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REVIEW ARTICLE

Challenges for future food systems: From the Green Revolution to food supply chains with a special focus on sustainability

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Abstract

Finding a food system to feed the growing worldwide population remains a challenge, especially in the current era, where natural resources are being dramatically depleted. From a historical point of view, the Green Revolution, together with biofortification and sustainable intensification, was established as a possible solution to counter hunger and malnutrition during the second half of the 20th century. As a solution, to overcome the limitations attributed to the Green Revolution, food supply chains were developed. The current food system, based on the long food supply chain (LFSC), is characterized by globalization, promoting several advantages for both producers and consumers. However, LFSC has been demonstrated to be unable to feed the global population and, furthermore, it generates negative ecological, environmental, logistical, and nutritional pressures. Thus, novel efficient food systems are required to respond to current environmental and consumers' demands, as is the case of short food supply chain (SFSC). As a recently emerging food system, the evaluation of SFSC sustainability in terms of environmental, economic, and social assessment is yet to be determined. This review is focused on the evolution of food supply systems, starting from the Green Revolution to food supply chains, providing a significant perspective on sustainability.

KEYWORDS
food system, long food supply chain, short food supply chain, sustainable assessment

1 | INTRODUCTION

Since the second half of 19th century, food systems have been affected by the phenomenon of globalization, which promoted the involvement of several intermediaries between producers and consumers. The expansion of food production and the massive population growth impulse a world trade which becomes necessary to balance the offer and demand between regions. At the same time, it provides insurance against regional production shocks, such as conflicts, epidemics, and environmental threats, sped up by climate change. This market globalization presents additional advantages, as it boosts the international exchange of goods and services, which ultimately confers a wider target to local food producers, who can invest a higher capital in their production. As a result, it increases the overall efficiency of food production by allowing regional specialization in the production of the most appropriate foods at the local level (Prosekov & Ivanova, 2018). Moreover, the globalization of agri-food systems goes beyond a mere increase in the agricultural trade, as it also involves the interchange of knowledge related to agricultural technology and production patterns between countries. In this sense, the investment of agri-food companies directed to foreign production is increasing, including the establishment of large multinational retailers.

However, globalization also presents serious disadvantages, including the widespread propagation of economic shocks with a higher impact on poorer regions; the establishment of unhealthy lifestyles; the opacity on food origin and quality assessment or the collapse of biodiversity and the degradation of different ecosystems which involves environmental damages (i.e., chemical leakages or greenhouse gases emissions) (Garcia-Oliveira et al., 2022; Pretty et al., 2005). In the last decades, consumers' awareness has increased about the disadvantages of globalized food products. Therefore, they awaked their interest in food production systems that promote a reduced environmental impact, increase the consumption of healthy foods, and recover direct contact with local producers. In response to this trend, recent investigations have proposed alternative food production systems, such as short food supply chain (SFSC), that may mitigate the difficulties attributed to globalized models.

Despite globalization, current food production and distribution systems are unable to feed the worldwide population. Indeed, in 2018, more than 820 million people were chronically undernourished in terms of energy, 2 billion people suffered from micronutrient deficiencies, whereas 1.9 million people presented either overweight or obesity (Drewnowski et al., 2020; FAO et al., 2020). According to estimated projections, this rising tendency in the prevalence of worldwide undernutrition, which is likely to get intensified due to the COVID-19 pandemic, can reach up to 9.8% of the total population by 2030 (FAO et al., 2020). Such imbalanced malnutrition paradigm with under- and overweight actors involved is known as the triple burden of malnutrition (Drewnowski et al., 2020). Hence, there is an urgent need for nutritional interventions to improve food policies aimed to minimize both forms of malnutrition. The reasons behind such a recent increment in malnutrition include the weakness of economic systems, together with a strong dependence on exports and imports of basic products. Besides, the increasing frequency of extreme climatic events makes productive countries and regions more vulnerable to external shocks and limits their contribution to a reliable food system (Hasegawa et al., 2021; Pretty et al., 2000).

Despite the development of efficient technological advances, the current food systems are far from meeting the requirements to achieve a sustainable nutrition regime worldwide. Therefore, feeding a globally growing population with limited agricultural resources remains a challenge for the agri-food sector (Prosekov & Ivanova, 2018). This issue is of especial relevance in developing countries, due to the adoption of diverse diet regimes, the existence of fast-growing urban populations, the restricted access to patented technologies, the accentuated vulnerability to climate change conditions, and the persistence of hunger and poverty of low-income countries.

The main objective of this review is to analyze the evolution of the established strategies to develop efficient food systems to achieve an efficient global nutrition. It provides a historical overview that evaluates from the establishment of the Green Revolution to the development of novel food supply chains, including the long and short food supply chains. Besides, it will provide a deep insight about the benefits and limitations of these food supply chains, paying special attention to the sustainability of these emerging food systems.

2 | A HISTORICAL PERSPECTIVE FACING GLOBAL NUTRITION

Agricultural intensification involved a change of paradigm since the early 20th century. It evolved from traditional agricultural systems, based on the use of natural resources and ecosystem services, to the modern ones where the use of modern technologies and engineered approaches for crop production or the application of fertilizers, and artificial control of plagues represented the main keys. Modern agricultural systems were expected to meet the nutritional requirements for the growing world population, expected to reach 9.7 billion people by 2050 (United Nations, 2022). However, none of the current food production systems, including the long and short food chains, is contemplated to fulfill the requirements to be considered to possess a high throughput, providing healthy and environmentally friendly products. Food systems need to effectively react against economic and sociocultural shocks, be able to solve the rural economy stagnate, avoid natural resources depletion, and impulse ecosystems restoration in addition to minimize the actions that prompt climate change (Drewnowski et al., 2020). Thus, the objectives to be fulfilled are the design and establishment of new methods to close the yield gaps between countries, the enhancement of food production, as well as the improvement of the economical accessibility to food resources, and the maintenance of environmental integrity and preservation (Dobbs & Pretty, 2004; Terán, 2007; Willett et al., 2019). Among the different solutions found for the agricultural-mediated improvement of global food supply and production, three major approaches have been already established: the Green Revolution, biofortification, and sustainable intensification.

2.1 | The Green Revolution

The Green Revolution is a term used to describe the massive increase in agricultural productivity in the United States and Europe in the 1960s. This revolution was contemplated as a possible solution to counter hunger, by boosting the production of certain crops in a relatively short period of time (Pingali, 2012). For this purpose, new exploitation strategies, such as the installation of irrigation systems, large-scale mechanization, and the use of fertilizers and other agrochemicals, were adopted. The widespread application of such approaches, in combination with novel technologies, like crop genetic improvement, led to a significant change in the food supply function, contributing to a drop in food price and the subsequent rise in food availability at global scale (Jimenez-Lopez et al., 2020; Scobie & Posada, 1978). In general, these strategies allowed a worldwide beneficial impact in consumers, including those from undeveloped countries. This increment of the agricultural production, in terms of significantly higher crop yields, led to an initial reduction in malnutrition rates, especially in multiple countries from Asia and Latin America (Pingali, 2012). Among the different crops that trigger this switch during the Green Revolution, cereals (especially corn, wheat, and rice) showed an impressive enhancement in their production, contributing to counter the effects of hunger-mediated malnutrition due to their nutritional properties as caloric staple crops (Evenson & Gollin, 2003).

Nevertheless, this revolution presented undesired consequences in different fields, including environmental, geographical, and nutritional concerns, which limited their effectiveness as a reliable food system. Concerning environmental issues, the extensive exploitation of the Green Revolution-associated methodologies contributed to depletion of water resources, soil degradation in cultivated areas, and chemical run-off (Burney et al., 2010; John & Babu, 2021). All these factors promoted a deceleration in yield growth, directly related with the degradation of the agricultural resources. These environmental impacts were widely recognized as a potential threat to the long-term sustainability and replication of the Green Revolution success (Béné et al., 2019; Pingali, 2012). Moreover, such exploitation of environmental resources was followed by several geographic disparities. The strategy of this revolution was predominantly performed on different areas of favorable intensification and focused on areas with high rainfalls or irrigated. Thus, this approach avoided including marginal lands that were left behind and widened differences between countries. Indeed, the Green Revolution technologies did not pay attention to such environmental and geographical constraints, and it omitted the establishment of solutions regarding tolerance to climatic threats and counter poverty of marginal cultivation areas (John & Babu, 2021; Rosegrant et al., 2001). Besides, the hunger-counteract initially promoted was quickly replaced by several malnutrition issues. As mentioned before, this revolution mainly focused on the exploitation of grain crops with low nutritional value, which ultimately caused a severe impact on higher-value traditional crops, and lead to the replacement of most of legumes, vegetables, and fruits, well-known as important sources of critical micronutrients, such as iron, vitamin A, and zinc.

As a result, despite the establishment of novel technologies associated, the Green Revolution was ineffective to meet its initial objectives at long term, being not only unable to counter hunger and poverty or improve food security assessment but, at the same time, it provoked very negative environmental impacts. Consequently, novel solutions must be explored to mitigate the disadvantages created by the development of the Green Revolution, such as biofortification and sustainable intensification (Figure 1).

2.2 | Biofortification

The loss of dietary diversification attributed to the Green Revolution was followed by an increase in grain yield during the next decades, together with the decrease in mineral concentrations in grains (Fan et al., 2008). In this sense, biofortification emerged as a possible solution. Biofortification is a process that seeks to improve the nutritional value of crops. The content of a different micronutrients was enhanced in the edible parts of plants using conventional breeding techniques or genetic engineering. It was conceived as a cost-effective approach to alleviate micronutrient malnutrition in rural populations in developing countries where the problem was prevalent (Nestel et al., 2006). Besides, the implementation of the biofortification presented several advantages: the enhanced production of basic crops, a positive sustainable impact on the environment, with the promotion of environmentally resistant products, cheap maintenance after the initial investment, and increased accessibility to rural and restricted areas (Dhaliwal et al., 2022).

Even though the theoretical principle of the biofortification is well established, not many practical cases are present in the agri-food market. The most representative examples include the fortification with zinc of rice and wheat developed in Asia, while in Africa the examples include the fortification with provitamin A of sweet potatoes and maize. Similarly, transgenic golden rice was fortified with provitamin A, whereas a multivitamin corn was developed to biosynthesize higher amounts of carotenoids, ascorbic acid, and folate and in addition presented a gene that protected it against the attack of *Bacillus thuringiensis*. Therefore, although the current examples are few, biofortification may represent a sustainable approach to improve the nutritional status of developing countries as far as the bioaccessibility and bioavailability of the newly incorporated nutrients can be comparable to those naturally present in plants (Díaz-Gómez et al., 2017). The principal limitations of biofortification are mostly due to different threats associated with the genetic improvement of such crops, including the cross-contamination and loss of biodiversity, with the subsequent destruction of pre-existing ecosystems to maximize the cultivation surface (Marles, 2017).

2.3 | Sustainable intensification

The current industrialization and urbanization level of extensive regions worldwide has accelerated soil degradation and drastically reduced the useful surface for crops cultivation (Hertel, 2016). In this context, sustainable intensification, defined as the system where agricultural yields are increased without harmful environmental impact and without the conversion of additional nonagricultural land, was proposed as an efficient and sustainable solution to increase production yields to support the accessibility of crop-derived products in rural areas and other communities presenting scarce resources (Prosekov & Ivanova, 2018).

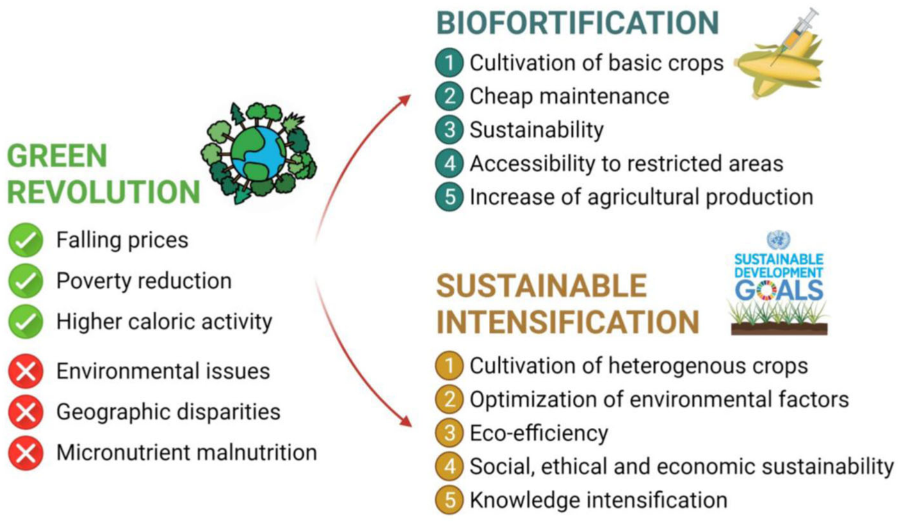

FIGURE 1 Advantages and disadvantages of the Green Revolution and its proposed solutions: biofortification and sustainable intensification

TABLE 1 Principles of sustainable intensification

Principle	Strategies
Environmental	Based on biological processes
	Integration of various plant species
	Rational use of external inputs as fertilizers and pesticides
Institutional	Large-scale combined action programs
	Formulation of new policies
	Expansion of pilot studies, farmers' experiences and local traditional knowledge
Social	Expand specific knowledge more than conventional approaches
	Adoption of traditional and nontraditional approaches by farmers

Sustainable intensification constitutes a systemic approach concerning natural resource management, based on a set of scientifically based environmental, institutional, and social principles, with the ability of being applied along the food chain to reinforce and increase its efficiency (Burney et al., 2010). An overview of the principles of this system is shown in Table 1. The overall aim of sustainable intensification consists of the transformation of the whole food chain into a fully sustainable procedure, developing good management practices to exploit the natural resources and reducing the harms derived from agricultural activities (Cassman & Grassini, 2020; Power, 2010). For this purpose, sustainable intensification management is achieved by the application of a set of agricultural measures (Pretty, 2008): (i) soil is considered a living organism whose health depends on taking advantage of natural sources of nutrients, it is a finite and fragile resource that must be exploited rationally; (ii) enhancement of the suitability of genetic techniques on the integrity of multiple agroecosystems and the performance of agricultural practices, as they promote excellent resistance mechanisms to climate change-derived threats; (iii) utilization of efficient irrigation technologies to reduce waste and water consumption to reach larger cultivation areas; (iv) implementation of an integrated pest management system since it prevents potential risks on food safety and agroecosystem health.

Therefore, the need for constant investment in agricultural innovation and productivity growth is as important today as it was in the early years of the Green Revolution, since emerging economies continue to rely on agricultural productivity as an engine for growth and hunger reduction (Johnston & Mellor, 2016). A change of approach is necessary, coming from public administrations, which should force a deep readaptation to legislate the adoption of sustainable practices in the food supply chain. In the same way, the scientific community should take advantage of the best of knowledge and technological advances to restore agricultural innovation and production systems to meet the current complex challenges worldwide. In response to that paradigm, two different food supply chains are established for the implementation of novel agricultural practices that ensure the sustainability in the exploitation of agri-food resources: the long and short food supply chains will be reviewed in depth and compared in the following sections.

3 | LONG FOOD SUPPLY CHAIN

Long food supply chain (LFSC) is a globalized production chain, where multiple intermediates are involved between producers and consumers (Figure 2). The four major principles of LFSC are as follows: production, transformation, logistic distribution, and retail delivery (Joltreau & Smith, 2020; Mentzer et al., 2001). The first step, developed at a local scale, implies the activity of producers that usually turn to intensive livestock and agricultural practices to generate large quantities of raw material in the shortest possible time. Therefore, this practice promotes the utilization of an excess of fertilizers,

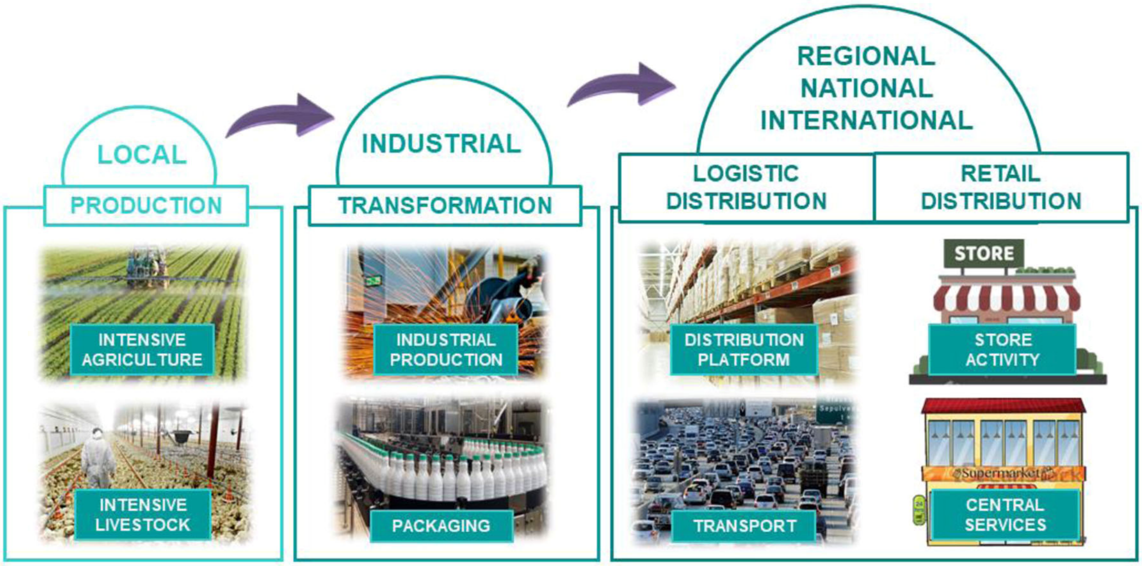

FIGURE 2 Workflow associated to the long food supply chain (LFSC)

herbicides, and pesticides. This initial stage is followed by a process of transformation of the raw materials into products, carried out at an industrial level, which also involves the packing step. Once packed, the produced goods are subjected to a logistic distribution stage in which they are transported from industrial areas to distribution platforms and/or wholesales centers by general means of transport, including airplanes, trains, or trucks. Finally, the transported products are delivered to retail centers at different scales, ranging from little stores to larger service centers, such as supermarkets or hypermarkets. Thus, LFSC represents the long journey, both in terms of distance and time, that food products suffer from their production origin to the destination where they become available to the consumers (Joltreau & Smith, 2020).

However, the dramatic growth of the world population and the subsequent increased pressure on the natural environment to meet the consumption demands have caused several implications of different nature attributed to LFSC (Garcia-Oliveira et al., 2022), whose responsibility relies on all the actors of the chain, including farmers, food suppliers, distributors, retailers, and consumers (Notarnicola, Tassielli, et al., 2017). Overall, LFSC presents a high number of problems associated with its ecological, environmental, logistical, and nutritional implications and, consequently, several solutions have been proposed to counter the negative impact of this globalized chain.

3.1 | Ecological and environmental implications of LFSC

The global increasing food consumption demands, combined with the depletion of natural resources, are leading to a harsh degradation of ecosystems, which has been attributed to LFSC. Such paradigm is mainly caused by the development of intensive agriculture and livestock, which leads to the overexploitation of natural habitats, forcing new transformation of biodiversity and the threatening of several species. Consequently, this destruction of ecosystems involved a subsequent reduction in yields, food security, and economical profits (Barbut & Alexander, 2016). In this sense, according to the United Nations data, natural ecosystems have been reduced by 47% on average, and land degradation has reduced productivity by 23% in all land areas. Globally, approximately 25% of all land is highly degraded, while 45% is considered stable or slightly/moderately degraded, and only 10% of all land is improving (United Nations, 2019).

Intensive agriculture is the main driver of such diversity loss and, as a solution, agroecology emerged as a good alternative to achieve the sustainable exploitation of agricultural resources, as a part of the current food systems. Agroecology is based on producing food through sustainable and regenerative systems, using resources more effectively to increase the productive capacity of biotic and abiotic system components (Migliorini & Wezel, 2017). Agroecological practices involve the substitution of pesticides and fertilizers and the dependence on fossil fuels with the use of compost, the implementation of removable resources and energy, the establishment of rotation crops, and soil erosion control. As a result, agroecology confers economic and social advantages, such as stable economic profits and an increase in employment rates (Van der Ploeg et al., 2019). On the other hand, the depletion of resources has been also observed in the marine ecosystems. Overfishing is an exponentially growing concern associated with LFSC intensive livestock, which has contributed to the reduction in the population of many fish species. Therefore, the implementation of catch share and promoting aquaculture production emerged as sustainable solutions (Garcia-Oliveira et al., 2022).

The depletion and mismanagement of natural resources, together with the high production of greenhouse gases (GHG) emissions of LFSC, have led to climate change-related implications that limit their sustainability. Intensive agricultural practices are responsible for about 30% of all anthropogenic GHG emissions worldwide (Watson et al., 2000). Moreover, the livestock sector also contributes to the environmental implications of LFSC produced by ruminants, especially cattle, whose enteric fermentation constitutes a relevant source of methane, considered as one of the gases with the highest impact on climate change (Doyle et al., 2019). Besides such biogenic GHG emission, the transport of products from producers to consumers is another factor that contributes to the emission of different harmful volatiles, mainly carbon dioxide (Paciarotti & Torregiani, 2020). In response to this situation, two major alternatives should be undergone to assess the long-term viability of LFSC: the development of resilient crop products and the reduction of GHG emissions. Concerning resilient crops, numerous studies have evaluated diverse molecular modifications to improve their resilience, such as genetic engineering to improve resistance to pathogens or to increase the adaptation against abiotic stresses associated with climate change, such as droughts, floods, and high salinity (Bailey-Serres et al., 2019). On the other hand, to diminish LFSC-mediated GHG emissions, the reduction of the enteric fermentation by ruminants is considered a valuable option, mainly achieved by cattle diet variation and supplementation. In the same way, biologic control approaches and the design of anti-methanogenesis vaccines are other alternatives that are currently underway (Doyle et al., 2019). Furthermore, the reduction of meat consumption is an additional strategy to counter the environmental implications of LFSC. Vegetarian and vegan diets have been revealed as rich plant-based protein sources with lower environmental impact (Lonnie et al., 2018). In addition to plant-based diets, new food formulations and products, which may help to reduce the current excessive consumption of animal protein, are being currently explored, as it is the case of algal, insect, and synthetic proteins.

3.2 | Logistical implications of LFSC

It has been estimated that about 1.3 billion tons of food produced for human consumption is lost or wasted along the food chain (Garcia-Oliveira et al., 2022), thus posing one of the major problems associated with LFSC. Food residues not only generate a negative impact on space, resources, and energy management but they have been also identified as a major cause of GHG emissions, due to their incineration. More than 3.3 gigatons of GHG is produced by food loss and waste (FLW) according to recent estimations (Notarnicola, Sala, et al., 2017). Thus, due to the relevant volumes of food waste annually generated, their potential revalorization is an exponentially growing approach regarding waste management. That is because the majority of agricultural by-products (i.e., grape pomace, banana peel, algae, seed hulls) have been revealed as important sources of bioactive compounds, such as polyphenols, carotenoids, and vitamins, which can be used as ingredients of functional foods and cosmetical and pharmacological products (Amit et al., 2017). With respect to FLW origin, there is a differential pattern depending on the developmental degree of countries. In underdeveloped and developing countries, FLW is predominantly produced between the industrial production and their transport to retail platforms, whereas in developed countries it is mostly generated between retail platforms and consumer consumption (Chaudhary et al., 2018). In terms of food products, roots, tubers, and oil-bearing crops are the major sources of FLW. The losses attributed to such crops account for up to 25%, produced from post-harvest to distribution, followed by vegetables and fruits, with a loss percentage greater than 20% (Garcia-Oliveira et al., 2022).

Among the alternatives proposed for preventing FLW, food preservation and traceability are the most extended approaches. In the case of food preservation, several techniques, such as the use of preservatives, high pressure, or electrical pulses, have been employed to guarantee the safety and quality of food products which also increase their shelf life and prevent spoilage. In addition, traceability is essential to ensure correct distribution of food products. It facilitates the logistics attributed to the food supply chain, since it avoids food fraud and preserves the information about food origin that consumers currently demand. Moreover, blockchain system facilitates the control of the traceability along the multiple and complex processes involved in the food chain. Blockchain systems are devoted to track the origin and pathway that products follow in the consecutive stages: from the production (agricultural activities developed at the farm and farmer work protocols), processing (transformation of the primary product and packaging), retailing, administration requirements (routinary inspections and others), and up to the consumption (evaluation of food products by consumers) (Galvez et al., 2018; Tian, 2016). As a result, blockchains enable end-to-end traceability by bringing a common technological language to the food chain while allowing consumers to access to the story and characteristics of foods on their label.

3.3 | Nutritional implications of LFSC

An important consequence of the globalized LFSC is the decrease in local food consumption and the inaccessibility of small farmers to the chain, due to high costs of production. Besides, a migratory movement has been observed from the rural areas to cities in the last years (Pradhan et al., 2020). Consequently, this exodus to urban areas caused important changes in dietary patterns, driving to a severe industrialization of food systems. In developed countries, the consumption of processed and fast food with high caloric index and poor nutritional value has incremented, and so the incidence of chronic diseases, such as obesity, dyslipidemia, and cardiovascular diseases (Béné et al., 2019; EAT, 2019). Besides, the productive requirements associated with fast food-based diets cause negative pressures on terrestrial, aerial, and aquatic ecosystems. Therefore, important changes in dietary patterns and nutritional education are required worldwide to improve and protect human health and environment, seeking for the disappearance of inequalities between countries with different income levels (Béné et al., 2019). In this sense, the World and Health Organization proposed that the dietary energetic profile should be characterized by a high consumption of fruits, vegetables, legumes, nuts and whole grains, avoiding an excessive intake of animal proteins and refined products. This switch would return improvements in the nutritional value of diets and prevent new environmental pressures associated with food production (World & Health Organization, 2019).

There are three main factors influencing diet: (i) culture and culinary traditions; (ii) socioeconomic status; and (iii) family influences, educational programs, and sustainable consciousness (Benedetti et al., 2018). Based on the impact of these factors, diet education can be modulated at different age ranges to reprogram people preferences and promote the establishment of a healthy diet. Besides, these diets should be based in sustainable pattern of productive systems to maximize the use of natural resources and minimize the emission of GHG. Concerning socioeconomic status, generally, it has been described a proportional relation in which population sectors with low socioeconomic status tend to present poorer diet habits. It has been suggested that it is mainly due to the high cost of healthier products and scarcity of nutritional knowledge. This combination of factors results in the adoption of diets rich in fat, sugar, and salt with a lower intake of fruits and vegetables (Hoek et al., 2017). On the contrary, sectors with higher socioeconomic status have been associated with higher daily fruit and vegetable intakes. Moreover, in the recent years, consumers are more conscious and interested in acquiring healthy products probably because of the increasing publication of nutritional information and studies are reaching more social sectors. For that reason, the food industry is currently focused on the design and development of functional foods. They present good nutritional properties, as well as positive effects on health by enhancing different cellular functions and/or reducing the risk of appearance of noncommunicable diseases (Munekata et al., 2021). Therefore, the effort of multiple actors, including stakeholders, individual consumers, and policy makers, is required to implement healthy and sustainable diets (Willett et al., 2019).

4 | SHORT FOOD SUPPLY CHAIN

Since the importance and limitations of LFSC on the current globalized food systems have been reviewed, new concerns have arisen to the redesign and redistribution of food supply chain. New perspectives and alternatives have been evaluated that led to the establishment of a completely renewed system, known as SFSC. It is defined as a chain with a limited number of intermediaries, usually none or one, and there is geographic proximity between producers and the consumers (Joltreau & Smith, 2020). The establishment of SFSC was mainly motivated by the limitations of LFSC: growing consumer awareness about sustainability and animal welfare, the current global trends regarding the adoption of a healthy lifestyle, and the higher interest in the information about the origin and quality assessment of food products (Thomé et al., 2021). Due to the relation between both kinds of food supply chains, Table 2 shows an in-depth comparison between LFSC and SFSC.

SFSC can be considered as a form of sustainable food production system. It responds not only to environmental objectives but also to social and economic matters (Rajesh, 2018), which ensures multiple benefits to all supply chain actors, especially since it prevents a negative impact on natural resources. Moreover, SFSC offers the possibility of developing supply chains that can shorten the complex industrialized process of LFSC (Joltreau & Smith, 2020; Marsden et al., 2000). This shortening confers an important added value to food production system, such as social relationships, the preservation of cultural heritage, food quality and safety assessment, and economic and technological sustainability (Thomé et al., 2021).

FIGURE 3 Main principles of the short food supply chain (SFSC)

Taking this into account, SFSC is based on six major principles correlated within a common sustainable background (D'Amico et al., 2014; Malak-Rawlikowska et al., 2019): (i) geographical or relational proximity, in terms of either distance or time, owing to political boundaries; (ii) traditional productivity methods; (iii) adaptation to consumer behavior patterns; (iv) regionalism, which can be eventually extended to international markets; (v) reduction and/or elimination of intermediaries between producer and consumer; and (vi) enhanced quality of healthier foods (Figure 3). In this sense, the sustainability attributed to SFSC is assessed by the Sustainability Assessments of Food and Agriculture Systems, in terms of the establishment of good governance systems, the maintenance of environmental integrity, the economic resilience, and the assessment of social well-being (Jawtusch et al., 2013). Furthermore, several authors have demonstrated the improvements and benefits brought by SFSC implementation in comparison with traditional food systems, especially regarding sustainability (Aubert & Enjolras, 2016; Galli & Brunori, 2013). Nevertheless, some specific case studies did not find a clear significant improvement of sustainability by SFSC in comparison with LFSC (Galli & Brunori, 2013; Pradhan et al., 2020; Schmitt et al., 2017; Schwarz et al., 2016). Therefore, a good design of SFSC and its continuous improvement is essential for the real achievement of sustainability goals. In the practice, the distribution and logistics for SFSC need to be smart, simple, quick, flexible, cheap, transparent, reliable, and sustainable to achieve a good traceability and a correct implementation of the environmental strategies. To that aim, SFSC must be properly designed to organize the traffic of

TABLE 2 Comparison between long food supply chain (LFSC) and short food supply chain (SFSC) by focal components

	LFSC	SFSC
Objective	Cooperation and strategic integration of the chain actors within a globalized context	Greater autonomy of the chain actors; establishment of alternatives for rural and local development
Configuration	Three or more actors directly involved, forming a network between producers and/or consumers	Reduction and/or absence of intermediaries between producer and consumer
Relations between actors	Formality and instrumentalization	Closeness and informality
Spatial relations	delocation. Loss of traceability	Regionalism. Traceability assessment
Value destination	Generation of value along the chain, implicating all the actors	Generation of value to the community for territorial development, greater added value generated to the consumer
Needs for improvement	Greater integration between actors to strengthen the chain	Greater integration among local farmers to strengthen the region

TABLE 3 Different indicators to evaluate the environmental, economic, and social sustainability of food supply chains (Malak-Rawlikowska et al., 2019; Wallgren, 2006)

		SFSC		LFSC	
		Min.	Max.	Min.	Max.
Environmental	Food distance (km)	15	250	750	24,000
	Food mile (km/kg)	0.1	3.6	0.01	0.4
	E_{spec} (MJ/tons km)	2.4	65	0.4	12.5
	E_{int} (MJ/kg)	0.2	17	0.45	10.1–50
	Carbon footprint (kg CO_{2eq}/kg)	0.1	1.2	0.1	0.2
Economic	Price premium (%)	61.9	96.7	5.3	23.5
	Chain added-value (%)	23.2	57.7	−10.6	10.3
Social	Labor to production ratio (%)	1.6	41.9	0.2	0.5
	Gender equality (%)	0.0	49.9	23.3	30.2
	Bargaining power	3.7	4.3	3.3	3.8
	Chain evaluation	3.4	3.8	3.3	3.9

Abbreviations: LFSC, long food supply chain; Min., minimum; Max., maximum; SFSC, short food supply chain.

goods and minimize transportation costs, for becoming as competitive as LFSC. The major challenge of SFSC is the successful implementation of innovative logistic solutions within food systems in the digitalization era while ensuring the specificities of distribution context of locally produced foods (Todorovic et al., 2018). In the same way, increasing efforts are being made to apply SFSC to a larger extent, supposing a true alternative to LFSC (Paciarotti & Torregiani, 2020). Among the several factors that need to be strengthen to reinforce the effectiveness of such transition, the most relevant is preserving the SFSC-sustainability in terms of environment preservation, economic stability, and social involvement (Malak-Rawlikowska et al., 2019; Thomé et al., 2021).

Both food supply chains, LFSC and SFSC are strongly relevant, but none of them represent an ideal approach which could meet the current and upcoming requirements of food systems. Table 3 presents a comparison of the environmental, economic, and social assessment of SFSC applied to a large scale against the already worldwide established LFSC.

4.1 | Environmental sustainability assessment of SFSC

Globalization has had considerable impact on the food supply systems. In the LFSC model, it caused the separation between producers and consumers which affected the traceability. Besides, it increased the dependence on exportations and, consequently, transport trade got also increased (Wallgren, 2006). In contrast, the short geographical distance between producers and consumers offered by SFSC may be essential for reducing the negative externalities connected to transport, such as GHG emissions. There are few indicators aimed to assess the environmental sustainability of food chain systems. Classical evaluation systems used the term "food distance" as a primary parameter, showing the distance (in kilometer) implicated in the whole process from producers to consumers. However, it was inadequate to guarantee environmental sustainability, as the transportation supposes a minimal proportion of the total impact associated with the whole food system. Consequently, food distance was soon replaced by the "food mile" indicator. It defines the distance from food origin to the place where it can be purchased by the consumer or end-user, and it is expressed as kilometer per kilogram of food product (Malak-Rawlikowska et al., 2019; Pirog et al., 2001). Several authors confirmed that the shorter the food mile, the lower GHG emissions and fewer distribution stages along the chain (Jones, 2002; Pirog et al., 2001). Some authors have reported that despite the significantly higher food distance for LFSC, food mile values were similar for both food chains (Malak-Rawlikowska et al., 2019; Wallgren, 2006). Indeed, higher food mile values were reported for SFSC (Table 3) because SFSC products are transported in small quantities and require the participation of different individual transports (Mancini et al., 2019; Pradhan et al., 2020).

Due to the inefficacy of these distance indicators on the evaluation of food chains, two other parameters related with energy requirements during food production were proposed. One is the transport energy intensity (E_{int}) defined as the amount of energy required to transport 1 kg of product to the market (in MJ/kg). The other one is the specific energy use (E_{spec}) defined as the E_{int} referred to a certain distance, in MJ/(tons km) (Wallgren, 2006). Lower energy values are associated with sustainable food chains. In general, LFSC presented lower E_{int} and E_{spec} values since more products are sold, when compared to SFSC. However, products that have been transported by airplanes represent an exception since they have traveled larger distances, which imply a higher fuel consumption. Thus, airplane-mediated transport causes a harsh increase in LFSC E_{int} (Table 3).

Finally, another key environmental indicator has been established to evaluate the sustainability of food chains: carbon footprint. It indicates the amount of carbon dioxide emitted to the atmosphere, expressed as GHG equivalents per kilogram of food product (kg CO_{2eq}/kg food). As it occurred for the previous analyzed parameters, carbon footprint values for SFSC are greater than those of LFSC (Table 3). The fuel consumption caused by the individual transport of the products to retail platforms implies higher rates of GHG emissions when compared to LFSC, where one unique transport manages the movement of huge volumes of products (Malak-Rawlikowska et al., 2019).

Therefore, the assessed environmental indicators of SFSC reflect that this food chain generates great externalities that play a negative role on its sustainability. Nevertheless, these analyzed parameters do not permit to achieve a complete sustainability assessment. For this aim, it is also necessary to consider the external costs of other processes and activities of the supply chain, including the energy consumed for food storage or the handling and administration along the supply chain (Paciarotti & Torregiani, 2020). As a matter of fact, packaging is an essential element of LFSC with a lower relevance in SFSC, which has a significant environmental impact and contributes to the generation of waste (Pérez-Neira & Grollmus-Venegas, 2018). Therefore, an integrative approach of multiple factors is fundamental to determine the real environmental impact of these two food supply chains (Pérez-Neira & Grollmus-Venegas, 2018).

4.2 | Economic sustainability assessment of SFSC

Two major economic indicators are established to promote the assessment of food chains (Malak-Rawlikowska et al., 2019). In this sense, price premium is defined as the increment imposed to a product considering its general benchmark price in the market, and it is expressed as percentage. The average value of price premium for SFCS is 72.2% compared with 16.7% in LFCS (Table 3). Prices paid by consumers for SFSC products were almost as twice higher as the average farm gate prices, which ultimately provide huge price premium data. This increment in the price creates an idea of exclusivity around food products sold at a local level.

On the other hand, another economic indicator used in food systems evaluation is the chain added value. This parameter is defined as the difference between farm gate and distribution costs, related to transportation, packaging, market fees and related labor inputs, expressed as a percentage. As observed for price premium, the average chain added values of SFSC double, and even quintuplicate, those of LFSC (Table 3). These data suggest that, as currently applied, SFSC is not an economically stable system for food production; hence, novel strategies should be proposed to produce price gains by the commercialization of its derived food products.

4.3 | Social sustainability assessment of SFSC

Concerning the social assessment of SFSC, four indicators have been established, placing the consumer as the principal actor along all the stages of the food chain. The first of these social indicators is the labor to production ratio. It takes into account the number of hours worked in all stages along the chain (including distribution, production preparation, transport, and selling), as well as the volume of sales, in terms of kilogram of products, in percentage (Malak-Rawlikowska et al., 2019). Consequently, this parameter increments when the volume of sales decreases. Thus, as the volume of sales in SFSC is lower than in LSFC, this indicator is much higher in SFSC (Table 3). It is mostly due to the higher efforts made by producers, who are normally in charge of the transport and selling of their own products. In contrast, in the case of LSFC, such responsibility is distributed between producers and intermediaries.

The second indicator of social sustainability is gender equality, which quantify the hours that women worked from the total number of hours devoted to distribution process, expressed in percentage. Gender equality is, as a rule, higher in SFSC than in LFSC (Table 3), since the labor input performed by women in farms and local markets that require portioning and packaging has higher prevalence.

The third indicator for food supply chain social assessment is bargaining power, which is defined as an estimation of self-assessment developed by business managers to evaluate their position in the chain. Since SFSC enables a direct implication of producers with consumers, bargaining power values are slightly higher for this system (Table 3). Nevertheless, LFSC does not show very different values due to the effect of hypermarket chains as trustful business partners, which enable the purchase of large quantities of products at reasonable prices (Malak-Rawlikowska et al., 2019).

Finally, the chain evaluation is the fourth social indicator, which represents the attractiveness of the chain, in terms of consumer satisfaction, labor requirements, and pricing strategy (Malak-Rawlikowska et al., 2019). Chain evaluation values are very similar for both chains (Table 3). In the case of SFSC, consumers express a high satisfaction level at good prices, which lead to higher incomes to producers, who receive regular and assured payments from a direct purchase. On the other hand, chain evaluation values in LFSC are due to the high capacity of product selling combined with the establishment of long-term contracts.

5 | CONCLUSION

Globalization has caused great inequalities between countries in terms of food supply. Initially, by the 1960s, the Green Revolution, in combination with biofortification and sustainable intensification, emerged as promising solutions to increase food production. However, they ended up causing a negative environmental impact. The inequalities got also reinforced by the establishment of LFSC, characterized by the presence of several intermediaries between local producers and end-consumers. In response to such paradigm, certain solutions were proposed to improve the expectations on this globalized food system, and reduce its ecological, environmental, logistical, and nutritional implications. Thus, the shortening of food chain, known as SFSC, may constitute a hopeful strategy to overcome the limitations associated with LFSC. SFSC is based on the elimination of intermediaries between producer and consumer, geographic proximity, and traceability. However, this emerging system must face its own difficulties, especially in terms of environmental, economic, and social sustainability to be applied at a larger scale and be able to compete against the well-established LFSC. In this sense, more studies are required to determine the suitability of SFSC as a profitable food system to be implemented, with a special focus on its environmental point of view.

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CONFLICT OF INTEREST

The authors confirm that they have no conflict of interest to declare for this publication.

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