A Systematic Literature Review on strategies to reduce the Food Loss and Waste

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Abstract: The Food and Agriculture Organization of the United Nations estimates that one-third of edible food, equivalent to 1.3 billion tons per year, is lost or wasted. The reduction of food losses and waste (FLW) presents opportunities under economic (e.g., wasting money), environmental (e.g., greenhouse gas (GHG) generation), and social (e.g., food security) perspective. There are appropriate responses to manage, according to a circular economy approach, the surplus food: prevention (i.e., reducing at the source; optimizing processes; adapting production to needs), recovery (i.e., redistributing food to people who need and/or want it), and finally recycling (i.e., feeding animals; using scraps for industrial production, energy, or compost). In the scientific literature, there are several proposals for reusing or valorizing agri-food industrial waste. This paper aims to compile and assess the existing sustainable strategies in the agri-food management adopted to minimize the FLW. For this scope, the scientific studies in this research area have been collected. The effects pursued from the various solutions have been evaluated, considering the long-term environmental and social impacts. Consistently to the research aim, a systematic literature review by implementing a manual search of the manuscript published in the last ten years has been conducted. The results provide a clear picture of the existing sustainable strategies in agri-food management to identify the benefits, limitations, and research gap of the current scientific research.

Keywords: Agri-food Waste, Agri-food Supply Chain Management, Valorisation of Agri-food Waste, Agri-food by-product, Circular Economy

1. Introduction

In recent years, the growing world population requires production and supply of food never seen before in history. The world population reached 7,7 billion in mid-2019, and the analyses carried out estimates that in 2030, the world population will increase to 8,6 billion. In 2050 it is expected to increase the world population to 10 billion people (UN World Population Prospects 2019). In figure 1 is showed the growth of the population and of global cereals production in last fifty years.

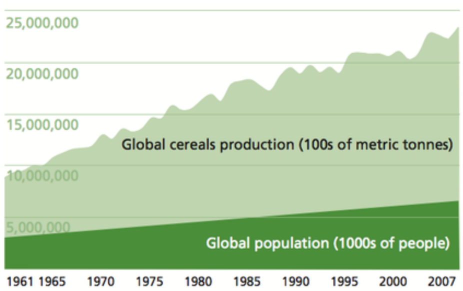

Figure 1: Trend of world population and cereals production (source: U.N. Food & Agriculture FAOSTAT database, U.S. Census International database)

The increasing of the food production led to intensive use of the environmental resources that generate adverse effects on soil fertility, erosion, water consumption, and biodiversity (FAO 2009). Recent scientific studies showed a direct relationship between increasing food production and negative effect on climate change (FAO, 2011). Consistently to these considerations, the agri-food supply chain (i.e., production, transportation, processing and manufacturing, and disposal) plays an essential role under environmental perspective. Recent data showed that the food production sector is responsible for one-quarter of the world's GHG emissions (Ritchie, 2019). In this context, new challenges and problems emerged, many of which are related to food supply chain management. Food and Agriculture Organization (FAO) of the United Nations estimates that one-third of edible food, equivalent to 1.3 billion tons per year, is lost or wasted (FAO, 2011). The "Roadmap to a Resource Efficient Europe", one of the pillars of the "Resource Efficiency Flagship" in the EU 2020 strategy (EC, 2011), underlines that the food waste reduction could contribute to improving resource efficiency and food security at a global level. Therefore, the planned strategy aims to reduce the food chain's resource inputs by 20%. Similarly, a reduction of the inedible food waste by 50% was setting as the 2020 target. Besides, the 2nd Sustainable Development Goal of the United Nations stresses the priority of "end hunger, achieve food security, and improve the nutrition promoting a sustainable agriculture" to halve the per capita food waste at the retail and consumer level. Hence, the reduction of food losses and waste (FLW) aims to ensure greater efficiency in using natural resources.

The food losses arise at all stages of the supply chain due to different problems: food degradation, mechanical damage, storage, sorting, processing, and transportation, or due to legal and private quality standards. The processing industry phase significantly affects the FLW in the agri-food supply chain: it is estimated a loss rate between 11% and 25% (Frieling et al., 2013, Willersinn et al. 2015). In this regard, in 2011, FAO referred to as "food losses" when the edible food gets lost at production, post-harvest, and processing stages. On the contrary, the food losses due to later stages of the supply chain are defined as "food waste" (FAO, 2011). The circular economy paradigm is an appropriate approach to manage the reduction of the FLW to address practices and approaches, allowing to join technological solutions, behavioural and cultural changes, and policy decisions (Vilarino et al., 2017) providing decision makers with a low-complexity and scalable Information and Communication Technology (ICT) (Carli et al., 2020). The management of the FLW is specifically analysed in the model defined "Food Waste Hierarchy" (Papargyopoulou et al., 2014) developed intending to identify different available options lead to planning a set of priority actions (Redlinghofer et al., 2020) classified in term of environmental impact (Cristobal et al., 2018). The main actions suggested are based on the:

- FLW prevention (i.e., reducing at the source; optimizing processes; adapting production to needs);
- FLW recovery (i.e., redistributing food to people who need and/or want it);
- FLW recycling (i.e., feeding animals; using scraps for industrial production, energy, or compost).

In the scientific literature, there are several proposals for reusing or valorising agri-food industrial waste like by-products for human consumption, food ingredients, or other industrial applications, contributing to FLW reduction providing the same time, economic benefits (Tlais et al., 2020). This paper provides a comprehensive literature review of the relevant works on existing sustainable agri-food management strategies to minimize the FLW. The various solutions have been evaluated, considering the long-term economic, environmental, and social impacts. The results provide a clear picture of the existing sustainable strategies in agri-food management to identify the benefits, limitations, and research gap of the current scientific research. The aim is to provide a useful tool for scholars (researchers), companies, policymakers, and interested in this field.

The paper is organized as follows. Section 2 describes the levels and the characteristics of the agri-food supply chain. Research methodologies are described in Section 3. In section 4, several research papers published in recent years dealing with food loss and waste management are presented differently. Finally, conclusions are shown in Section 5.

2. Agri-food Supply Chain management

The supply chain management (SCM) represents the set of integrated planning, coordination, and control phases of all business processes and the supply chain activities to provide higher value for the customer, ensuring the minimum overall cost for the supply chain (Van der Vorst, 2000). The value is related to the so-called "triple P": People, Planet and Profit; therefore, the social and environmental aspects are also incorporated alongside financial performance (Van Der Vorst, 2006). In the agri-food sector, the supply chain is considered a complex food chain network, also called the Food Supply Chain Network (FSCN). Each company is in at least one supply chain (generally has more suppliers and customers at the same time). The FSCN can be described through different levels where different supply chains can be developed. The main four levels are farmers, processors, distributors, and retailers. The vision in which the supply chain in agri-food is considered a simple chain of linear actors connected with one-way arrows that move from producer to final consumer (Tan, 2001) is quite essential compared to the actual complexity of the system.

An integrated decision-making process is needed to manage the Agri-food Supply Chain, which has become more complex and multilevel. According to Gokam and Kuthambalayan, there are two main constraints considered in the Agri-food Supply Chain management. The first one concerns the specific shelf-life of foods treated. In particular, there are products with a long shelf-life (i.e., cereals, legumes, etc.) and with a short shelf-life, also defined as perishable (i.e., fruits and vegetables) (Gokam and Kuthambalayan, 2017). Second one concern the types of agri-food supply chains. There are raw products and processed foods that add value by storing, portioning, and further processing (Van der Vorst, 2000). The strategies to be adopted for each case can be very different, and in many cases, the constraints highlighted lead the manager to set appropriate actions case-by-case.

The new approach with multi-dimensional levels in the agri-food supply chains can be considered a constellation of actors connected to combine knowledge and skills capable of mutually producing value. In 2018, a configuration defined as "molecular" for the visualization of the agri-food supply chains was proposed by Lioutas et al.; the proposed model is structured in three different levels. The nucleus of interconnected, mutually dependent farmers, processors, wholesalers, retailers, and consumers are shown in the first level. Other less cohesive but slightly interconnected actors (i.e., entities that provide the main actors with resources, information, raw materials, intermediate products, by-products, and residuals) are included in the second level. In the third level, the external market environment defined by a cloud of actors including banks, research institutes, institutional, and others are considered (Lioutas et al., 2018). The synergies and the dynamic relationships are formed and remodeled during the functioning of this constellation, facilitating the exchange of knowledge and information within an agri-food supply chain (Neutzling et al., 2018). This model is interconnected with other chains and networks through some common nodes in the real market environment. Therefore, knowledge and innovation can also spread in an agri-food supply chain system through an interchange mechanism.

Consistently to the development of the ICT in the sector, the main technologies provided by Industry 4.0 in the last years (Saetta and Calderelli, 2019) led to increasing of the vertical integration and horizontal of the alliances in FSCN with referring to aspects like logistics, distribution, quality and food standard, and retailer forms (Dotoli et al., 2014). The innovations in agri-food supply chain management improved several aspects in terms of system efficiency, environmentally sustainable processes, reduction of FLW, quality, and security foods. The transformation processes adopt smart devices that allow access to important information in real-time throughout the entire supply chain and check the efficiency of the single part of the system (Raheem, D. et al., 2019). The ICT tools introduced by industry 4.0 (i.e., big data, Internet of Things, advanced analytics, cloud computing, and cyber-physical systems) allowed to adopt strategies that gather, process, and analyse temporal (Piccinni et al, 2017), spatial, and individual data and combine it with other information to support management decisions to improve resource use efficiency, productivity, quality, profitability and sustainability of the agricultural production (Huang et al., 2007). In recent years, another important innovation also applied in the agri-food sector is related to the blockchain. This technology allowed transparency, verifiability, and immutability of data and information to all stakeholders. It is a digital ledger not based on centralized servers but peer-to-peer links. In this way, it is possible to have trust and reliability throughout the supply chain (Caro et al., 2018). According to experts, the main issues in this field depend on losses during the growing and harvesting phase, the process losses, the contamination in the process causing quality loss, and the losses caused by lack of cooling/cold storage (Parfitt et al., 2010).

Consistently with the observations mentioned above, to fully investigate the research problem, the following subsidiary research questions are raised:

RQ1: Which are the existing strategies to reduce the FLWs in the agri-food supply chain under a sustainable perspective?

RQ2: What are the approaches that affect the efficiency of the agri-food processes?

This work focuses on the study of strategies and approaches that reduce the FLW in the processing stage of the agri-food supply chain by analyzing the proposals in the scientific literature.

3. Methodology

In this section, a methodology was applied to assess the existing sustainable agri-food management strategies adopted to minimize the FLW. As aforementioned, the Systematic Literature Review (SLR) method includes academic research papers on the existing agri-food management strategies. Contrarily to a narrative literature review (Baumister and Leary, 1997), in which a personal approach was adopted to select the authors' contribution (Tranfield et al., 2003); an SLR develops a rigorous approach that can reduce the narrative literature review's disadvantages, ensuring a structured approach to scientific contributions' identification. SLR aims to identify works critically evaluating and integrating all relevant and high-quality studies addressing one or more research questions. The SLR methodology was based on the following key stages: (i) research scope; (ii) planning of the study; (iii) identification of the works; and (iv) screening and eligibility (Siddaway, 2014).

In the first phase, the keywords/search terms have been identified to achieve the research scope (i). Consistently to this target, the main words adopted are "Agrifood" associated with "Waste", "Losses and Waste", "Supply Chain Management", "By-product", "Reuse", "Strategy" and "Containment". Besides, the word "Reuse" was used with "Food Losses", "Damage Food", and "Waste for food application". Finally, the research was completed with the keywords "Valorization Agrifood Waste" and "Food Waste Hierarchy". The literature review has been addressed for the planning of the study (ii), adopting four electronic databases: "Scopus", "Web of Science", "Science Direct" and "IEEExplore". The identification of the works (iii) has been conducted on 16 February 2021, with a time window referring to the last ten years. The total number of works identifies with the keywords mentioned above for each electronic database are shown in Table 1. The screening and eligibility (iv) of the identified works were pursued by including and excluding the works considered outside the SLR scope. In particular, the inclusion and exclusion criteria were identified to conduct the analysis with methodological rigor and evaluate the contributions' relevance. Therefore, the inclusion criteria considered are:

- selection of only scientific articles;
- only in English language;
- contribution with a peer-reviewed;
- studies based on agri-food losses and waste;
- studies based on minimize the FLW through management strategies, considering in particular the supply chain phase.
- studies based on the valorisation of the FLW, using the by-product especially for reuse to feed humans.

The exclusion criteria considered to refuse contributions inconsistent with the research scope are:

- lectures, theses, books, books chapter, reports, presentations, and other types of contributions were rejected;

- contribution without a peer-reviewed;
- studies based on food waste generated after consuming and household food waste;
- studies based on minimizing FLW in retailers;
- studies based on the valorisation of the FLW in recovery for energy or other purposes, recycling for cosmetics, pharmaceutics, and other fields, and reuse for animal reed.

Table 1: Search strings used in SCOPUS, WOS, SCIENCE DIRECT and IEEE database.

	Database			
Search String	SCOPUS	WOS	SCIENCE DIRECT	IEEE
Agrifood Waste	83	64	34	1
Agrifood Losses and Waste	9	10	3	0
Agrifood Supply Chain Management	63	45	32	11
Agrifood By-product	21	19	13	0
Valorization Agrifood Waste	11	11	4	0
Agrifood Reuse	8	9	6	0
Reuse food losses	87	159	111	1
Reuse damage food	26	29	30	2
Reuse Waste for food applications	231	199	128	3
Food Waste Hierarchy	147	122	100	2

The temporal subdivision of the paper selected (i.e., 2010-2020) proved that most of the paper identified are published in the period included in last three years (41%), in the period from 2013 to 2017 a share of 35% of the articles was identified. The rest of the paper was published before 2013.

4. Results and discussion

Food loss and waste in the agri-food supply chain is a crucial inefficiency both from an ethical and economic point of view. For fruit and vegetable, the issue can be quantified in a loss and waste of about 50% of the annual harvest (FAO, 2011). Therefore, it is essential to analyze the phases of the agri-food supply chain to reduce these values. In the EU-28, it is estimated that excluding households waste, which is responsible for 53% of the total food waste, the other FLW in the supply-chain are due to processing (around 19%), production (about 11%), and retail (around 5%), (Stenmarck et al., 2016). At the EU level, the main objective consists of optimizing the resources adopted from the food production, reducing the environmental impact in the agri-food supply chain, according to the Circular Economy paradigm. The two European Directives (2008/98/EC and 2018/851) lead to a policy aimed at preventing, managing, and reducing waste at all supply chain stages. Both Directives lead the Member States to develop waste prevention programs, concentrate on the key environmental impacts considering the whole life cycle of products and materials. The priorities of Directives are focusing on the prevention and management of waste, according to the following hierarchical strategies: prevention, preparing for re-use, recycling, another recovery (energy), and disposal (Papargyropoulou et al., 2014). Under this perspective, some countries implemented a national plan for food waste prevention and reduction, while others applied specific laws on food waste issues or plans at the municipal level. The prevention of the FLW is the first objective in waste management to implement strategies to increase environmental sustainability. It is possible to implement this approach at the strategic or operative planning level. The analysis was conducted focusing on the scientific research pursued to reduce the FLW in the agri-food supply chain processing phase. The FLW in the processing phase origins on different causes:

- misshaped or malformed or damaged food at the entry of the processor during the processing phase (Teigiserova et al., 2020).
- non-conformity or not-compliant food products with standard imposed (Ciculllo et al., 2021).

The FLW can be divided into the following main categories:

- reusable food for human consumption also through transformation processes into different food products
- reusable food for animal consumption
- reusable resource as by-products in another sector
- waste which it is not possible to reuse

Several technologies allow reducing the FLW in this phase. Many strategies aim to limit the surplus in food production, identifying the target products to commercialize in the specific market, adopting advanced tools such as forecasting, monitoring, and grouping. Chemical (e.g., active packaging) and mechanical preservation (e.g., storage and transport systems) allow extending the shelf-life of the product, improving at the same time the quality.

4.1 Use as by-products to make new products for human consumption

The technological innovation in the processing phase allowed the development of strategies for the reuse of the food. In most cases, these technologies consist of transforming fresh FLW, like fruits and vegetables, into other products like snacks, soups, fruit juices, etc. (Ciculllo et al., 2021), creating value from waste or low-value products. High potential opportunity derived with the implementation of further processing technologies to obtain a new edible derivative product (Galanakis, 2012). Fruit and vegetable waste and by-products are considered ingredients in the food industries (Malenica and Bhat, 2020). Studies evaluating the potential of fruit and vegetable waste developing value-added products and functional foods are currently underway. The fruit and vegetable waste assessed in the studies are apple, beet, potato, and carrot waste.

4.2 Reprocessing or repacking to ensure a desired degree of quality

In the agri-food supply chain, often at the retail stage, the surplus food (especially fresh food) could be reused for human consumption (e.g., adopting redistribution initiatives) (Giordano et al., 2020). Unfortunately, in most cases, the transport and distribution costs prevent food relocation (Buzby et al., 2014). Generally, the difficulty to manage the excess of food depends on hygiene rules that limit the amount of food to reuse (Priefer et al., 2016). An Intrinsic Recoverability parameter is defined to evaluate the degree of use of the surplus food for human consumption in the lack of additional management efforts from farmers, producers, retailers, and intermediaries. This parameter depends on the type of product and the activities required for food management (Garrone et al., 2014). Several opportunities have been developed to reuse surplus food. In particular, it is possible to remake, remanufacture, and repackage some products incurred in production errors or other events.

4.3 Donation to food banks, charities, other no-profit organizations, or redistribution initiatives

An interesting approach is to provide free of charge to non-profit organizations that assist the poor; in this case, organizations can be front-end or back-end, such as food banks (Garrone et al., 2016). A similar experience was applied in Turin's city retailer market to reuse food waste at the end of a day, providing these edible foods to the people who needed them (Fassio and Minotti, 2019). Cooperative is another opportunity to reuse the FLW for human consumption. In the wine sector, some practices use wastes of the primary process to add value in various sectors to the wine pomace and lees (Donner et al. 2020).

4.4 Discount and promotion of malformed food products or sales through secondary markets

The malformed fruits and vegetables are considered sub-standard; one of the latest actions under investigation consists of re-introducing these products into the market. The aesthetic defect does not compromise the taste or health benefits. Many companies intend to supply these malformed products to retail customers with minimal costs (Slate, 2015). Another strategy is the sale with promotions and discounts surplus food with a close internal expiration date in the primary market and alternatively in the secondary market.

4.5 Research Gaps

Few works were identified to reduce the FLW in the processing of the agri-food supply chain. In particular, there is no in-depth analysis of business models to valorize the potential of FLW without or with new processing phases, including human consumption. ICT and the innovations provided by Industry 4.0 are a great opportunity for the agri-food supply chain to reduce FLW during the various steps and create tools, systems, and other improvements to manage and reuse FLW.

5. Conclusion

Agri-food supply chain is a significant activity to connect producers with consumers effectively. Increasing the quantities of the food necessary to meet the needs of the world's growing population requires an essential effort to reduce FLW. A great amount of human feed is lost or wasted. Reducing the FLW is an economic (wasting money), environmental (GHG emissions), and social (food security) opportunity, allows generating interesting positive effects for all stakeholders. The circular economy approach is applied in this sector to manage the surplus food to create more efficient processes. The most exciting strategies and solutions to reduce FLW, reusing it for human feed, are classified in four main categories:

1. Use as by-products to make new products for human consumption.
2. Reprocessing or repackaging to ensure a desired degree of quality.
3. Donations to food banks, charities, other no-profit organizations, or redistribution initiatives.
4. Discount and promotion of malformed food products or sales through secondary markets.

One of the limits of the present research concerns the lack assessment of the volume of the FLW reduced, could support the study to identify the most sustainable strategies from an environmental, social, and economic point of view.

The literature review shows few researches and works in the reuse of FLW for human consumption purposes. Research opportunities can be carried out in this context given the gap identified, especially by implementing new business models, using ICT tools to develop systems, platforms, and Apps. With the innovations provided by Industry 4.0 also in the agri-food supply chain.

Starting from the result of the scientific literature conducted, the next step of the research could be focused on the develop of a new circular business model aiming to prove the benefit in sustainable term due to adoption oof ICT and Industry 4.0 technologies in the agri-food supply chain.

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