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The sustainability challenges of fresh food supply chains: an integrative framework

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Abstract
Fresh food supply chains (FFSC) are pivotal in food and agricultural systems, with effective management crucial for addressing hunger and poverty globally and contributing to various Sustainable Development Goals (SDGs). Increasing consumer demand for safer, eco-friendly, and sustainably produced fresh products has highlighted the importance of sustainability in FFSC. This growing focus poses challenges for academics and practitioners dedicated to sustainable development and meeting evolving consumer expectations. FFSC management is notably complex due to unique factors such as varying perishability, seasonal production, and the need for adherence to safety and quality standards, amidst complex and diverse networks. Despite its critical role, a structured approach to navigating FFSC sustainability challenges is lacking. Our research undertakes a thorough two-stage examination of current scholarly work to identify key factors affecting FFSC sustainability. Initially, we reviewed 182 papers on broader FFSC management to gauge the field's research landscape, guiding a focused review. Subsequently, a detailed analysis of 39 papers specifically on FFSC sustainability led to the development of a comprehensive framework, comprising FFSC characteristics, entities, management practices, and enabling factors. This framework aims to enhance understanding and guide efforts by researchers, practitioners, and policymakers towards fostering sustainability in FFSC, thereby supporting the achievement of SDGs.

Keywords Fresh food supply chain · Food access · Food waste · Food loss · Sustainable supply chains

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Abbreviations

ASC	Agriculture supply chain
FAO	Food and Agriculture Organization
FFSC	Fresh food supply chain
GHG	Greenhouse gas
ICT	Information and communication technology
IoT	Internet of things
IYFV	International Year of Fruits and Vegetables
OM	Operations management
RFID	Radio frequency identification
RPC	Reusable plastic container
SDG	Sustainable Development Goal
SLR	Systematic Literature Review
UAV	Unmanned aerial vehicles
3DP	Three-dimensional printing

1 Introduction

The Food and Agriculture Organization estimates that between 720 and 811 million people worldwide faced hunger in 2020 (FAO et al., 2021). Climate change on agri-food systems is growing worldwide, contributing to further exacerbating the risks of hunger and malnutrition especially in the most vulnerable groups (COP 27, 2022). The global food and agriculture system plays a crucial role in alleviating this, making a profound change in it, such as increasing agricultural productivity and sustainable food production (United Nations, 2022a). The fresh food supply chain (FFSC) not only broadly affects the food and agriculture system as a whole but also plays a key role in healthy diets, as fresh food is a crucial component for ensuring adequate access to several micronutrients (Maestre et al., 2017).

According to the GBD 2017 Diet Collaborators (2019), low fruit intake (i.e. less than 200–300 g per day) is one of the top three causes of death related to dietary risk factors in the world. The significance of fresh foods calls for a focus on fresh food supply chains involving the operations necessary to bring farm products to final consumers (Gómez & Ricketts, 2013). This supply chain encompasses the farm, wholesalers, warehouses, and retailers from the production to distribution stages and distribution to consumption stages (Gokarn & Choudhary, 2021), being differently designed if we compared, for example, conventional pesticide-based agriculture production with agroecological.

Managing fresh food supply chains presents major challenges owing to specific characteristics, such the perishability of food items. According to Kumar et al. (2020), these chains are marked by increasing concerns about food quality and safety, alarming levels of food waste and food loss, and lack of economic sustainability. The rate of product deterioration can be faster depending on the condition of the product and its environment and can also be largely affected by supply chain's design and planning, since it affects the duration that products spend in each facility and vehicle (Jouzdani & Govindan, 2021). Therefore, perishable products should be harvested, procured, processed, and marketed in a timely manner to avoid a set of negative consequences to this supply chain players, society and environment,

such as catastrophic waste volumes, financial crises for farmers, societal distress, and economic losses across the marketplace (Kumar et al., 2021).

Another concern in the fresh food supply chain is consumers' growing interest in buying cheaper produce and safer, ecologically friendly, and sustainably grown fresh products (Chanda et al., 2021). Hence, FFSC sustainability is becoming an important challenge in this supply chain. The food supply chain, through its production and consumption activities, faces major environmental issues, including the extensive use of natural resource for agriculture (Adebayo, 2023), including water and land, greenhouse gas (GHG) emissions (Adebayo, 2023; Alola & Adebayo, 2023, Ramzan et al., 2022), water pollution, land-use change and biodiversity degradation (Ramzam et al., 2022), the use of synthetic chemicals, food waste, and energy consumption. Social aspects in supply chains relate to topics such as food safety, animal welfare, fairness, employment/training, equal job opportunities, better living conditions, safer workplaces. Economic aspects, which frequently intersect with environmental and social concerns, encompass issues such as profitability, efficiency, quality-based pricing, consumer preferences, cost reduction, and income administration. (Chanda et al., 2021; Gokarn & Choudhary, 2021; Zhu et al., 2018).

Therefore, further investigations should examine the most economically, socially, and environmentally viable system configurations. Recent reviews of food and fresh food supply chains (Kumar et al., 2022; Tort et al., 2022) pointing out some significant insights about this field, they also highlight the importance of considering and incorporating relevant elements into research, such as food characteristics (e.g., perishability), food loss and waste management strategies, and the use of advanced technologies, to analyze their effect on FFSC sustainability.

Although relevant information has already been published, it has been presented in a fragmented manner. A comprehensive view that integrates the main elements influencing FFSC sustainability is still lacking. Consequently, there is a need to develop a conceptual model that compiles and discusses the main elements influencing FFSC sustainability, including those mentioned, along with the main management and control practices applied in the sector. As sustainable food systems are critical to attaining sustainable development (United Nations, 2021), it is of utmost importance to understand how the FFSC can contribute in different ways to improve social, economic, and environmental aspects, to raise the pathways available for further exploration and to reveal the remaining opportunities that require further investigation (Westerholz & Höhler, 2022).

In this context, we conducted a rigorous and structured assessment of the current state of scholarly research in the field to answer the following research question: *What are the key elements in the FFSC configuration to enhance its sustainability?* The main contribution is to provide a comprehensive, integrative framework to improve the systemic understanding of the key elements influencing FFSC sustainability, thereby assisting academics in designing research that advances the topic, and practitioners, organizations, and governments in developing strategies and policies to improve FFSC sustainability.

In summary, this study provides a more integrative framework that enhances the capacity to understand the factors that influence FFSC sustainability, so that existing FFSC can be effectively managed or better redesigned, and in this way contributing to alleviate hunger and malnutrition, achieving progress on SDGs, and contributing to tackling climate change.

2 Methods

We performed a systematic literature review (SLR) in two stages. First, we focused on understanding the overall state of the literature concerning FFSC management. Second, we narrowed the scope down to focus on the key elements contributing to the sustainability of FFSC. The initial stage of the SLR informed and steered our efforts and review parameters for the second stage. Both stages followed the same methodological approach. Figure 1 presents the three-step approach adopted in this SLR (Tranfield et al., 2003). The three steps and research scope ensure replicability and develop a research agenda based on evidence. The subsequent section elaborates on each of these steps.

2.1 Planning: development of the review protocol

We formed a team of three researchers who helped to formulate the research problem. In the first stage of the literature review, we aimed at answering the following question *What is the state of the literature on the management of FFSCs?* In the second stage of the literature review, we framed the following research question: *What are the key elements that play an important role in FFSC configuration to enhance sustainability?* Subsequently, we performed a preliminary search of the databases to identify the current state of the literature and the overall content of recently published papers for both stages. After the initial screening of relevant literature, we set the following criteria to define the scope of the review.

The first criterion emphasized the need to restrict the keywords to obtain an adequate number of relevant papers for further analysis. The second criterion involved the consideration of different keywords. It requires focusing on widely used synonyms and specific expressions in operations management (OM), sustainability and related disciplines. Because these terms were acquired after familiarization with the papers selected for the review, they were included apart from the terms considered before the database search. The fourth criterion required covering the interests of different audiences, such as scholars from OM-related fields (e.g., engineering, management, urban studies, and sociology), given that fresh food operations are multifaceted and interdisciplinary.

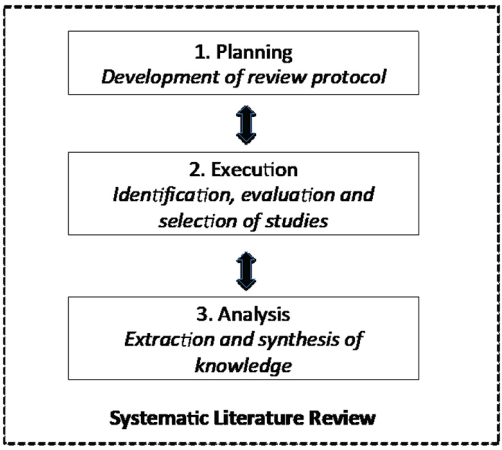

Fig. 1 The overall research approach

2.2 Execution: identification, evaluation, and selection of studies

The literature search comprised the following steps: selecting the bibliographic database or journals, searching keywords, reviewing the selected abstracts, applying the criteria for the inclusion and exclusion of studies, and a full-text review of the selected papers. The searches included only journal papers and literature reviews to capture peer-reviewed studies in different fields. Scopus and Web of Science were selected due to their advanced web search capabilities, large quantities of indexed articles, and their pertinence to our areas of interest (Adriaanse & Rensleigh, 2013; Gavel & Iselid, 2008; Mongeon & Paul-Hus, 2016).

2.2.1 First stage: fresh food supply chain management

We iteratively and exhaustively tested 24 different strings, focusing on the research subject "fresh food supply chain.". In the *first phase*, the ten strings comprised keywords in the general search field: "fresh food," "fresh produce," "perishable food," "supply chain," "value chain," "logistics," and "delivery." delivery. The results yielded a wide range of papers; because several papers were outside the defined scope, there was a need to limit the search by making it more focused. We tested nine combinations of these strings in the general search field in the second phase. However, an analysis of the results called for a *third phase* wherein we performed five-string searches focusing on the research subject "fresh food supply chain."

After analyzing each string, we selected *"fresh food supply chain" OR "fresh food logistics," OR "fresh food delivery," OR "fresh food value chain," OR "fresh produce supply chain" OR "fresh produce logistics" OR "fresh produce delivery" OR "fresh produce value chain" OR "fresh product* supply chain" OR "fresh product* logistics" OR "fresh product* delivery" OR "fresh product* value chain" OR "perishable food supply chain" OR "perishable food logistics" OR "perishable food delivery" OR "perishable food value chain."*

This string was placed in the search field for extracting the title, the abstract, and keywords from both the databases. From Scopus and Web of Science, we retrieved 190 and 127 papers, respectively, amounting to a total of 317 papers. From this set, 118 papers were duplicates (retrieved from both databases). Therefore, our final set had *199 unique papers*. After retrieving these 199 papers, the three researchers individually analyzed the titles and abstracts of each paper to ensure that they were consistent with the objective of the research protocol. After downloading these papers, we excluded 17 papers because they were not written in English. Finally, the database of the first stage consisted of 182 papers.

2.2.2 Second stage: sustainability elements in fresh food supply chain management

After analyzing the results from the first stage, we limited the results to the theme of "sustainability" by combining the search terms used in the first stage (string 1) with a second string formed by the terms "sustainability" OR "sustainable" (string 2). Therefore, the final research string comprised two parts: "string 1" and "string 2".

This combination of strings was placed in the search field to extract the titles, abstracts, and keywords from both databases. We retrieved 52 and 44 papers from Scopus and Web of Science, respectively, totaling 96 papers. From this set, 37 papers were duplicates (retrieved

from both databases). Therefore, our final set contained 59 unique papers. Twenty articles were then rejected due to the defined exclusion criteria (papers that did not address any sustainability dimension of fresh food supply chains; studies whose focus was not fresh food supply chain; studies with a superficial stance). The final database of the second stage consisted of 39 papers.

2.3 Analysis: extraction and synthesis of knowledge

From each of the final set of 39 papers, we extracted and systematized the following data: title; the journal title; authors, the year of publication, country; the sustainability aspects (social, environmental, economic); the FFSC entities studied; the main characteristics of FFSC; the FFSC management and control practices applied; the FFSC enablers. We performed a content analysis to synthesize the findings and constructed an integrative framework that was lacking in the literature, to fill the gap on the elements that most influencing FFSC sustainability.

3 Results

The findings from the first stage of the SLR indicate that FFSC is often conceptualized as part of the agriculture supply chain (ASC). Sustainability aspects are treated in a fragmented, diffuse way. Patidar et al. (2018) explain that ASC presents a vast area of research, including a variety of products such as fruits, pulses, vegetables, nuts, oilseeds, cereals etc. The authors also claim that the diverse array of products poses challenges in supply chain differentiation and in reporting all the categories under a single supply chain. Some relevant decisions in the ASC include harvest planning, transportation, supplier identification and selection, storage, and manufacturing (Soto-Silva et al., 2017).

Most of the studies found in the first stage of the SLR categorize fresh produce under perishable goods that have short life cycles, fail to generate significant end-of-season value, and accumulate quality and quantity losses, with vast sustainability impacts. Since these products undergo deterioration risks and uncertainty, FFSCs involve overly complex supply chain coordination. Given that fresh produce is a daily necessity, it plays crucial economic, social and environmental roles that go beyond the operational aspects of the supply chains. In this context, a knowledge of effective supply chain sustainability aspects can help FFSC players to ensure the seamless delivery of fresh produce from the farm to the plate (Conrad et al., 2012; Su et al., 2014; Wang and Chen, 2013).

Hence, the second stage of the SLR identified the factors affecting sustainability in the fresh food supply chain. The 39 relevant papers show these factors and the sustainability aspects impacted by them. This low number indicates the need for a deeper examination of FFSCs sustainability. The first paper on the topic was from 2007; however, studies on sustainability in FFSC have gained academic attention recently. 85% of all papers were published after 2016 (see Fig. 2), the year in which the 17 Sustainable Development Goals (SDGs), officially came into force (United Nations, 2022b).

There was a peak in 2021, with 38% of the papers published in that year. This can be explained by the designation of 2021 by the UN General Assembly as the International Year of Fruit and Vegetables (IYFV). It raised consciousness of the key role that vegetables and

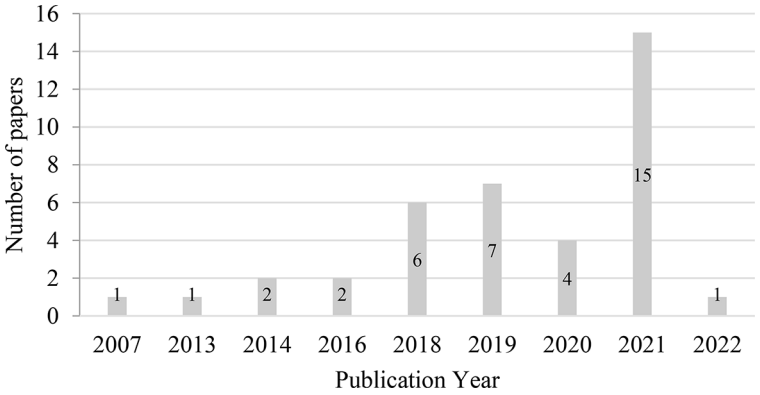

Fig. 2 Growth of FFSC sustainability publications in the food industry

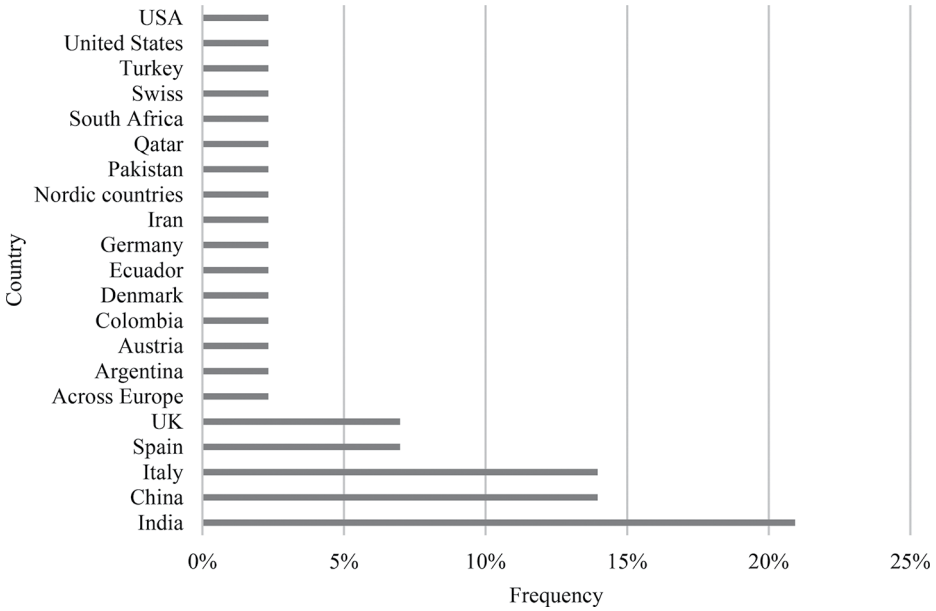

Fig. 3 Growth of FFSC sustainability publications in the food industry

fruits play in nutrition, ensuring food security, and overall health (FAO, 2020). Although the number of papers on the topic has grown in recent years, they are concentrated in a few countries, such as India (21%), China (14%), and Italy (14%), followed by Spain (7%), and the UK (7%). The other countries presented only one study each (see Fig. 3).

Moreover, a deeper analysis of these studies shows that most of the papers focus their analysis on how FFSC impacts the environmental sustainability aspect (79% of the total studies), followed by the economic aspect (67%), and less attention is given to the social aspect (36%). Additionally, the social aspect was first studied only in 2016, while the economic aspect was studied in 2013 and the environmental aspect in 2007.

Considering the environmental aspects, studies show that distinct elements of FFSC mainly impact CO_2 emissions (38% of the papers) and food loss and waste (26%). Other aspects were cited less often: less use of pesticides, fertilizers, and chemicals in production, less use of natural resources (energy, fuel, water, and land), reuse of food waste and recycled waste, reduction in effluent discharge, safe and sound dumping of packaging substances, environmental certification, improvement in environmental stewardship, and ecological problems (ozone layer weakening, eutrophication, acidification, water toxicity etc.).

Concerning economic aspects, we found that most of the papers (28%) showed cost optimization (e.g., pesticide costs, recall costs, food processing and logistics costs, transaction costs, waste management costs, waste disposal costs, and vehicle operation fixed costs), followed by a reduction in food loss and waste (15%) and profit maximization (10%). Other aspects were less mentioned, such as increased productivity, efficiency, income, competitiveness, market share, and price reduction and fluctuations.

Regarding social aspects, 8% of the papers showed reduced food loss and waste. Other aspects were less cited; however, there are a considerable number of papers that show aspects related to some improvement in the livelihood of farm workers, such as better wages and working conditions, better education to the farmworkers' families, improved ethically responsible labor treatment, improvement in the economic status of the farmers, reduction of farmer suicides, employment growth, and securing profits to the farmers. We also observed a concern with the reduction in the number of accidents, job creation, diversity or miscellany of employees, combat of absenteeism problems, unfairness minimization, and efficient and effective delivery of food, particularly to those in vulnerable groups.

The literature review indicated that sustainable FFSC management is achieved through important elements that need to be considered. Knowing them is critical as they may have distinct contributions at different supply chain stages. Thus, we extracted, analyzed, and discussed information from four main elements from the literature review (entities, characteristics, management and control, and enablers) to improve the systemic understanding of the variables influencing FFSC sustainability.

3.1 FFSC entities

Most textbooks point out mapping supply chain entities as one of the first steps toward understanding a complete supply chain and its links. However, the effects of COVID-19 showed that, surprisingly, many companies know little about their supply chain (Norwood & Peel, 2021), which affects their ability to anticipate and act on the causes of supply chain disruptions. This importance is even greater when dealing with FFSCs.

The diversity of products and the complex and heterogeneous network that connects input suppliers (technical and financial services, equipment, seeds, fertilizer, and packaging), farmers (small, medium, large, familiar, local, co-operatives), manufacturers/processors (small, medium, large), intermediaries (warehouses, wholesalers, retailers, transporters, distribution centers, logistics providers, e-commerce enterprises), customers (final customer, restaurants, hotels), and waste services (recycling center, incinerator, food banks, energy retrieval company) (Desiderio et al., 2022; Kumar et al., 2020; Vlajic et al., 2018) make supply chain mapping more relevant to avoid shortages, losses, and wastes.

Therefore, when we look at each supply chain link, we can see that they can be a combination of different entities with very particular related characteristics. For example, the

quantity (many or few), size (large or small), and vulnerability of producers and consumers (high- or low-income) can facilitate and broaden the understanding and characterization of the FFSC. However, these studies do not clearly characterize these aspects, nor do they relate them to the sustainability of the chain. This lack of fundamental characterization hinders the development of improved mechanisms to address the sustainability of FFSC and better frame and understand its impacts of FFSC.

3.2 Main characteristics of FFSC

FFSC is commonly used as a classification of agricultural supply chains (ASC) that differentiates products in their degrees of perishability and freshness, reflecting the differences in how the supply chains are designed and managed. Lusiantoro et al. (2018) considered that the perishability characteristics of each fresh product vary and remain unexplored in research on supply chains. FFSC includes frozen produce, fresh produce, fungus, fruits, meat, dairy, seafood and prepared meals (Pal & Kant, 2020).

Unlike non-perishable products, perishable products are known for their short shelf life cycle, seasonal production, diverse quality and quantity, special requirements for logistical services, compliance with safety and quality standards, demand and cost uncertainties, dependency on climatic conditions, order lead-time, and overall supply chain lead time (Patidar & Agrawal, 2020; Patidar et al., 2018; Salin, 1998; Siddh et al., 2018; Van Der Vorst & Beulens, 2002). Fresh products exhibit different combinations of these characteristics. Along this line, we characterize the products concerning three different cycles (production, consumption, and distribution) and check their impact on the sustainability aspects of FFSC.

Related to the production cycle, some products have a long productive cycle - meat and various perennial fruits. For example, it takes two to three years for an animal to be ready for slaughter and five years for a mango plantation to bear the first fruit. The production plan for these products must have a long-term perspective, provide high initial investment, and ensure good cash flow management. Inertia in decision-making is high because any product change incurs high investments. Other products have shorter production cycles, such as the vast majority of vegetables (e.g., lettuce, arugula, carrots, and cabbage), some fruits (e.g., strawberries and tomatoes), and some grains (e.g., corn, beans, and soybeans). These products have shorter production cycles and are not perennial. Therefore, these crops were replanted in each cycle. While this allows for continuous improvement from one crop to another, it is labor-intensive and requires intensive planting (including input suppliers) and preharvest planning.

Despite the great differences mentioned above, we did not find any study that relates these aspects to the sustainability of FFSC. It is important to highlight the degree of product perishability in the consumption cycle. Some products must be consumed quickly, as they are highly perishable, as is the case with most vegetables. However, other crops, such as cereals, are less perishable. Fruits have both climacteric and non-climacteric characteristics (WRAP, 2011). Climacteric fruits (e.g., mango, papaya, banana, and avocado) can be harvested and ripen after harvest under certain storage conditions. The same does not happen with non-climacteric fruits, as they degrade over time and do not ripen. Supply chain management strategies can leverage this product characteristic, enabling production in places away from consumption areas and longer storage.

In our review, some papers highlight how the quality of perishable food products decreases (Wu et al., 2019) and is very likely to be lost or wasted (Jouzdani & Govindan, 2021; Kumar et al., 2021; Siddh et al., 2022), which could lead to financial crises, societal distress, and economic losses throughout the marketplace (Kumar et al., 2021). Furthermore, environmental aspects are also affected by the increased use of energy and greenhouse gas emissions (Collison et al., 2019; Siddh et al., 2020).

We also found that for more perishable foods, the relevance of adopting management and control practices may increase (Wu et al., 2019), and the importance of considering trade-offs such as between SDG 2 (Zero Hunger) and SDG 7 (Affordable and Clean Energy) are more significant compared to conventional perishable products; that is, much more energy must be consumed to decrease the amount of perishable food products (Jouzdani & Govindan, 2021).

Finally, we verified the distribution cycle of the FFSC, that is, the distance between production and consumption, and its impact on FFSC sustainability. FFSC literature recurrently discusses short and local supply chains. The French Ministry of Agriculture defines the short food supply chain as "a marketing mode used to sell agricultural products either through direct sales from producers to consumers or through indirect sales, provided that there is only one middleman" (Ogier et al., 2013). Concerning the local food supply chains, consistent with the US Food Conservation and Energy Act 2008, "locally and regionally produced food" can be understood as "raised, produced, and distributed within a local area with a total transport distance less than 400 miles from the origin to the consumption" (Nakandala & Lau, 2019). Local food can be described as those food items that are readily available in local food shops, including street markets, boxes and cooperatives (Hinrichs, 2000).

We found that the distribution cycle plays an important role in environmental sustainability (Collison et al., 2019; Sim et al., 2007; Zhang et al., 2019). Positive outcomes are obtained when the production-consumption distance is minimized; however, a holistic view is necessary. For example, if fresh produce items are to be offered to consumers all year round, one possible strategy is to import produce from overseas, so transport impacts should be considered, as well as the source used for the production of electricity in the country of origin (Sim et al., 2007). Collison et al. (2019) also warned that if consumers drive to a farm to purchase their food directly, and each family only buys a few kilograms of product, the cumulative greenhouse gas emissions from all these car trips could be orders of magnitude greater than if the farmer used a truck to transport their product to the city.

3.3 FFSC management and control

Managing the FFSC is challenging and involves multiple practices and strategies, each of which can have a different impact on the overall sustainability of the chain. In this context, we analyzed how management and control practices contribute to promoting the environmental, social, and economic sustainability of the FFSC. We classified these into logistics, information, risks, quality, food, food loss, and waste management. The aim is to identify suitable practices for better designing and managing a sustainable FFSC.

3.3.1 Logistics management and control

Fresh and perishable food logistics are typically performed with low transport efficiency due to partially filled trucks, a wide variety of products, and a lack of sharing and coordination between supply chain entities. Nonetheless, a company competent in logistics management has the abilityto implement sustainable methods, that decreas food loss and waste at every stage (Gokarn & Choudhary, 2021). In this review, we found research focused on packaging improvement, transport optimization, optimal distribution center location, and inventory management to improve FFSC sustainability.

Logistics packaging plays an important role in protecting against physical damage, contamination, loss, and waste while transporting and storing fresh food. However, it is one of the main factors that contribute not only to the cost of the product but also to the environmental impact of the supply chain (Battini et al., 2016).

The reviewed papers discuss the importance of appropriate packaging management in providing FFSC sustainability, focusing on the importance of evaluating the impact of the choice of packaging materials (Accorsi et al., 2014; Battini et al., 2016; Bortolini et al., 2018; Chen et al., 2019; López-Gálvez et al., 2021; Yontar & Ersöz, 2021).

They mainly compare disposable packaging (which ends its life in the last stage of the distribution chain) and re-usable packaging (which requires reverse flows to collect, recondition, and then reuse it) (Bortolini et al., 2018). Each has a different impact on the costs and emissions. For example, reusable packaging containers necessitate specialized reverse logistics, overseen by poolers. This results in an increase in logistics expenses, complexity, and environmental emissions; however, a significant reduction in the use of raw packaging material can save resources and prevent waste from being directed to either incineration or landfilling (Bortolini et al., 2018). These findings emphasize the importance of a comprehensive view of the particularities of the chain to better choose the most optimal package or a mix of them, aiming to reach a global optimum (Accorsi et al., 2014; Battini et al., 2016; Bortolini et al., 2018; Wu et al., 2019). It also highlights the necessity for a holistic assessment to deal with trade-offs, such as maintaining food quality and safety and improving environmental aspects when using re-usable packaging (Chen et al., 2019; López-Gálvez et al., 2021).

Regarding transport, when considering fresh foods, a poor transport system can increase food losses, as these products display shortened shelf lives and long distances between the points of production and consumption. According to Raut and Gardas (2018), strategies to reduce transport losses help achieve sustainability, as they may contribute to reducing the final price of the produce, improving the economic condition of farmers, reducing farmer suicides, increasing employment, and reducing food waste. The authors highlighted the most significant barriers to overcome: (i) the lack of refrigerated vehicles, leads to significant spoilage and subsequent loss of the produce, and (ii) the excessive loading on the vehicles without adequate separation, resulting in the produce overheating, that leads to rapid quality deterioration, further exacerbated by exposure to elements like rain and sunlight.”.

Kumar et al. (2020) also claimed that refrigerated vehicles are a key challenge to the triple bottom line, given their considerably higher energy consumption compared to non-refrigerated vehicles. In this way, to enhance the sustainability of FFSC, Rossi et al. (2021) and Patidar et al. (2018) proposed novel transport systems, and Mejía et al. (2021) introduced a model for food hub locations. The model proposed by Rossi et al. (2021) integrates

a newly designed transport unit (FNX box cooling) with intermodal transport and the hub-and-spoke network topology. This enables each manufacturer or retailer to deliver/receive small amounts per trip using various modes of transportation, thereby reducing carbon dioxide emissions and minimizes food waste that occurs due to temperature fluctuations during transport. The strategy proposed by Patidar et al. (2018) includes designing an IT-based logistics system using smart transportation. Mejía et al. (2021) also showed that a reduction in CO2 emissions could be achieved through a good facility location strategy using hubs for cargo consolidation.

Inventory decisions impact (and are impacted) by storage conditions, the risks of interruption and excess of product, and the pricing policies practiced by the supply chain entities; however, only one study (La Scalia et al., 2017) was found on the topic. In addition, inventory management and control are significant concerns when working with fresh foods. The authors demonstrated the efficacy of implementing inventory policies based on product shelf-life (such as, first-in-first-out and first-expired-first-out), proven to be economically effective. Additionally, they assessed the reduction in the carbon footprint.

3.3.2 Information management and control

The supply chain must have adequate coordination to maintain high quality and service levels due to the uncertain nature of production and demand and the product shelf-life variability. Sharing information facilitates supply chain management and control and adjusts inventory levels to increase product freshness.

Our findings show that the sustainability of FFSC can be improved by more efficient information management (Esteso et al., 2022; Gokarn & Kuthambalayan, 2019; Kaipia et al., 2013; Leithner & Fikar, 2022; Sharma et al., 2022; Song et al., 2018). When a company has access to information from all involved parties, it can efficiently manage supply and demand and find solutions to challenges (Sharma et al., 2022). However, Song et al. (2018) noted that if the participants in the supply chain are solely focused on their financial gains, it often results in the overall economic performance of the supply chain, and even its environmental and social performance, experiencing certain losses; therefore, their coordination is essential, as well as a formulation of good coordination mechanisms.

The analysis reveals that visibility, traceability (see Sharma et al., 2022), and tracking (see Collison et al., 2019) are among the information practices that enhance FFSC sustainability. Visibility aims to ensure that the target information is easily accessible to all entities, thereby increasing supply chain transparency (Lee et al., 2014). The notion of traceability is related to the capacity to retrieve product's information and traceability through all phases of the supply chain (Tagarakis et al., 2021), which intensifies risk in instances of defective batches (Kumar et al., 2020). Tracking systems allow problems such as temperature spikes to be identified quickly and help to take correct actions (Collison et al., 2019). They can improve chain sustainability at various points (e.g., reduction in food loss and waste, lowering greenhouse gas emissions, cutting costs, boosting return on investment, increasing profits, augmenting sales volume, minimizing economic disparity among farmers, and decreasing waste disposal expenses) (Collison et al., 2019; Esteso et al., 2022; Gokarn & Kuthambalayan, 2019; Leithner & Fikar, 2022).

3.3.3 Quality management and control

The acceptance of fresh food by consumers depends on several quality attributes, such as safety, nutrition, taste, appearance, and texture. Quality management and control are of the utmost importance in the food industry to meet regulatory standards and enhance food quality safety (Dora et al., 2013; Lim et al., 2014). In this review, we found that it can have a crucial role in the sustainability of FFSC.

Different quality management and control strategies (Chanda et al., 2021; Siddh et al., 2018), certifications (Ahsan et al., 2018; Chanda et al., 2021), and food safety practices (Yontar & Ersöz, 2021) have been shown to enhance organizational sustainability and embrace economic, environmental, and social sustainability. Chanda et al. (2021), for example, demonstrate how farmers are following best management strategies for tomato cultivation to conserve water resources and to effectively control the use of fertilizer, irrigation, and the water table. They also adhere to the food safety certification demanded by buyers to minimize food waste linked to foodborne diseases and food recall. Furthermore, they implemented a fair food program to improve the livelihoods of agricultural workers and strengthen social security.

Despite these positive results, López-Gálvez et al. (2021) showed the importance of checking for possible trade-offs. They observed that conflicts emerge when examining the relationship between environmental sustainability and microbial safety. For example, farmers are often advised to eliminate vegetation to mitigate the risks of wildlife interference and the occurrence of disease-causing bacteria in their crops; however, having vegetation barriers around farm fields can be environmentally beneficial and can also restrict the wind-driven dispersion of pathogenic bacteria. Consequently, a comprehensive worldwide strategy is necessary to address these interactions between safety and sustainability. Broadening the understanding of food safety, co-management, decision-making based on multiple criteria, agroecological practices, technological progress (e.g., reliable and accurate cold chains), collaboration in cross-disciplinary teams, and education involved stakeholder are some approaches to resolving conflicts between sustainability and safety.

Agroecology, for example, is already recognized for addressing environmental and social sustainability issues within food production, however, Kerr et al. (2021) also show that more sophisticated agroecological systems, which include various elements, as crop diversification, combined crop systems with livestock, and networks connecting farmers, can bring positive outcomes on safe and nutritious food.

3.3.4 Management and control of food loss and food waste

Waste management is required in order to reduce food losses and food waste that appear through the whole supply chain (Yontar & Ersöz, 2021). The authors suggested that addressing inefficiencies to reduce food loss from the farm to the consumption points can result in significant economic, social, and environmental advantages. Similarly, they highlighted the importance of minimizing waste to increase sustainability.

Vlajic et al. (2018) demonstrate the potential of value recovery processes, including reuse, reprocessing and recycling, to reduce unnecessary production volumes and tackle food waste by redistributing food appropriately to the right customers. The authors present a set of practices applicable in different circumstances, for example: (i) sell crop surpluses

to alternative customers; (ii) finish unprofitable and very perishable products as animal feed at the nearby farm; (iii) process and use products (e.g., transforming vegetables into soup ingredients in-store and selling them on-site or to food services at higher prices relative to purely raw food); (iv) donate small amounts of to food banks; (v) recycle food waste and use as compost, which improves nutrient cycling through the food system, among others.

3.3.5 Risk management and control

Fresh food businesses are at a higher risk (Fu et al., 2019; Kumar et al., 2021; Zhang et al., 2020) as they struggle against greater waste and product life cycle issues (Kumar et al., 2021). In this review, we found two papers (Zhang & Yu, 2021; Zhang et al., 2020) that showed the relevance of identifying, analyzing, and proposing risk mitigation strategies to enhance the sustainability of FFSC.

Kumar et al. (2021) stated that a delay in the harvesting, procurement, processing, and marketing of perishable items like fruits and vegetables could lead to catastrophic levels of waste, financial crises for farmers, societal upheaval, and economic losses across the market.This, along with the risks posed by with the COVID-19 pandemic, motivated them to identify and analyze risk-mitigation strategies. These strategies include collaborative management, proactive planning for business continuity, and financial sustainability. The aim is to improve the socioeconomic-ecological performance of perishable food supply chains, thereby achieving the sustainable development goal of providing healthy and safe food for all. Moreover, many countries worldwide have implemented specific measures to mitigate food waste in the form of laws, systems, and policies, focusing at the national strategic level, with approaches such as legislation, food donation, waste recycling, awareness and education, and data gathering (Shen et al., 2023).

Zhang et al. (2020) focus is on the development of a risk assessment system with a focus on green logistics for fresh produce, as low-risk transport and preservation methods can help minimize product loss and at the same time provide consumers with access to high-quality and safe produce. They claim that prompt recognition and mitigation of risks can decrease costs and keep the fresh produce market stable. They considered five risk factors: *technological* (i.e. risk related to food preservation to secure freshness), *biological* (i.e. the sensitivity of fresh product to risk factors), *sustainability* (i.e. fresh food loss and damage due to technology and packing material), *environment* (i.e. the ithmpact of uncertainties, such as weather or traffic), and *emergency* (i.e. deficient capabilities of logistics companies).

Agroecological practices can also play an important role in promote healthy food; for example, the substitution of chemical fertilizer and pesticides by bio-pesticide control methods, as well as the replacement of chemical fertilizer by fertilizer tree systems (Mockshell & Villarino, 2018; Dagunga et al., 2023).

3.4 FFSC enablers

Several factors can facilitate supply chain management in complex FFSCs. Advanced technologies, infrastructure, regulations, and public policies are examples of facilitators that can help reduce costs, monitor, and control losses and waste, and provide a more sustainable FFSC.

In this review, 28% of the papers showed the role of advanced technologies in FFSC sustainability, only 8% discussed infrastructure, and 5% discussed regulations and public policies. With regard to advanced technologies, the papers show the adoption of a wide variety of them, such as blockchain, which contribute to enhance traceability and visibility of perishable food (Gokarn & Choudhary, 2021; Haji et al., 2020; Kayikci et al., 2022), radio frequency identification (RFID), which can effortlessly track, trace, and disclose the history of any perishable product (Bottani et al., 2014; Haji et al., 2020), Internet of things (IoT) to aid in identifying, locating, and tracking the status of perishable food (Gokarn & Choudhary, 2021; Haji et al., 2020), three-dimensional printing (3DP), which assists in decreasing the inventory and minimizing demand and supply instability since their production is order-based (Haji et al., 2020), autonomous vehicles to decrease cost of transportation and reduce the number of accidents (Chanda et al., 2021; Collison et al., 2019; Haji et al., 2020), unmanned aerial vehicles (UAV) as drones to reach difficult areas and monitor agricultural fields (Chanda et al., 2021; Haji et al., 2020), big data analytics and artificial intelligence for facilitating improved decision-making, enhancing productivity, optimizing supply chains, and creating new, data-driven business models (Collison et al., 2019; Gokarn & Choudhary, 2021), among others (see Chanda et al., 2021; Collison et al., 2019; Pal & Kant, 2019; Zhang & Yu, 2021). One key aspect to note is that these technologies would have a short-term detrimental effect to human workers. The widespread adoption of autonomous vehicles and other emergent technologies, for example, could lead to job displacement for workers in driving, delivery, and manufacturing sectors. However, it may also create new job opportunities in tech, maintenance, and oversight of these systems, though possibly requiring different skill sets.

Gokarn and Choudhary (2021) also emphasize the positive aspects of reducing several of supply chain uncertainty – such as demand uncertainty, supply uncertainty and price – which can considerably reduce food loss and waste at every stage. Further, Kumar et al. (2021) found that digital and technological transformation is key strategy to reduce risk and enhance the sustainability performance of supply chains dealing with perishable food items. They can contribute to mitigating contingencies such as demand fluctuations, abrupt increases due to demand shifting from physical stores to e-commerce, and operational hurdles demanding digital capabilities.

Despite the benefits of applying these technologies, according to Bottani et al. (2014), it is necessary to evaluate each situation to check for possible trade-offs. The authors showed the positive aspect of RFID implementation as the minimization of product waste due to expired shelf life; however, they warned about the environmental burdens resulting from emissions and energy consumption during tag production, transportation, and disposal.

Even though these technologies contribute to the sustainability of FFSC, their adoption can still be a challenge to some entities of the chain, such as farmers, in India. According to Kumar et al. (2020) and Gokarn and Choudhary (2021), they are reluctant to use information and communication technology to share data.

Enablers related to infrastructure were also analyzed. Studies have found that they play an important role in assisting FFSC management and control to minimize food loss and waste, thereby improving supply chain sustainability (Gokarn & Choudhary, 2021; Kumar et al., 2020). However, Balaji and Arshinder (2016) observed the inadequate logistics infrastructure in India and suggested a public-private partnership to build a large number of cold-storage facilities that would effectively address the issues related to the inventory man-

agement of perishable products; in addition, they emphasized the importance of creating an adequate infrastructure for waste disposal, given the vast potential for energy recovery and nutrient recycling through composting facilities. Kumar et al. (2020) also pointed out infrastructure issues. The authors argue that power outages, poor infrastructure connectivity to agricultural areas, and an insufficient road and highway networks lead to unforeseen delivery delays, shelf-life loss, and obstruct economic activities across the chain. They recommend solutions that include investing in infrastructure, nurturing local markets, aggregators, hubs, and cold chain technologies along with the development of related organizations such as packing facilities, ripening units, and refrigerated transport.

Furthermore, knowledge of the territorial particularities should be also considered in the management of FFSC leading up to the planning the production of healthy food (Lamine et al., 2019). It can be characterized considering social, cultural, economic, and biophysical units (López-García & González de Molina, 2021). Planning the production of healthy food according to the main characteristics of the territory integrates agricultural practices with local environmental, resource, and socio-economic conditions to optimize land and water use, and preserve biodiversity. When aligning crop selection and farming methods with soil composition, climate patterns, and water availability, this approach enhances the sustainability of food systems, ensuring the resilience and nutritional adequacy of local food supplies. Simultaneously, it bolsters the socio-economic framework by leveraging indigenous knowledge, fostering local employment, and reducing reliance on imported foods, thereby reinforcing community development and stability within the natural capacities of the region (Lamine et al., 2019).

Legal and public policy issues are closely related to infrastructure. In research put forth by Chanda et al. (2021), the authors highlight the importance of government subsidies since they can assist farmers in adopting advanced technologies such as safeguarded structures, superior irrigation systems, and high-class machinery, which can enhance productivity and sustainability profiles. Meanwhile, Gokarn and Choudhary's (2021) found that facilities, physical infrastructure, technological infrastructure, and foreign investment are critical to the development of a market infrastructure in any country that will be supportive of sustainability-oriented practices. According to Gokarn and Choudhary's (2021), policies that promote distributed production may well diminish the need for transportation, thereby helping to decrease food loss and waste; hence, regulatory agencies and food policy are viewed as representative factors that shape helpful food policies to encourage sustainable practices.

4 Discussion

FFSCs worldwide strive to enhance their sustainability, so knowing the best options to accomplish this is of utmost importance. Hence, we reveal and discuss the influencing elements that can contribute to this end by examining how FFSC are increasing their social, economic, and environmental sustainability aspects and highlight the main opportunities that should be further explored. The results provide a comprehensive framework (Fig. 4), which is useful in both theoretical and practical terms. It expands the knowledge of FFSC sustainability, assists academics in designing research that advances the topic, and assists practitioners, organizations, and governments in developing strategies and policies to improve FFSC sustainability.

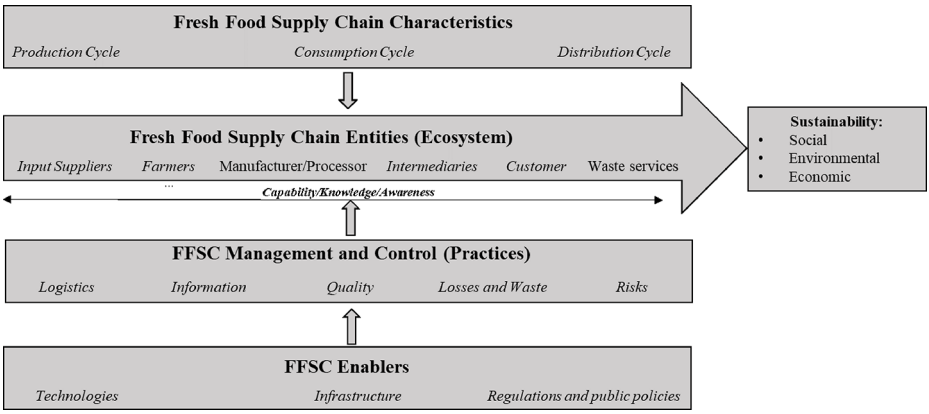

Fig. 4 A framework for fresh food supply chain sustainability

Managing FFSC is complex and involves multiple entities with characteristics, from suppliers to waste services, including farmers, manufacturers, intermediaries, and customers, each contributing differently to SC sustainability. Their choice can impact different product costs, reverse logistics costs, disposal costs, and emissions, among others. Packaging suppliers, for example, can play a fundamental role in this chain (see Battini et al., 2016; Bortolini et al., 2018; Haji et al., 2020) considering that the product they provide is critical to protect and handle products across the many tiers of FFSCs.

Although the distinct characteristics of FFSC entities may affect the sustainability of the chain, this study does not clearly discuss this topic. There is a good opportunity for supply chain researchers to explore the size, quantity, vulnerability, and particularities of each FFSC link. For example, in recent years, mergers and acquisitions involving large multinational companies have reshaped the seed and biotechnology sectors, reducing the number of players in the sector (OECD, 2018). Likewise, there is great concern about the shortage of fertilizers and the consequent increase in food prices (Reuters, 2021). Future studies should evaluate how the particularities of the entities impact FFSC design and management and their influence on sustainability.

Other important characteristics related to the entities that impact sustainability are technical knowledge and the capacity to perform their functions, especially in the production and commercialization of the product. Researchers and managers should consider deficiencies in technical and commercial knowledge in small rural producers, as well as the lack of good management practices in small fresh food retailers, are aspects to consider. However, it is necessary to identify the level of awareness regarding the consumption and production of fresh products with greater nutritional quality. The importance of food awareness for communities, especially for the most vulnerable, can increase the intake of more nutritious and healthy foods.

The understanding of such public awareness is highly fragmented. Firstly, addressing the role of industrial agriculture in perpetuating the unsustainability of FFSC is essential. The industrial model, with its intensive use of chemicals, water, and energy, significantly contributes to environmental degradation and the disruption of local food systems. In contrast, agroecological production processes (as mentioned under Sect. 3.3.5), as a second factor,

offer a sustainable alternative by promoting biodiversity, soil health, and local resilience, aligning closely with the ecological cycles and minimizing the ecological footprint.

Furthermore, the role of government is as hugely important as it is highly understudied. This role extends beyond regulation and it involves active participation in promoting sustainable practices, providing infrastructure, and supporting transitions towards sustainable FFSCs. This aligns with an additional factor: initiating the production of healthy foods driven by local demands and markets. Such a shift not only ensures food sovereignty but also reduces reliance on long-distance transportation, thereby decreasing the emission of greenhouse gases.

We also observed that the main FFSC characteristics related to production, consumption, and distribution cycles remain widely understudied. We did not find any studies that relate the production cycle to sustainability. Despite some evidence related to the distribution cycle's impact on environmental sustainability, there is still a lack of information to provide a holistic view of these relationships. The consumption cycle, that is, the perishability of food, plays a crucial role in FFSC sustainability and can drastically influence its cost and social and environmental aspects. However, more studies are needed to define the best strategies to be adopted, aiming to obtain a better combination of social, environmental, and economic results for FFSC, considering the potential trade-offs.

Concerning the management and control dimensions, a deeper examination of the papers shows that five different elements can contribute to improving the sustainability of FSSC. The findings indicate that the studies mainly focused on logistics management and control (36% of the papers). This was followed by information (21%), quality (15%), food loss and waste (8%), and risk (5%). Packaging is the most studied aspect of logistics. In the long term, traditional packaging systems negatively impact the sustainability of the chain as they consume non-renewable resources, emit greenhouses from manufacturing, transportation, and usage, and produce solid waste (Accorsi et al., 2014).

This review identified a set of pathways to deal with this: (i) define the best packaging material or a combination of them through an overall view of the major characteristics of the chain and its specific parameters, as well as their main goals; (ii) address trade-offs that may exist through a holistic assessment; and (iii) evaluate the possibility of applying new alternative packaging solutions as the options proposed in Battini et al. (2016). These alternatives can promote a more sustainable FFSC, so we encourage more studies on this dimension to clarify pathways and assist practitioners with more knowledge to underpin better choices.

This review also emphasizes the importance of good transport management and a strategic plan for hub locations in this chain, the introduction of new alternatives to transport systems, and the necessity to overcome barriers to increasing sustainability. This review also emphasizes the importance of good transport management and a strategic plan for locating hubs in this chain, introducing new alternatives to transport systems, and the need to overcome barriers to increase sustainability. We found benefits in emission and cost reduction and great potential for further exploration. Another dimension requiring study is inventory management and control since only one study showed the effectiveness of introducing shelf-life-based inventory policies.

Our findings also indicate that FFSC decisions to promote sustainability should encompass information practices, such as visibility, traceability, and tracking. In their study, Kumar et al. (2020) showed a set of recommendations to improve information sharing in

the Indian context, including (i) cooperative demand forecasting, sharing information, storage facilities for excess produce, and contract farming to deal with stockouts or overstocks; (ii) vertical integration and mandatory traceability across the supply chain; (iii) labeling of produce to enable tracking of environmental footprints; and (iv) enhanced marketing connectivity and sharing of demand information. The same should be evaluated for other realities. Quality management and control were the other relevant elements found. Practitioners can apply different quality strategies, certifications, and food safety practices to improve their economic, environmental, and social sustainability. A set of quality practices can be found in Siddh et al. (Siddh et al., 2018); Yontar & Ersöz, (2021). Various FFSC players, from chain production to transportation, are responsible for this.

Future studies could enrich the body of knowledge on food quality with more studies that focus on the importance of quality to satisfy regulatory requirements and improve food quality safety, as well as on improving the sustainability aspects of FFSC. Yet, more research should be performed on agroecology transitions in the food system due to its systemic nature and promising approach to achieve superior sustainability outcomes (Geck et al., 2023). Furthermore, approaches to minimizing food loss and waste remains neglected in the literature, which poses a potential element that should be better explored and applied together with other elements to enhance FFSC sustainability. To amplify the results, practices should include every single stage of the process, from generation to waste (Yontar & Ersöz, 2021). Value recovery processes (Vlajic et al., 2018), which include reuse, remanufacturing, and recycling, should be further explored by practitioners, as well as the process of obtaining compost (e.g. from products that returned from customers, unsaleable products, products 'out of specification').

Risk management and control are also important elements. Their mitigation can affect the sustainability of the FFSC, reduce product loss and waste, reduce costs, and improve social aspects. Despite its importance, there is a lack of information on this topic. Zhang et al. (2020) presented important directions for practitioners; however, they focused on systems for risk assessment in the transport of fresh food items. Other studies should be conducted to complement this finding.

As FFSC is closely related to the agriculture supply chain, the proposed types of risks (production, market, institutional, personal, and financial) analyzed by Komarek et al. (2020) for agriculture could also be evaluated, as well as their impact on FFSC sustainability. In this review, we also identified some elements that can facilitate FFSC management to enhance its sustainability. Recent studies have shown the application of advanced technologies, such as blockchain, RFID, and IoT, and their contribution to assisting FFSC management through improvement in traceability, visibility and tracking, reduction in uncertainties, cost of transportation, inventory, and food loss and waste. Despite their relevance, there is still a lack of research on this topic. The main challenges in their implementation are unclear. Only two studies showed this in the context of farmers in a specific country. Therefore, further studies should explore the main barriers that still affect FFSC implementation.

A further opportunity for studies that appeared little in our research is the importance of good infrastructure and legal and public policy. The papers briefly showed the relevance of logistics infrastructure and technology, waste disposal, and market infrastructure. These could be further studied as well as in other areas. Public policies are also a field to be explored in studies of FFSC sustainability. Public policies, as a means of improving agricul-

tural workers' health, food quality, and safety, in addition to encouraging sustainability and social justice for producers and consumers, are relevant topics.

Finally, we found that the appropriate use of these elements can promote the sustainability of FFSC, mainly by improving environmental aspects through a reduction in CO2 emissions, economic aspects through cost reduction in different links of the supply chain, and finally, by improving the livelihoods of farm workers. We also observed significant efforts to reduce food loss and waste. Some studies attribute this reduction to one of three sustainability aspects; however, they have an enormous impact on all. It can improve environmental sustainability (e.g., natural resource utilization), social (e.g., improving access to quality food), and economic (e.g., profit margin) (Gokarn & Choudhary, 2021; Gokarn & Kuthambalayan, 2019).

Even though FFSC has already reached great achievements, the low number of published papers and the variety of understudied topics indicate a wide opportunity to conduct research in this field and expand this result to other FFSC organizations, particularly across social sustainability aspects. This is in line with the limited findings in social sustainability reported by Khan et al. (2021) where work-life balance and safe/healthy working environments were among the most prominent social variables across supply chains. To this end, this framework provides an important direction. First, it provides systematic evidence of the various elements contributing to FFSC sustainability as whole. It provides a classification scheme that characterizes FFSC into three cycles (production, consumption, and distribution). We show that FFSC can have distinct characteristics in each of these cycles. Therefore, adopting this classification allows future studies to understand FFSC better, thereby making better choices and decisions to design and manage it. Finally, the framework reveals a set of management and control practices that impact FFSC sustainability and the technologies, infrastructure, regulations, and public policies that contribute to FFSC management in enhancing its sustainability. This may encourage organizations to apply a broader number of practices and enablers to obtain sustainability results.

5 Conclusion

Improving the sustainability of the FFSC is extremely important to people, profit (or prosperity), and the planet, and has a significant role in helping to achieve the United Nations Sustainable Development Goals. Hence, an all-embracing framework was developed to guide practitioners, organizations, and governments, summarizing the main characteristics, elements, and enablers that can improve the sustainability of FFSC. This research enhances understanding of the factors that influence FFSC sustainability so that existing FFSC can be effectively managed or better redesigned.

Our findings reveal that the sustainability aspects of FFSCs are significantly affected by different factors across the entire supply chain. However, very few studies comprehensively integrate the two. Studies have focused on individual elements to improve sustainability in FFSC. Elements related to logistics management and control have been the most explored. However, as FFSC become more sustainable, they need to embrace other elements as new technologies, together with efficient information, risk, quality, food loss, and waste management, as these can contribute to different aspects of sustainability. These facts reveal the importance of combining and applying numerous elements to enhance results.

Another important contribution of this study involves bringing three levels of classification (production, consumption, and distribution) to FFSC so that these elements can be chosen and adopted according to the distinct characteristics of FFSC. The study also highlights the importance of mapping each of the FFSC entities to verify their contribution to each aspect of the sustainability of the entire chain.

Therefore, these elements proved to be crucial for FFSC in promoting sustainability. Those that have been underexplored need to be researched further to help FFSC deliver their potential.

This paper is not without limitations. First, the decision to restrict the review to publications in English only may have led to the exclusion of relevant studies and insights, stemming from diverse perspectives documented in other languages, potentially introducing a language bias. Additionally, in spite of our comprehensive search strategy, the rapid evolution of sustainability practices and emerging technologies in fresh food supply chains might mean that very recent developments are underrepresented. Furthermore, our focus on academic and peer-reviewed literature could overlook valuable insights from industry reports, white papers, or expert opinions that are not formally published. The synthesis of findings into a theoretical framework inherently simplifies the complex, multifaceted nature of sustainability in fresh food supply chains, possibly overlooking context-specific nuances. Recognizing these limitations is crucial for interpreting our findings and should be considered when applying our proposed theoretical framework in practice or in future research. Future studies could adopt a multilingual research strategy to systematically evaluate non-English sources and capture grey literature to ensure a wider spectrum of insights, including those from industry practitioners and policymakers. They could also investigate not only the individual key elements of the supply chains we have identified in this research, as most of them lack research, but also their fundamental relationships, how they affect each other, and the results obtained from their integration to enhance FFSC sustainability.

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Data availability Upon a reasonable request, the corresponding author can provide the datasets that were used during this research.

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