, N., Terry, L.A., 2018. Recent advances in controlled and modified atmosphere of fresh produce. Johns. Matthey Technol. Rev. 62 (1), 107–117. https://doi.org/10.1595/205651318X696684.

Formentini, M., et al., 2021. Enablers and barriers to circular supply chain management: a decision-support tool in soft wheat bread production. J. Enterp. Inf. Manag. https://doi.org/10.1108/JEIM-02-2021-0069 [Preprint]. Available at:

García-Hernández, Á., et al., 2023. Stale bread waste recycling as ingredient for fresh oven-baked white bread: effects on dough viscoelasticity, bread molecular organization, texture, and starch digestibility. J. Sci. Food Agric. 103 (8), 4174–4183. https://doi.org/10.1002/jsfa.12442.

Garrone, P., et al., 2016. Reducing food waste in food manufacturing companies. J. Clean. Prod. 137, 1076–1085.

Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 114, 11–32.

Gillman, A., Campbell, D.C., Spang, E.S., 2019. Does on-farm food loss prevent waste? Insights from California produce growers. Resources, Conservation and Recycling 150. https://doi.org/10.1016/j.resconrec.2019.104408.

Glew, R., Hernandez, M.P., McFarlane, D., 2021. Analysing the effect of food supply chain traceability on product waste. In: Proceedings of the Operational Research Society 10th Simulation Workshop, SW 2021. Operational Research Society, pp. 145–154. https://doi.org/10.36819/SW21.015.

Goffart, J.P., et al., 2022. Potato production in Northwestern Europe (Germany, France, the Netherlands, United Kingdom, Belgium): characteristics, issues, challenges and opportunities. Potato Research. Springer Science and Business Media B.V., pp. 503–547. https://doi.org/10.1007/s11540-021-09535-8

Gogo, E.O., et al., 2017. Nutritional and economic postharvest loss analysis of African indigenous leafy vegetables along the supply chain in Kenya. Postharvest Biol. Technol. 130, 39–47. https://doi.org/10.1016/j.postharvbio.2017.04.007.

Gokarn, S., Kuthambalayan, T.S., 2019. Creating sustainable fresh produce supply chains by managing uncertainties. J. Clean. Prod. 207, 908–919. https://doi.org/10.1016/j.jclepro.2018.10.072.

Goossens, Y., et al., 2019. How origin, packaging and seasonality determine the environmental impact of apples, magnified by food waste and losses. Int. J. Life Cycle Assess. 24 (4), 667–687. https://doi.org/10.1007/s11367-018-1522-0.

Goryńska-Goldmann, E., et al., 2021. Magnitude, causes and scope for reducing food losses in the baking and confectionery industry —A multi-method approach. Agriculture 11 (10). https://doi.org/10.3390/agriculture11100936 (Switzerland) Available at:

Gustafsson, K., et al., 2006. Retailing Logistics and Fresh Food packaging: Managing Change in the Supply Chain. Kogan Page Publishers.

Gómez, M., Martinez, M.M., 2023. Redistribution of surplus bread particles into the food supply chain. LWT. Academic Press. https://doi.org/10.1016/j.lwt.2022.114281.

Göransson, M., Nilsson, F., Jevinger, 2018. Temperature performance and food shelf-life accuracy in cold food supply chains – Insights from multiple field studies. Food Control 86, 332–341. https://doi.org/10.1016/j.foodcont.2017.10.029.

Hassoun, A., et al., 2023. Use of industry 4.0 technologies to reduce and valorize seafood waste and by-products: a narrative review on current knowledge. Curr. Res. Food Sci., 100505.

Hernández-Cruz, X., et al., 2021. Fresh produce analytical framework. In: Proceedings of the 2021 IISE Annual Conference.

Hernández-Cruz X. et al. (2022) Layered decision environment for agricultural market intelligence.

Herzberg, R., Schmidt, T., Keck, M., 2022. Market power and food loss at the producer-retailer interface of fruit and vegetable supply chains in Germany. Sustain. Sci. 17 (6), 2253–2267. https://doi.org/10.1007/s11625-021-01083-x.

Hewett, E.W., 2013. Postharvest innovation: current trends and future challenges in the global market. In: Proceedings of the 25 Southeast Asia Symposium on Quality Management in Postharvest Systems. *in conj. w/Asia-Pacific Symp. Posthar. Quality Mgt. Root & Tuber Crops*.

Hu, G., et al., 2019. Potentials of GHG emission reductions from cold chain systems: case studies of China and the United States. J. Clean. Prod. 239 https://doi.org/10.1016/j.jclepro.2019.118053.

Islam, M.J., Peñarubia, O.R., 2021. Seafood waste management status in bangladesh and potential for silage production. Sustainability 13 (4), 1–17. https://doi.org/10.3390/su13042372 (Switzerland)Available at:

Jedermann, R., et al., 2014. Reducing food losses by intelligent food logistics. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 372 (2017) https://doi.org/10.1098/rsta.2013.0302.

Jedermann, R., Praeger, U., Lang, W., 2017. Challenges and opportunities in remote monitoring of perishable products. Food Packag. Shelf Life 14, 18–25. https://doi.org/10.1016/j.fpsl.2017.08.006.

Jones, S.L., Gibson, K.E., Ricke, S.C., 2021. Critical factors and emerging opportunities in food waste utilization and treatment technologies. Frontiers in Sustainable Food Systems. Frontiers Media S.A. https://doi.org/10.3389/fsufs.2021.781537

Kale, S.D., Patil, S.C., Patil, S.G., 2021. Effect of vehicle characteristics on quality of perishable foods in cold chain. In: Proceedings of the 2021 International Conference on Smart Generation Computing, Communication and Networking, SMART GENCON 2021. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/SMARTGENCON51891.2021.9645828

Kayikci, Y., et al., 2022. Data-driven optimal dynamic pricing strategy for reducing perishable food waste at retailers. J. Clean. Prod. 344 https://doi.org/10.1016/j.jclepro.2022.131068. . Available at:

Kazancoglu, Y., et al., 2021. Performance evaluation of reverse logistics in food supply chains in a circular economy using system dynamics. Bus. Strategy Environ. 30 (1), 71–91. https://doi.org/10.1002/bse.2610.

Ketzenberg, M., et al., 2023. Retailer inventory data sharing in a fresh product supply chain. Eur. J. Oper. Res. 307 (2), 680–693. https://doi.org/10.1016/j.ejor.2022.08.043.

Kirchherr, J., et al., 2023. Conceptualizing the circular economy (Revisited): an analysis of 221 definitions. Resources, Conservation and Recycling. Elsevier B.V. https://doi.org/10.1016/j.resconrec.2023.107001

Kostyukovsky, M., Trostanetsky, A., Quinn, E., 2016. Novel approaches for integrated grain storage management. Israel Journal of Plant Sciences. Taylor and Francis Ltd., pp. 7–16. https://doi.org/10.1080/07929978.2016.1159410

Kraus, S., et al., 2022. Literature reviews as independent studies: guidelines for academic practice. Rev. Manag. Sci. 16 (8), 2577–2595.

Kumar, A., et al., 2020. Challenges in perishable food supply chains for sustainability management: a developing economy perspective. Bus. Strategy Environ. 29 (5), 1809–1831. https://doi.org/10.1002/bse.2470.

Kummu, M., et al., 2012. Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Sci. Total Environ. 438, 477–489. https://doi.org/10.1016/j.scitotenv.2012.08.092.

Kumngen, A., et al., 2023. Effects of compost from food waste on growth of lettuce (Lactuca sativa Var Crispa L.). Int. J. Recycl. Org. Waste Agric. 12 (2), 247–258. https://doi.org/10.30486/ijrowa.2022.1960507.1481.

Lamberty, A., Kreyenschmidt, J., 2022. Ambient parameter monitoring in fresh fruit and vegetable supply chains using internet of things-enabled sensor and communication technology. Foods 11 (12). https://doi.org/10.3390/foods11121777.

Latino, M.E., Menegoli, M., De Lorenzi, M.C., 2024. A pattern-based tool to support companies in sustainability-oriented business strategies: grounded theory research in agribusiness. Corp. Soc. Responsib. Environ. Manag. [Preprint].

Lima, D.M., et al., 2022. Strategies for reducing the waste of fruit and vegetable supply chains: the search for sustainable wholesale systems. Hortic. Bras. 40 (3), 334–341. https://doi.org/10.1590/s0102-0536-20220313.

Lin, S.W., Januardi, 2023. Two-stage pricing of perishable food supply chain with quality-keeping and waste reduction efforts. Manag. Decis. Econ. 44 (3), 1749–1766. https://doi.org/10.1002/mde.3780.

Lipińska, M., Tomaszewska, M., Kołożyn-Krajewska, D., 2019. Identifying factors associated with food losses during transportation: potentials for social purposes. Sustainability 11 (7), 2046.

Liu, C., et al., 2022. Achieving zero hunger goal through minimizing waste in food supply chain: evidence from asian emerging region. Sustainability 14 (10). https://doi.org/10.3390/su14105930 (Switzerland)Available at:

Loisel, J., et al., 2021. Cold chain break detection and analysis: can machine learning help? Trends in Food Science and Technology. Elsevier Ltd, pp. 391–399. https://doi.org/10.1016/j.tifs.2021.03.052.

Lorite, G.S., et al., 2017. Novel, smart and RFID assisted critical temperature indicator for supply chain monitoring. J. Food Eng. 193, 20–28. https://doi.org/10.1016/j.jfoodeng.2016.06.016.

Lowrey, J.D., Richards, T.J., Hamilton, S.F., 2023. Food donations, retail operations, and retail pricing. Manuf. Serv. Oper. Manag. 25 (2), 792–810.

Ludwig-Ohm, S., Dirksmeyer, W., Klockgether, K., 2019. Approaches to reduce food losses in German fruit and vegetable production. Sustainability 11 (23). https://doi.org/10.3390/su11236576 (Switzerland)Available at:

Magalhães, V.S.M., Ferreira, L.M.D.F., Silva, C., 2021. Using a methodological approach to model causes of food loss and waste in fruit and vegetable supply chains. J. Clean. Prod. 283 https://doi.org/10.1016/j.jclepro.2020.124574.

Majluf-Manzur, Á.M., et al., 2021. An operational planning model to support first mile logistics for small fresh-produce growers. Communications in Computer and Information Science. Springer Science and Business Media Deutschland GmbH, pp. 205–219. https://doi.org/10.1007/978-3-030-76310-7_17.

Mangla, S.K., et al., 2019. Logistics and distribution challenges to managing operations for corporate sustainability: study on leading Indian diary organizations. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2019.117620, 238. Available at:

Markowska, J., et al., 2022. Innovative management of vegetable outgrades as a means of food loss and waste reduction. Sustainability 14 (19). https://doi.org/10.3390/su141912363 (Switzerland)Available at:

Mattsson, L., Williams, H., 2022. Avoidance of supermarket food waste—employees' perspective on causes and measures to reduce fruit and vegetables waste. Sustainability 14 (16), 10031.

Meagher, K.D., et al., 2020. Relational and logistical dimensions of agricultural food recovery: evidence from California growers and recovery organizations. Sustainability 12 (15). https://doi.org/10.3390/su12156161 (Switzerland)Available at:

Mendes, A., et al., 2020. Logistics strategy (FIFO, FEFO or LSFO) decision support system for perishable food products. In: Proceedings of the 2020 International Conference on Decision Aid Sciences and Application, DASA 2020. Institute of Electrical and Electronics Engineers Inc., pp. 173–178. https://doi.org/10.1109/DASA51403.2020.9317068

Mercier, S., et al., 2018. The Canadian food cold chain: a legislative, scientific, and prospective overview. Int. J. Refrig. 88, 637–645. https://doi.org/10.1016/j.ijrefrig.2018.01.006.

Mongeon, P., Paul-Hus, A., 2016. The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics 106 (1), 213–228.

Monteiro, C.A., et al., 2018. The un Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. Public Health Nutrition. Cambridge University Press, pp. 5–17. https://doi.org/10.1017/S1368980017000234.

Monteiro C.A. et al. (2019) Ultra-processed foods, diet quality, and health using the NOVA classification system. Available at: http://www.wipo.int/amc/en/mediation/rules.

Moubarac, J.-C., et al., 2014. Food Classification Systems Based on Food Processing: significance and Implications for Policies and Actions: a Systematic Literature Review and Assessment. Curr. Obes. Rep. 3 (2), 256–272. https://doi.org/10.1007/s13679-014-0092-0.

Navarro-del Aguila, I., de Burgos-Jiménez, J., 2022. Sustainable innovation through developing hybrid agri-food supply chains: a case in South-Eastern Spain. Toxics 10 (12). https://doi.org/10.3390/toxics10120752.

Ncube, A., et al., 2021. Upgrading wineries to biorefineries within a Circular Economy perspective: an Italian case study. Sci. Total Environ. 775 https://doi.org/10.1016/j.scitotenv.2021.145809.

Ndraha, N., et al., 2018. Time-temperature abuse in the food cold chain: review of issues, challenges, and recommendations. Food Control. Elsevier Ltd, pp. 12–21. https://doi.org/10.1016/j.foodcont.2018.01.027.

Ndraha, N., et al., 2020. Challenges with food waste management in the food cold chains. Food Industry Wastes: Assessment and Recuperation of Commodities. Elsevier, pp. 467–483. https://doi.org/10.1016/B978-0-12-817121-9.00022-X.

Negi, S., Anand, N., 2019. Wholesalers perspectives on mango supply chain efficiency in India. J. Agribus. Dev. Emerg. Econ. 9 (2), 175–200. https://doi.org/10.1108/JADEE-02-2018-0032.

Negi, S., Trivedi, S., 2021. Factors impacting the quality of fresh produce in transportation and their mitigation strategies: empirical evidence from a developing

economy. J. Agribus. Dev. Emerg. Econ. 11 (2), 121–139. https://doi.org/10.1108/JADEE-07-2020-0154.
Onggo, B.S., et al., 2019. Agri-food supply chains with stochastic demands: a multi-period inventory routing problem with perishable products. Simul. Model. Pract. Theory 97. https://doi.org/10.1016/j.simpat.2019.101970.
Onwude, D., et al., 2022. Physics-driven digital twins to quantify the impact of pre- and postharvest variability on the end quality evolution of orange fruit. Resour. Conserv. Recycl. 186 https://doi.org/10.1016/j.resconrec.2022.106585.
Orjuela-Castro, J.A., Orejuela-Cabrera, J.P., Adarme-Jaimes, W., 2019. Last mile logistics in mega-cities for perishable fruits. J. Ind. Eng.d Manag. 12 (2), 318–327. https://doi.org/10.3926/jiem.2770.
Paini, J., et al., 2022. Valorization of wastes from the food production industry: a review towards an integrated agri-food processing biorefinery. Waste BioMass Valorization 13 (1), 31–50. https://doi.org/10.1007/s12649-021-01467-1.
Pallathadka, H., et al., 2022. A review of using artificial intelligence and machine learning in food and agriculture industry. In: Proceedings of the 2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering, ICACITE 2022. Institute of Electrical and Electronics Engineers Inc., pp. 2215–2218. https://doi.org/10.1109/ICACITE53722.2022.9823427
Papargyropoulou, E., et al., 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. J. Clean. Prod. 76, 106–115. https://doi.org/10.1016/j.jclepro.2014.04.020.
Parmar, A., et al., 2018. Post-harvest management and associated food losses and by-products of cassava in southern Ethiopia. Food Secur. 10 (2), 419–435. https://doi.org/10.1007/s12571-018-0774-7.
Pikora, M., Trzaska, K., Ponder, A., 2021. Assessment of the impact of the functioning of the fifo on the occurrence of organic products with an exceeded use-by date. Ochr. Sr. Zasobow Nat. 32 (3), 29–36. https://doi.org/10.2478/oszn-2021-0012.
Porat, R., et al., 2018. Postharvest losses of fruit and vegetables during retail and in consumers' homes: quantifications, causes, and means of prevention. Postharvest Biology and Technology. Elsevier B.V., pp. 135–149. https://doi.org/10.1016/j.postharvbio.2017.11.019
Porter, S.D., et al., 2018. Avoidable food losses and associated production-phase greenhouse gas emissions arising from application of cosmetic standards to fresh fruit and vegetables in Europe and the UK. J. Clean. Prod. 201, 869–878. https://doi.org/10.1016/j.jclepro.2018.08.079.
Poudel, D.D., et al., 2020. Climate smart dry chain for food and nutrition security in Nepal. Strateg. Plan. Energy Environ. 39 (3–4), 131–150. https://doi.org/10.13052/spee1048-4236.39147.
Priefer, C., Jörissen, J., Bräutigam, K.-R., 2016. Food waste prevention in Europe - A cause-driven approach to identify the most relevant leverage points for action. Resour. Conserv. Recycl. 109, 155–165. https://doi.org/10.1016/j.resconrec.2016.03.004.
Principato, L., et al., 2019. Adopting the circular economy approach on food loss and waste: the case of Italian pasta production. Resour. Conserv. Recycl. 144, 82–89. https://doi.org/10.1016/j.resconrec.2019.01.025.
Raak, N., et al., 2017. Processing- and product-related causes for food waste and implications for the food supply chain. Waste Manag. 61, 461–472. https://doi.org/10.1016/j.wasman.2016.12.027.
Rahman, M.M., Nguyen, R., Lu, L., 2022. Multi-level impacts of climate change and supply disruption events on a potato supply chain: an agent-based modeling approach. Agric. Syst. 201 https://doi.org/10.1016/j.agsy.2022.103469.
Ramirez-Asis, E., et al., 2022. A review on role of artificial intelligence in food processing and manufacturing industry. Mater. Today Proc. 51, 2462–2465. https://doi.org/10.1016/j.matpr.2021.11.616.
Raut, R.D., et al., 2019. Improvement in the food losses in fruits and vegetable supply chain - a perspective of cold third-party logistics approach. Oper. Res. Perspect. 6 https://doi.org/10.1016/j.orp.2019.100117.
Riesenegger, L., Hübner, A., 2022. Reducing food waste at retail stores—An explorative study. Sustainability 14 (5), 2494.
Sadhukhan, J., et al., 2020. Perspectives on "game changer" global challenges for sustainable 21st century: plant-based diet, unavoidable food waste biorefining, and circular economy. Sustainability 12 (5). https://doi.org/10.3390/su12051976 (Switzerland)Available at:
Saengsathien, A., et al., 2023. The cold chain of golden apple snail: a case study. Engineering and Applied Science Research. Paulus Editora, pp. 1–9. https://doi.org/10.14456/easr.2023.1.
Saldaña, J. (2013) *The Coding Manual for Qualitative Researchers*. 2nd edn. Edited by J. Seaman. London: SAGE. Available at: www.sagepublications.com.
Santos, D., Lopes da Silva, J.A., Pintado, M., 2022a. Fruit and vegetable by-products' flours as ingredients: a review on production process, health benefits and technological functionalities. LWT. Academic Press. https://doi.org/10.1016/j.lwt.2021.112707.
Santos, M.J., et al., 2022b. On the impact of adjusting the minimum life on receipt (MLOR) criterion in food supply chains. Omega 112. https://doi.org/10.1016/j.omega.2022.102691 (United Kingdom)Available at:
Satiti, D., Rusdiansyah, A., 2018. Model of refrigerated display-space allocation for multi agro-perishable products considering markdown policy. In: Proceedings of the IOP Conference Series: Materials Science and Engineering. Institute of Physics Publishing. https://doi.org/10.1088/1757-899X/337/1/012019.
Sawaya, W.N., 2017. Impact of food losses and waste on food security. Water, Energy and Food Sustainability in the Middle East: The Sustainability Triangle. Springer International Publishing, pp. 361–388. https://doi.org/10.1007/978-3-319-48920-9_16.
Selvaggi, R., et al., 2021. Assessment of tomato peels suitable for producing biomethane within the context of circular economy: a gis-based model analysis. Sustainability 13 (10). https://doi.org/10.3390/su13105559 (Switzerland)Available at:
Sert, S., et al., 2016. Surplus food redistribution for social purposes: the case of coop Lombardia. Organizing Supply Chain Processes for Sustainable Innovation in the Agri-Food Industry. Emerald Group Publishing Limited, pp. 153–173.
Seubert, F., et al., 2020. Making the newsvendor smart - order quantity optimization with ANNs for a bakery chain. In: Proceedings of the AMCIS 2020. https://aisel.aisnet.org/amcis2020.
Seuring S. et al. (2005) 'Conducting a literature review—The example of sustainability in supply chains', Research Methodologies in Supply Chain management: in Collaboration with Magnus Westhaus, pp. 91–106.
Shewfelt, R.L., Prussia, S.E., 2021. Challenges in handling fresh fruits and vegetables. Postharvest Handling: A Systems Approach. Elsevier, pp. 167–186. https://doi.org/10.1016/B978-0-12-822845-6.00006-3.
Shoji, K., et al., 2022. Mapping the postharvest life of imported fruits from packhouse to retail stores using physics-based digital twins. Resour. Conserv. Recycl. 176 https://doi.org/10.1016/j.resconrec.2021.105914.
Silapeux, A.G.K., et al., 2021. Waste of fresh fruits in Yaoundé, Cameroon: challenges for retailers and impacts on consumer health. Agriculture 11 (2), 1–12. https://doi.org/10.3390/agriculture11020089 (Switzerland)Available at:
Singh, G., et al., 2023. Modeling the growth barriers of fresh produce supply chain in the Indian context. Benchmarking 30 (2), 653–677. https://doi.org/10.1108/BIJ-09-2021-0517.
Skendi, A., et al., 2020. Advances on the valorisation and functionalization of by-products and wastes from cereal-based processing industry. Foods. MDPI Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/foods9091243.
Somkun, P.N., 2020. Mathematical modeling approach applied to food waste reduction at retailer and consumer levels in food supply chain. Food Industry Wastes: Assessment and Recuperation of Commodities. Elsevier, pp. 409–429. https://doi.org/10.1016/B978-0-12-817121-9.00019-X.
Stancu, V., Haugaard, P., Lähteenmäki, L., 2016. Determinants of consumer food waste behaviour: two routes to food waste. Appetite 96, 7–17. https://doi.org/10.1016/j.appet.2015.08.025.
Steynberg, P., Goedhals-Gerber, L.L., van Dyk, E., 2022. An analysis of the impact of logistics processes on the temperature profile of the beginning stages of a blueberry supply chain. Horticulturae 8 (12). https://doi.org/10.3390/horticulturae8121191.
Strauss, A., Corbin, J., 1990. Basics of Qualitative Research. Sage publications.
Sundgren, C., 2020. Supply chain structures for distributing surplus food. Int. J. Logist. Manag. 31 (4), 865–883. https://doi.org/10.1108/IJLM-10-2019-0267.
Surucu-Balci, E., Tuna, O., 2021. Investigating logistics-related food loss drivers: a study on fresh fruit and vegetable supply chain. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2021.128561, 318. Available at:
Tagarakis, A.C., et al., 2021. Bridging the gaps in traceability systems for fresh produce supply chains: overview and development of an integrated iot-based system. Appl. Sci. 11 (16) https://doi.org/10.3390/app11167596 (Switzerland)Available at:
Tedesco, D.E.A., et al., 2019. Bioconversion of fruit and vegetable waste into earthworms as a new protein source: the environmental impact of earthworm meal production. Sci. Total Environ. 683, 690–698. https://doi.org/10.1016/j.scitotenv.2019.05.226.
Teigiserova, D.A., Hamelin, L., Thomsen, M., 2020. Towards transparent valorization of food surplus, waste and loss: clarifying definitions, food waste hierarchy, and role in the circular economy. Sci. Total Environ. 706 https://doi.org/10.1016/j.scitotenv.2019.136033.
Thakur, M., et al., 2021. A multidisciplinary approach for improving resource efficiency in the Indian surimi supply chain. Appl. Sci. 11 (22) https://doi.org/10.3390/app112210984 (Switzerland)Available at:
Thi, T.H.H., Tang, M.H., Nguyen, Q.L., 2022. Cold chain and food loss in the Vietnamese food chain. Transportation Research Procedia. Elsevier B.V., pp. 44–52. https://doi.org/10.1016/j.trpro.2022.09.006
Thomas, D.R., 2006. A general inductive approach for analyzing qualitative evaluation data. Am. J. Eval. 27 (2), 237–246. https://doi.org/10.1177/1098214005283748.
Tostivint, C., et al., 2017. Measuring food waste in a dairy supply chain in Pakistan. J. Clean. Prod. 145, 221–231. https://doi.org/10.1016/j.jclepro.2016.12.081.
Tranfield, D., Denyer, D., Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br. J. Manag. 14 (3), 207–222.
Trento, L.R., et al., 2021a. Industry-retail symbiosis: what we should know to reduce perishable processed food disposal for a wider circular economy. J. Clean. Prod. 318 https://doi.org/10.1016/j.jclepro.2021.128622.
Trento, L.R., et al., 2021b. Industry-retail symbiosis: what we should know to reduce perishable processed food disposal for a wider circular economy. J. Clean. Prod. 318 https://doi.org/10.1016/j.jclepro.2021.128622.
Tröger, K., et al., 2020. *Re*-framing post-harvest losses through a situated analysis of the pineapple value chain in Uganda. Geoforum. 111, 48–61. https://doi.org/10.1016/j.geoforum.2020.02.017.
Turan, C., Ozturkoglu, Y., 2022. A conceptual framework model for an effective cold food chain management in sustainability environment. J. Model. Manag. 17 (4), 1262–1279. https://doi.org/10.1108/JM2-09-2020-0239.
UNEP, W., 2021. UNEP Food Waste Index Report 2021. United Nations Environment Programme Nairobi.
United Nations, 2015. Transforming Our world: The 2030 Agenda For Sustainable Development. United Nations, Department of Economic and Social Affairs, New York [Preprint].

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. J. Cult. Econ. 13 (2), 207–220. https://doi.org/10.1080/17530350.2019.1684339.
Verghese, K., et al., 2015. Packaging's role in minimizing food loss and waste across the supply chain. Packag. Technol. Sci. 28 (7), 603–620. https://doi.org/10.1002/pts.2127.
Villalobos, J.R., et al., 2019. Research directions in technology development to support real-time decisions of fresh produce logistics: a review and research agenda. Computers and Electronics in Agriculture. Elsevier B.V. https://doi.org/10.1016/j.compag.2019.105092
Viscardi, S., Colicchia, C., Creazza, A., 2022. Circular economy and food waste in supply chains: a literature review. Int. J. Logist. Res. Appl. 1–26. https://doi.org/10.1080/13675567.2022.2128095.
Vlajic, J.V., Mijailovic, R., Bogdanova, M., 2018. Creating loops with value recovery: empirical study of fresh food supply chains. Prod. Plan. Control 29 (6), 522–538. https://doi.org/10.1080/09537287.2018.1449264.
Weaver, R.D., Moon, Y., 2018. Pricing perishables with uncertain demand, substitutes, and consumer heterogeneity. Int. J. Food Syst. Dyn. 9 (5), 484–495. https://doi.org/10.18461/ijfsd.v9i5.958.
Wickrama Gunaratne, K., Jayaratne, P., 2020. Assessing significant factors for sustainable cold chain performance in Sri Lankan context. Int. J. Integr. Supply Manag.
Wigati, L.P., Sutrisno, Darmawati, E., 2019. Losses and waste of tomato and red chilli along the supply chain. In: Proceedings of the IOP Conference Series: Earth and Environmental Science. https://doi.org/10.1088/1755-1315/230/1/012001.
Wu, W., et al., 2019. Environmental trade-offs in fresh-fruit cold chains by combining virtual cold chains with life cycle assessment. Appl. Energy 254. https://doi.org/10.1016/j.apenergy.2019.113586.
Xue, L., et al., 2019. Efficiency and carbon footprint of the German meat supply chain. Environ. Sci. Technol. 53 (9), 5133–5142. https://doi.org/10.1021/acs.est.8b06079.
Yan, H., Song, M.J., Lee, H.Y., 2021. A systematic review of factors affecting food loss and waste and sustainable mitigation strategies: a logistics service providers' perspective. Sustainability 13 (20). https://doi.org/10.3390/su132011374 (Switzerland)Available at:
You, L., Schudel, S., Defraeye, T., 2023. Developing of biophysical food for monitoring postharvest supply chains for avocado and potato and deploying of biophysical apple. J. Food Eng. 338 https://doi.org/10.1016/j.jfoodeng.2022.111219.
Zhu, J., et al., 2022. Environmental perspectives for food loss reduction via smart sensors: a global life cycle assessment. J. Clean. Prod. 374 https://doi.org/10.1016/j.jclepro.2022.133852.
Ögel, İ.Y., Ecer, F., Özgöz, A.A., 2023. Identifying the leading retailer-based food waste causes in different perishable fast-moving consumer goods' categories: application of the F-LBWA methodology. Environ. Sci. Pollut. Res. 30 (12), 32656–32672. https://doi.org/10.1007/s11356-022-24500-9.