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The influence of sustainability on the complexity of food supply chains

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ABSTRACT
The sustainability of food supply chains (FSCs) depends on the concurrent successful performance in the environmental, economic, and social dimensions. However, FSCs are complex socio-technical systems subjected to inevitable trade-offs and the impossibility of full control. Based on a systematic literature review, this study investigates how sustainability affects the complexity of FSCs. A total of 75 articles were analyzed. A thematic analysis revealed 16 factors associated with the three dimensions of sustainability. These factors were then associated with five complexity attributes: a large number of elements, dynamically interacting elements, diversity of elements, unexpected variability, and resilience. All factors amplify the complexity of FSCs, mostly in terms of increasing the number and diversity of elements. Findings made it possible to develop a complexity-based account of the sustainability of FSCs, raising questions and insights that might inform the design and operation of more sustainable FSCs, which effectively cope with their inherent complexity.

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Sustainability; complexity; food supply chain; resilience; systematic literature review

1. Introduction

Ensuring food security for a growing global population while protecting the environment and promoting social equity requires a comprehensive approach (Rasul, 2021). The COVID-19 pandemic posed an additional challenge for food security, farmers, and vulnerable populations as the lockdowns led to disruptions in the food supply chain and higher instances of undernourishment (García et al., 2020; Khan, Razzaq, et al., 2022). As such, the pandemic gave visibility to weaknesses and improvement opportunities for FSCs worldwide. For example, Yao et al. (2020) argue that China should increase soybean stocks and international cooperation to achieve long-term food security through the profitable cultivation of soybeans and the development of sustainable planting chains. In this context, the importance of Sustainable Food Supply Chain Management (SFSCM), defined as 'the integration of sustainability into the food supply

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chain at every step, during manufacturing, transportation, distribution, and collection, cannot be overstated' (D. Li et al., 2014).

This importance is highlighted by Hamam et al. (2021), who emphasize the need for increased stakeholder responsibilities, awareness from producers and consumers, and policies and tools to support sustainability practices. In the same vein, Khan, Yu, et al. (2021) examine the association between environmental and socioeconomic indicators, concluding that adopting Green Supply Chain Management (GSCM) practices contributes to reducing mortality rates while spurring economic growth through trade opportunities. Moreover, Khan, Mathew, et al. (2022) found that a closed-loop supply chain strategy is the most effective for ensuring the long-term stability of food systems. In turn, Gibson et al. (2020) offer insights into India's integrated design of agriculture and health policies. Their study highlights the potential to reduce supply chain losses by effectively using energy sources and maintaining favorable climatic conditions in modern silo storage systems. However, according to Yu et al. (2022), energy poverty and its implications for environmental degradation remain a significant issue in developing countries.

Like other supply chains, the sustainability of food supply chains also relies on the triple bottom line (TBL), encompassing financial success (economic pillar), environmental quality (environmental pillar), and social justice (social pillar) (Elkington, 1999; Liu et al., 2019). The environmental dimension is related, for example, to the concern with environmental impacts caused by natural resources exploitation and pollutant emissions. The economic dimension focuses, among others, on achieving profit, efficiency, and generating competitive advantage. The social dimension entails a concern with social impacts, inside and outside the organization, such as good working conditions, health, safety, fair pay, and gender equity (G. Kumar et al., 2021; Kolling et al., 2022).

However, given the nature of food production, which inevitably occurs partly in natural environments, sustainability in this context is interwoven with factors external to the supply chain. On the one hand, SFSCM is vulnerable to factors such as climate change, water scarcity, demographic change, and land use (Gunarathne et al., 2018). On the other hand, the food supply chain itself can amplify these problems as a result of deforestation for agricultural commodities (e.g. beef, soybeans, palm oil, cocoa, and coffee) (Sotirov et al., 2020).

In addition, globalization, urbanization, and agro-industrialization have also influenced the structure and functioning of food supply chains across the production, distribution, and retail stages (Allaoui et al., 2018; Amoozad Mahdiraji et al., 2019; Srivastava et al., 2015). Thus, SFSCM tends to be complex, implying upsides (e.g. collaborative practices between supply chain agents) and downsides (e.g. vulnerability to external threats). Given their far-reaching scope, sustainability efforts will likely have mixed complexity implications for food supply chains. Understanding these implications might shed light on the fundamental characteristics of SFSCM that provide a new account of how sustainability can be obtained. Against this background, the following research question arises: how does sustainability affect the complexity of food supply chains? A systematic literature review of sustainability in the food supply chain was conducted to answer this question.

This article is structured in five sections. The first is this introduction. The second presents the theoretical background. Section 3 presents the methodological procedures used to carry out this study. In Section 4, the results and discussions are described. Finally, Section 5 presents conclusions, limitations, and suggestions for future studies.

2. Background

2.1. Sustainability of food supply chain

Several reviews on the sustainability of the food supply chain have been published, addressing various themes. Jazinaninejad et al. (2022) reviewed sustainable operations in the biomass supply chain. Siddh et al. (2017) used a structured literature review to discuss the evolving quality of the agro-fresh food supply chain over 23 years. Rizou et al. (2020) presented a review summarizing possible ways of transmitting COVID-19 throughout the food supply chain, along with recommended preventive measures.

There are also reviews focused on life-cycle assessments. For example, Zingale et al. (2022) analyzed prior reviews on the life-cycle of durum wheat, concluding that the cultivation phase is the most critical from an environmental perspective. Pagotto et al. (2021), using life cycle assessment and circular economy concepts, developed in their review a framework to analyze the environmental, social, and economic effects of implementing sustainable production and consumption processes in the food production system. Corallo et al. (2020) developed a research map for product life-cycle management and food traceability.

Furthermore, several studies of Sustainable Food Supply Chain (SFSC) explicitly adopt the triple bottom line as a lens. For example, Rota et al. (2013) propose that the organizational dimension should be added to the triple bottom line dimension in the life-cycle analysis of food supply chains. Zhu et al. (2018) propose using mathematical techniques to model the triple bottom line in SFSC. Thomé et al. (2021) highlighted that strategic orientation towards the triple bottom line causes a significant change in the business environment. Chiffoleau and Dorian (Chiffoleau & Dourian, 2020) concluded that although the literature generally agrees on the social benefits of SFSCs, their economic and environmental impacts generally lead to more diverse results.

An emergent theme of the SFSC literature is the adoption of blockchain. In exploring this theme, Priyadarshini and Abhilash (2021) reviewed the literature on blockchain in sustainable supply chain management, while Dasaklis et al. (2022) conducted a systematic literature review on the technical aspects of implementing blockchain-enabled supply chain traceability systems. Additionally, Rana et al. (2021) discussed the impact of blockchain technology on sustainability, and Park and Li (2021) argued that blockchain technology could potentially improve the sustainability performance of the supply chain.

A. Kumar et al. (2022) and Palazzo and Vollero (2022) present future studies opportunities and trends in sustainable food supply chain management. A. Kumar et al. (2022) present a map of nine key research themes in SFSCM. Palazzo and Vollero (2022) highlight the main research directions in Sustainable supply chain management (SSCM), emphasizing opportunities in emerging countries. According to these authors, although previous reviews have focused on aspects such as traceability, food safety, and performance measurement, sustainability has rarely been considered a means of integrating these issues.

Some studies also refer to the complexity of the food supply chain. For example, M. Kumar et al. (2022) analyze risks in food supply chain management, acknowledging that the chain is complex and subject to endogenous and exogenous risk factors n. According to Prima Dania et al. (2016), sustainability requires collaboration between chain members, given the complexity of the food supply chain. Their study suggests collaborative practices are important in supporting complex food supply chain management. However, these authors do not discuss how sustainability relates to complexity. Ada (2022) indicates that the complexities of the food supply chain add a layer of complexity to the selection process of suppliers. Despite the contributions of the aforementioned studies, the complexity of the SFSC was not their main focus. In fact, complexity is often briefly mentioned as a background for discussing other topics or used loosely as a metaphor for the difficulties of developing an SFSC.

2.2. SFSCM as a complex socio-technical system

Attributes of complex socio-technical systems are commonly cited in the literature, such as non-linear interactions between a large number of diverse elements (e.g. people, materials, companies (Perrow, 1999; Snowden & Boone, 2007), and adaptive behavior (Kurtz & Snowden, 2003; Stacey et al., 2000). According to Behdani (2012), these characteristics are generally present in supply chains. The social elements of this complex system are suppliers, manufacturers, retailers, and clients, who interact in different ways. The technical element in the supply chain is characterized by facilities (e.g. warehouses) and transportation infrastructure. The supply chain performance emerges from the interactions of the elements of this system, rendering it complex (Behdani, 2012) and socio-technical (Kull et al., 2013; V. Roy et al., 2018).

For Gebler et al. (2022), the design of complexity attributes impacts sustainable development. SSCM is arguably a source of complexity as it aims to balance economic growth, environmental protection, and social well-being by implementing sustainable practices throughout the supply chain (Seuring et al., 2019). These practices require a significant investment of resources and effort, and their implementation is highly dependent on the support and participation of all actors within the supply chain (H. R. Vandchali, S. Cahoon, & S. L. Chen, 2021). Therefore, SSCM involves a wide range of actors, including suppliers, manufacturers, retailers, and consumers, all interacting within a highly complex network of relationships (H. R. Vandchali, S. Cahoon, & S. -L. Chen, 2021). As such, the social and cultural dimensions of SSCM are also critical (Naderi et al., 2021), requiring a significant investment in education and training to build the knowledge and skills necessary to implement sustainable practices effectively (Siems et al., 2021). SSCM also involves the use of technologies to support sustainable practices, such as the use of advanced logistics, the integration of sustainability metrics into supply chain management software, and the use of blockchain technology to track and verify the sustainability of supply chain operations (Khan, Zkik, et al., 2021). Due to this complexity, inventory management plans and flexible procurement strategies are important to increase the supply chain's responsiveness, which is an important part of resilience (Hobbs, 2020). Collaborative and reliable relationships are also essential to supply chain resilience (Hobbs, 2020) as well as the minimization of waste (Suryawanshi et al., 2021)

Table 1. Attributes of complex socio-technical systems and examples in food supply chain.

Attribute	Attribute description	Examples of sustainable food supply chain
Large number of elements	The system has many elements, such as technical parts, people, procedures, and regulations.	Partners, consumers, transport companies, retailers, and bulk distributors, facilities, warehouses, vehicles, information systems, blockchain.
Dynamically interacting elements	Interactions occur between tightly coupled elements and allow, for example, the quick propagation of errors.	Exchange of materials and information is at the core of any supply chain. These interactions are constantly changing, and they may have non-linear implications – e.g. bullwhip effect
Diversity of elements	Elements differ according to various categories such as hierarchical levels, tasks division, inputs, and outputs.	The elements that compose the supply chain differ according to several categories, such as consumer profile, supply sources, and the diversity of evaluation methods. -Social diversity: age, instruction level, nationality, language, culture, etc. -Technical diversity: different equipment (with more or with less technology); a myriad of supplies and raw materials, procedures, etc. - Work organization diversity: hierarchical levels, sectors, departments, subsidiaries, business types; management styles, roles played by workers etc. - External environment diversity: environmental laws and regulations, national and international.
Unexpected variability	Complex systems are open, that is, they interact with their environment, which alone is an important source of variability. Non-linear interactions are also a source of unexpected variability.	Internal variability: absenteeism, machine breakdown, material quality, uncertainty of measures, workarounds, etc. External variability: demand oscillation, economic and political crisis, exchange rate, strikes, natural disasters, terrorism, war, COVID-19 pandemic, weather conditions, etc.
Resilience	Resilience is the ability of a system to maintain and adapt its operational performance against failures and other adverse conditions	Remote work, investment in equipment, diversification in work schedules, scheduled delivery systems, improved inventory control, outsourcing, in response to challenges and adverse conditions. Do not choose practices where industrial agriculture is not resilient (monoculture, CAFOs, etc.).

Source: Adapted from (Saurin & Gonzalez, 2013) and (Soliman et al., 2018).

Given this context, SFSCM can be described in terms of its complexity attributes. Saurin and Gonzalez (2013) present five complexity attributes adopted as a basis in this article (Table 1). These attributes were identified from a literature review of seminal papers and books on complexity theory, such as Perrow (1999), Johnson (2007), and Dekker (2011). Other studies used these same five attributes, such as Azevedo and Saurin (2018) in water distribution systems, Soliman et al. (2018) in lean production, and Righi and Saurin (2015) in the emergency department of a large public hospital.

3. Method

3.1. Research strategy

This study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) protocol, which guides systematic reviews (Moher et al., 2009). The systematic review identifies various aspects of sustainability in the food supply chain, examining how sustainability is implemented. Furthermore, the choice for a review approach was mostly due to the substantial body of knowledge on SFSCM, which despite addressing some complexity implications, does not make them explicit regarding the affected complexity attributes. Thus, the investigation of the research question was assumed not to require further empirical work but rather a re-interpretation of the existing literature. This review was carried out in two stages. The first stage included selecting keywords, defining inclusion and exclusion criteria, and conducting a search in scientific databases, then analyzing the selected articles. The second stage consisted of general characterization and qualitative e quantitative analyses of the selected articles.

3.2. Search and selection of articles

The search and selection of articles (Figure 1) involved (Moher et al., 2009):

(i) *Identification of articles*: at this stage, journal databases and keywords were selected. Six databases available at the authors' institution were consulted, namely: ScienceDirect, Web of Science, Wiley, Scopus, and ProQuest. These databases were accessed in September 2021.

The search algorithm used was: 'Supply chain' AND 'Sustainability' AND 'Food' in the abstract, title, and keywords. The period of publication was not specified. The search resulted in 4,548 results. Out of these, 802 articles were from the ScienceDirect database, 1,874 from the Web of Science database, 121 from the Wiley database, 1,751 from the Scopus database, 352 from the ProQuest database, and 4 from additional records

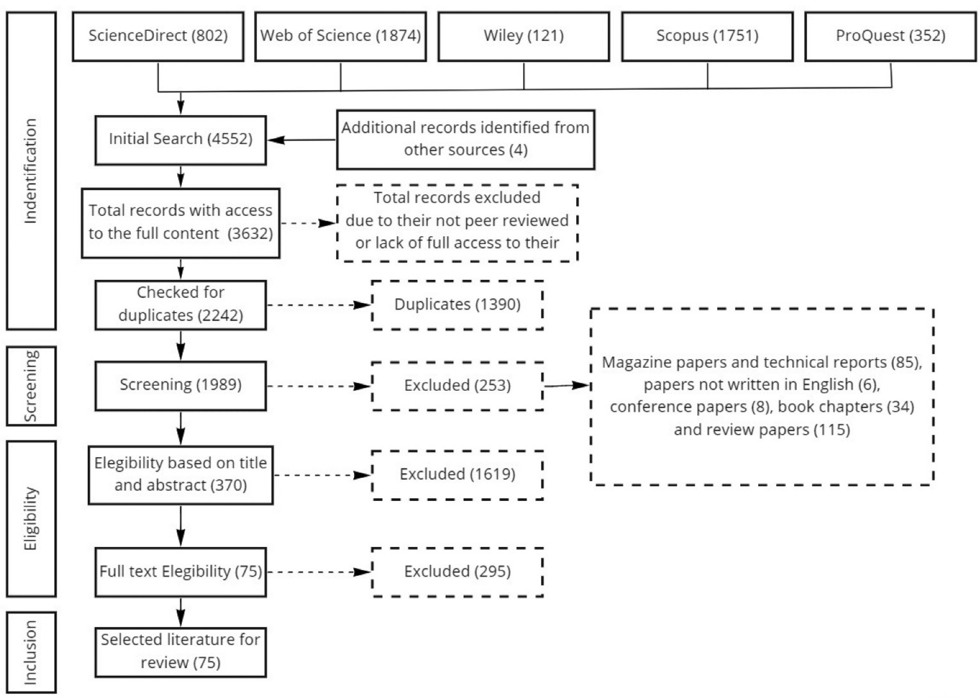

Figure 1. Steps to carry out the systematic review.

identified from other sources. After deleting 920 articles due to their not being peer-reviewed or lack of full access to their content (Stüve et al., 2022), 3,628 entries remained. Out of these articles, 1,390 were duplicates. Thus, 2,238 articles were selected at the end of this stage;

(i) *Screening*: at this stage, six exclusion criteria were applied, namely: magazine papers and technical reports (85); papers not written in English (6); conference papers (8); book chapters (34); and review papers (115). Based on this, 253 entries were excluded, and 1,985 remained in the next stage.
(ii) *Eligibility*: at this stage, the selected articles presented sustainability concepts related to the supply chain or its components and covered one or all of the sustainability pillars (environmental, social, and economic). We excluded articles that used the concept of sustainability referring to business sustainability as a means of company's competitive advantage, sustainable products instead of sustainable supply chains, articles that used the sustainability concept as a synonym for reverse logistics without directly dealing with social, environmental, economic or sustainable components, or that used it as a synonym of circular economy, without directly dealing with social, environmental, and economic components. Based on these criteria and after reading the article's titles and abstracts, 1244 articles were excluded. Then, after reading the entire text, 295 documents were excluded. Thus, 75 articles remained for the next step.
(iii) *Inclusion*: at this stage, no other articles were included. The 75 articles were alphabetically sorted by title, with their identification information registered and the article's content included in the data analysis (Table 4 in the Appendix).

3.3. Data analysis

In order to obtain an overall characterization of the selected articles, bibliographic information was recorded. This information made it possible to identify the journal, year of publication, and country where the studies were conducted.

The initial portion of data analysis was a thematic analysis to identify contextual factors that influenced the three sustainability pillars. As such, we highlighted excerpts of text connected to each pillar. Each excerpt could be associated with one or more factors. Then, those factors were grouped according to their similarity. The first author conducted the first coding round, and then the other two researchers reviewed the results to minimize bias. Disagreements were discussed until a consensus was reached.

Since each factor identified in the previous steps can influence more than one complexity attribute and be related to more than one sustainability pillar, additional analytical steps were conducted to shed light on the different strengths of these relationships. This assessment was carried out by assigning scores to the relationships as follows:

(i) Sustainability: this analysis aimed at identifying to what extent each factor was related to each sustainability pillar. The score ranged from zero (factor not related to the sustainability pillar) to four (factor firmly associated with the sustainability pillar). The score could include non-integers numbers.

(ii) Complexity: this analysis aimed at identifying to what extent each factor influenced each complexity attribute. The scores were: −2: the factor substantially reduces the intensity of the complexity attribute; −1: the factor moderately reduces the complexity attribute; zero: the factor has no/neutral influence on the complexity attribute; 1: the factor moderately amplifies the complexity attribute; 2: the factor strongly amplifies the complexity attribute.

The four authors individually assigned the scores. Then, the authors met to discuss the relationships whose scores differed by more than 1 point. In this meeting, authors could modify the scores they had previously assigned. The final results presented in the paper are the mean scores from all authors.

Two factor rankings were developed based on this final score, considering their overall mean scores. The first ranking considers the pillars of sustainability and determines how much the factor is related to the sustainability pillar. The second considers the relationships with the five complexity attributes identifying to what extent each factor influenced each complexity attribute.

4. Results and discussion

4.1. Characterization of the studies

The 75 selected papers were published in 35 different journals, suggesting a broad audience interested in the topic. The three most frequent journals were: *Sustainability* (13 papers), *Journal of Cleaner Production* (11), *British Food Journal* (4), *Resources, Conservation and Recycling* (3), and *International Journal of Operations and Production Management* (3). All the journals in the database with the number of publications are found in the Appendix in Table 5. In turn, the selected papers had authors and co-authors in 32 countries, with a higher frequency in *the United Kingdom* (50%), *Italy* (47%), *Netherlands*, and *Spain* (each accounting for 25% of the total). Of the selected articles, 40% were published between 2020 and 2022; approximately 30% were published between 2019 and 2018, and 11% were published between 2016 and 2017. Articles published in other years account for less than 5%. Therefore, it can be inferred that the topic is of current interest, which may be due to the influential movement that took place in the United Nations, as mentioned in the publication 'Transforming our world: the 2030 Agenda for Sustainable Development' (UN, 2015).

4.2. Sustainability and complexity attributes in food supply chain

The thematic analysis pointed out 16 Food Supply Chain factors that influence the complexity attributes and are related to the sustainability pillars, presented in Table 2. In this Table, 'Freq' refers to the number of articles cited for each factor.

The factor mentioned in most of the selected articles was a *Large number of tiers in the supply chain (LN)* in 47 articles, followed by *Uncertainty in the judgment because of the Diversity of criteria for waste and pollution assessment (DC) and Prevention of*

Table 2. Factors that influence the complexity attributes.

Factors	Description	Code	Freq.
Large number of tiers in the supply chain	The high number of links (e.g. supplier, industry, distribution, retail) in FSC results in many stops and changes in food transportation. Hinders maintaining quality and food safety (due to shelf life and variations in storage and transport conditions) can lead to food loss.	LN	47
Uncertainty in the judgment because of the Diversity of criteria for waste and pollution assessment	Uncertainty in the judgment of decision-makers, conflicting decision criteria, lack of standardized measures among FSC members to analyze losses and pollution.	DC	39
Prevention of occupational and process health and safety hazards	OHS benefits from resilient performance as people of FSC members and food systems can effectively fill out gaps in (inevitably) underspecified standard operating	PO	39
Exchange of information	The members of the FSC need to invest in sharing important and confidential information between them. Thus, integrating information to achieve SFSCM.	EI	38
External variability	Market demand variation in periods of demand fluctuation, economic, political, or exchange crises, strikes, natural disasters, terrorism, wars, among others, influences the availability and accessibility of certain foods.	EV	38
Clean Technologies	Clean technologies used in the food supply chain to reduce soil pollution and pollutant emissions bring benefits, for example, soil preservation and increased use of fossil fuels. Relatively simple and low-cost technologies for businesses (e.g. biomass, water reuse for irrigation, and composting) can benefit.	CT	37
Large number of consumers	The social aspect that results from urbanization is a large urban population concentrated in a small area. Urbanization shapes a country's food system and creates longer food chains, a greater need for processing, packaging, refrigeration, and more food losses.	LC	36
Climate change	Climate change generating more losses in harvesting, production, distribution, transport, storage, among others, due to increased susceptibility to disease and extreme weather events.	CC	30
Diversity of partners' types	Diversity of financial resources available, among FSC members, to invest in acquisition, for example, of equipment and technology.	DT	30
Internal variability	Variability related to absenteeism and employee dissatisfaction of FSC members.	IV	30
Food price	The increase in food prices can lead the population to decrease its daily consumption.	FP	30
Natural resource management	The adaptive capacity of the FSC members to conserve natural resources, especially water and soil, and maintain sustainability under expected and unexpected conditions.	NS	24
Demographic Diversity of employees	Members of the FSC must know how to deal with their employees' characteristics (age, education level, nationality, language, culture, gender, etc.)	DD	20
Slack resources	Extra resources to deal with variabilities, such as inventory, time, or people, create slack in the system.	SR	20
Diversity of consumers' profiles	Food waste by consumers, and its economic implications, are related to their characteristics (e.g. age, education, culture, and purchasing power)	DP	15
Diverse supply sources	Diversity of suppliers, for example, such as large multinational companies, small companies, and companies from other cities.	DS	10

Table 3. Quantitative assessment of a factor associated with sustainability.

Factor	Code	Environmental	Social	Economic
Climate change	CC	4,0	3,5	3,5
Clean Technologies	CT	4,0	2,0	3,3
Uncertainty in the judgment because of the Diversity of criteria for waste and pollution assessment	DC	3,8	1,4	2,1
Demographic Diversity of employees	DD	0,3	4,0	1,3
Diversity of consumers' profiles	DP	3,3	2,5	3,3
Diverse supply sources	DS	1,0	2,3	2,8
Diversity of partners' types	DT	1,3	1,3	2,8
Exchange of information	EI	1,0	1,0	1,8
External variability	EV	2,0	3,0	3,5
Food price	FP	2,5	3,3	3,8
Internal variability	IV	0,8	4,0	2,0
Large number of consumers	LC	3,8	3,3	3,8
Large number of tiers in the supply chain	LN	1,8	1,5	2,3
Natural resource management	NS	4,0	1,5	2,0
Prevention of occupational and process health and safety hazards	PO	0,5	4,0	2,5
Slack resources	SR	3,0	2,3	3,8

occupational and process health and safety hazards (PO), both found in 39 articles. The factor *Diverse supply sources (DS)* were the least frequent, appearing in 10 articles.

The factor *LN* is related to the high number of interactions (e.g. between supplier, industry, distribution, and retail) in the supply chain, which creates additional transportation and storage processes that pose risks to food quality (e.g. bruises or wilt) and losses before reaching the end consumer. A high number of links (supplier, industry, distribution, retail in the chain) result in many exchanges between partners, hindering quality and food safety (Bustos & Moors, 2018). In turn, the factor *DC* refers to encompasses the Diversity of quantitative and qualitative measures that supply chain managers rely on to make crucial decisions under high uncertainty to relate the differences in waste and pollution assessment (J. Roy et al., 2020).

The factor *Prevention of occupational and process health and safety hazards (PO)* is related to workers' physical and mental health, safety, and hygiene (Morais, 2017). *PO* allows the creation of slacks in the face of adverse conditions about Occupational Health and Safety (OHS). *Exchange of information (EI)* refers to the importance of collaboration among companies and considers efficient information flows essential since they reveal long-term sustainability opportunities throughout the supply chain (Stüve et al., 2022; Tsolakis et al., 2018), developing the strategic partners that support sustainable products and processes (Pullman & Dillard, 2010).

The *External variability* (*EV*) refers to the variation of demand that reflects on products and processes throughout the chain (Brunori et al., 2016). Factor *Clean Technologies* (*CT*) can minimize risks to humans and the environment, increase the green efficiency of the process, and improve products and services (Agyabeng-Mensah et al., 2020).

Climate change (CC) is related to extreme weather events that generate more losses in harvest and production and increased susceptibility to diseases impacting the number of products available (Merlino et al., 2020). *Diversity of partners' types (DT)*corresponds to the different availability of the partners' economic resources, especially small and medium-sized, which lack technical and financial resources to optimize and improve your processes (Singh et al., 2015).

Internal variability (IV) refers to the company's contribution to employee satisfaction, improving productivity with positive effects on the company's profits and reputation (Nirino et al., 2019). The *Food price (FP)* factor evaluates the product's price considering that the food's acquisition and subsequent consumption are related to the amount to be paid. For example, some consumers are more price-sensitive and always buy the cheapest product or prefer to associate the product's price with its quality (Merlino et al., 2020).

The *Natural resource management* (*NS)* factor refers to the adaptive capacity of the FSC members to a constantly changing environment and continually adapt to maintain natural resources (for example, soil and water) (Brunori et al., 2016). Quality in managing natural resources is achieved by maintaining and using biodiversity with efficient resources (Peano et al., 2015).

Demographic Diversity of employees (*DD)* refers to the different characteristics of the employees, which in turn brings different needs of each employee. It is encouraging, for example, to hire employees of each gender in the different departments (Tiwari & Khan, 2019) and offer workers fair opportunities that encourage Diversity within the company (Pullman et al., 2009). In addition, Kayikci et al. (2020) state that investing in the education and training of the employees can reduce food waste and increase the quality of the sector.

The *Slack resources (SR)* relate to extra resources made available to deal with variability in inventory, time, or people, which creates a slack in the system. Thus, organizations must tactically invest in activities that change the company's strategy in order to have resources to deal with the oscillations of the production system (Merlino et al., 2020; Shnayder et al., 2015)

Diversity of consumers' profiles (DP) refers to food waste due to the different profiles of consumers discovering a correlation between green consumption habits and a number of demographic factors, including age, gender, financial position, and educational attainment (M. Li, 2020). *Diverse supply sources (DS)* indicate the different types of suppliers depending, for example, on their size or location (Allaoui et al., 2018; Banaeian et al., 2015; Shnayder et al., 2015).

The Food System is all the people and activities involved in cultivating, transporting, supplying, and eventually ingesting food. Food preferences and resource investments are two examples of invisible aspects in these systems. The components of Food Systems are Food Supply Chains, Food Environments, Individual Factors, and Consumer Behavior. The External Drivers of Food Systems are Climate Change, Globalization and Trade, Income Growth and Distribution, Urbanization, Population Growth and Migration, Politics and Leadership, and Socio-cultural Context. In this work, some identified factors are linked specifically to the food supply chain, and others are related to the Food System as a whole (Fanzo et al., 2020).

The factors *LN, EI, DT, DS, CT, DC*, and *NS* were included because they directly relate to sustainable FSC. The other factors were considered because they belong to the Food System (HLPE, 2017) and are necessary for the sustainability of the FSC. These factors have been analyzed and can be related to the Food System factors (Fanzo et al., 2020). The factor *FP* (to food affordability), *PO* and *SR* (to Individual Factors), and *DP* (to Consumer Behavior) were included, and the external drivers in food systems: *LC* (population growth and migration and urbanization), *DD* (to socio-cultural context), *EV* (to globalization and trade, politics, and leadership), *CC* (to climate change) were also considered.

4.3. Food supply chain factors and sustainability

Table 3 presents the relationships between factors and the sustainability pillars (environmental, social, and economic). The scores ranged from 0 (a factor not related to sustainability) to four (a factor strongly associated with sustainability), including non-integer numb ers.

The factors may be strongly related to more than one sustainable pillar. Thus, according to the relationships presented in Table 3, it was possible to identify:

- Factors that are strongly related to the three pillars of sustainability: *Climate change* (*CC*) and *Large number of consumers* (*LC*). It is known that the *Climate change* (*CC*) has a significant impact on the environment (environmental pillar) which can include changes in biodiversity, increased need for fertilizers and pesticides, and increased need for irrigation which leads to the need for more significant investments (economic pillar). In addition, the emergency event database (EM-DAT) in 2021 recorded 432 disasters caused by natural causes worldwide. There were 10,492 deaths, 101.8 million people affected, and $252.1 billion in economic damage due to these events (CRED, 2022). Heat-related disorders, vector-borne diseases, food, and water-borne infections, respiratory and allergic disorders, hunger, collective violence, and mental health difficulties are all adverse health effects caused by climate change (social pillar) (Levy & Patz, 2015).

Urbanization and the concentration of a *Large number of consumers (LC)* in small urban areas shape a country's food system. Urbanization causes an increase in food supply chains, with a greater need for processing, packaging, refrigeration, and, consequently, more losses. According to M. Li (2020), resource efficiency and the population's mode of consumption are essential for reducing food losses in urban chains. This consumption should be geared towards protecting the environment (environmental pillar), with more conscious choices and supporting, for example, the recycling of product packaging. Consideration should be given to the consequences that consumer behavior today can generate for future generations (social pillar). In addition, food chains can be significant economic sources due to many consumers and the global market for products (economic pillar) (M. Li, 2020).

- Factors that showed a strong relationship with two of the sustainability pillars, environmental and economic: *Slack resources (SR)*, *Clean Technologies (CT), and Diversity of consumers' profiles (DP)*. Cheng and Kesner (1997) claim that companies can better respond to changing needs with *Slack resources* (*SR*) and may have more freedom to protect the environment (environmental pillar). The presence of *Slack resources* (*SR*) in an organization helps allocate investments in innovative initiatives (such as CT) and environmental research (Leyva de la Hiz et al., 2019). On the other hand, slack can generate inefficiency, as Baker and Nelson (2005) mentioned when they state that scarcity motivates management to increase resource efficiency, while abundant resources encourage waste, negatively impacting the environment and reducing profitability (economic pillar). In the early stages of a disruptive event like the coronavirus pandemic COVID-19, os

Slack resources, which implies excessive expenditure and can be considered a potential waste of resources in average time, have a fundamental role of a 'buffer' (Z. Li, 2021).

Investments in *Clean Technologies (CT)*, used in the food chain to reduce soil pollution and pollutant emissions, are driven by economic considerations that are company-specific or market-related. According to Hrovatin et al. (2016), energy cost is a significant driver of investment in clean technology (economic pillar). The lack of clean technologies and low economic development sabotage sustainable development through carbon emissions (environmental pillar) (Hishan et al., 2019).

The economic and environmental implications related to consumers' characteristics (e.g. age, education, culture, and purchasing power) (*PD*) cause preferences for consuming some foods. An example is organic products, which have a high production cost compared to traditional products (economic pillar) (Hamzaoui-Essoussi & Zahaf, 2012), and therefore have a relationship with the purchasing power of consumers. However, agricultural practices used in organic production emphasize environmental sustainability (environmental pillar) (Niggli, 2015).

- Factors that showed a strong relationship with two pillars of sustainability, social and economic: *Food price (FP)* and *External variability (EV)*. Regardless of the origin of food price increases (*FP*) and the population affected, information on price elasticity is essential to understand that these changes affect consumption and population health (Social pillar) (Cornelsen et al., 2015). When access to and consumption of food increases, there can be an increase in environmental impacts, such as methane emissions from increased meat production (environmental pillar) (Sanchez-Sabate et al., 2019).

The External variability (EV) of market demand in economic crises, politics, and wars, among others, influences the availability and accessibility of certain foods. The conflict between Russia and Ukraine significantly impacts the global economy with disruptions in the food supply chain, financial sanctions, and commodity prices (social and economic pillars) (Painoli, 2022).

- Factors that showed a strong relationship only with the social pillar: *Internal variability (IV), Prevention of occupational and process health and safety hazards (PO), and Demographic diversity of employees (DD)*. This strong relationship with the social pillar corroborates with what Sarkis et al. (2010) present as the category of internal human resources where employment, safety, health, and capacity development practices are inserted.

- Factors that showed a strong relationship only with the environmental pillar: The factors *Natural resource management (NS)* and *Uncertainty in the judgment because of the Diversity of criteria for waste and pollution assessment (DC)*. Anantha et al. (2021) study showed that Natural resource management (NS) works could generate benefits to strengthen environmental services. This means that they state that understanding at the system level the impact of natural resource management positively impacts the expansion of water resources, intensification of crops, productivity, and environmental services, and being able to generate a balanced use of resources without causing damage to the environment. According to Chan (2016), the diversity of criteria in terms of responsibility and capacity, the share of emissions, and mitigation potential, linked to global objectives and targets are essential for the correct environmental performance of the global food supply chain.

Thus, the factors that emerged from the content analysis of the selected articles are related to the pillars of sustainability. As can be seen, the same factor can contribute to more than one sustainability pillar with greater or lesser intensity. In section 4.4, factors will be related to factors with complexity theory.

4.4. Food supply chain factors and complexity attributes

The Figure 2 presents the relationships between the five complexity attributes considered in this article (Table 1) and the 16 Food Supply Chain factors (Table 2), presenting the complexity of sustainable food supply chains. According to described in the Method in Section 3.3 in Second stage: data analysis in the item ii) Complexity. The score is −2 (the factor will substantially reduce/lower the intensity of the complexity attribute); −1 (the factor will have a moderate influence for reducing/lowering the complexity attribute); zero (the factor has no/neutral influence on the complexity attribute); 1 (the factor will moderately amplify the complexity attribute); 2 (the factor will substantially/strongly amplify the complexity attribute).

The information presented in Figure 2(a-e) shows the factors and their relationship with the increase or decrease of the complexity attribute. In Figure 1(a), it is noted that the factors *Prevention of occupational and process health and safety hazards* (*PO*)*, Internal variability(IV), Food price (FP), Exchange of information (EI)*, and *Climate change (CC)* do not influence the complexity attribute Large number of elements. The factors Slack resources (*SR*)*, Natural resource management (NS), Large number of tiers in the supply chain (LN), Large number of consumers (LC), External variability (EV), Diversity of partners' types (DT), Diverse supply sources (DS), Diversity of consumers' profiles (DP), Demographic Diversity of employees (DD), Uncertainty in the judgment because of the Diversity of criteria for waste and pollution assessment (DC)*, and Clean Technologies (*CT)* increase a complexity attribute Large number of elements increasing the complexity of the chain.

Figure 1(b) shows that all factors increase the relative complexity of the attribute Dynamically interacting elements, except for the *SR* factor, which is negatively related (reducing the complexity attribute). All factors, as shown in Figure 2(c), are related to the attribute Unexpected variability, being that the factors *SR, PO, NS, EI*, and *CT* reduce the complexity attribute and the others increase.

In Figure 2(d), it is noted that factors *IV and PF* do not influence the complexity attribute, and the other factors increase the complexity attribute Diversity of elements. Figure 2(e) shows that all factors are related to Resilience. However, the factors *IV, FP, EV, DP, DC*, and *CC* reduce the complexity attribute, and the others (SR, PO, NS, LN, LC, ET, DT, DS, DD, and CT) increase.

The results also show that the *SR* factor is a factor that can increase Resilience and reduce Unexpected variability and Dynamically interacting elements. Thus, if the company uses the number of employees as an extra resource to deal with variability, for example, this increases Resilience by offering conditions to deal with unexpected situations, reducing Unexpected variability. In addition, having more employees as a time resource means that more people are interacting, which reduces the propagation of actions to overcome adverse situations, which may decrease Dynamically interacting elements.

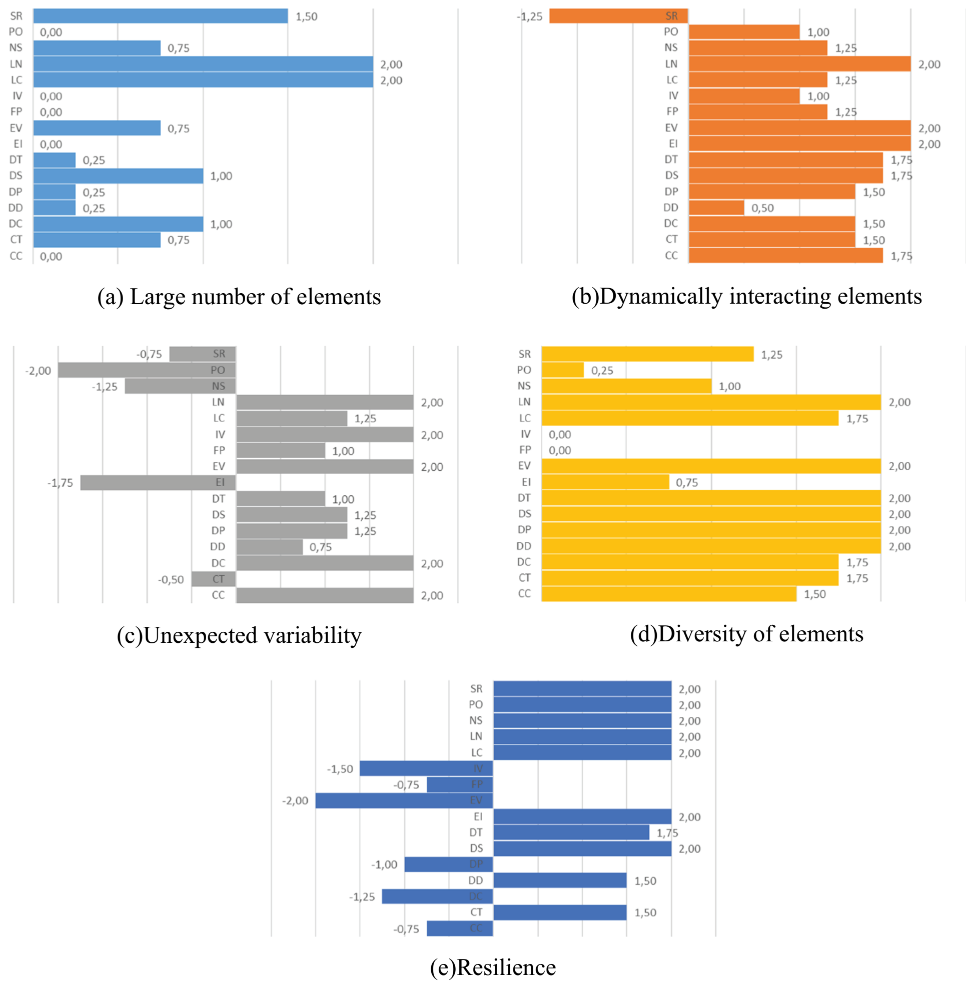

Figure 2. Scores to the relationship between factors and complexity attributes.

Factor *VI* is a factor capable of increasing Unexpected Variability and generating an increase in Dynamically interacting elements. If the internal variability is employee absenteeism, for example, this increases Unexpected variability, and it is necessary to increase the Dynamically interacting elements to adjust the system.

According to Blumenfeld and Inman (2009), when absent workers grow, the need for assistance grows linearly. It is known, however, that the ability to meet it is not linear due to competing requests for support. Thus, it is noted that the internal variability influences the dynamic interactions for disseminating adjustments in the system, increasing the complexity and propagating positive or negative impacts.

Another finding of the research refers to the diversification in the characteristics of employees (age, education, nationality, language, culture, gender, etc.). The *DD* factor is a factor that has the potential to increase the Diversity of elements and Resilience. Personal characteristics are essential to a successful collaboration (Touboulic & Walker, 2015). According to Blumenfeld and Inman (2009), managing a diverse

Table 4. Articles selected for the systematic review.

Articles	Author/year	Title	Journal
1	(Turan & Ozturkoglu, 2022)	A conceptual framework model for an effective cold food chain management in sustainability environment	Journal of Modelling in Management
2	(Liu et al., 2019)	A fuzzy decision tool to evaluate the sustainable performance of suppliers in an agrifood value chain	Computers and Industrial Engineering
3	(Jabarzadeh et al., 2020)	A multi-objective mixed-integer linear model for sustainable fruit closed-loop supply chain network	Management of Environmental Quality: An International Journal
4	(Sgarbossa & Russo,2017)	A proactive model in sustainable food supply chain: Insight from a case study	A proactive model in sustainable food supply chain: Insight from a case study
5	(Tavakkoli Moghaddam et al., 2019)	A reverse logistics chain mathematical model for a sustainable production system of perishable goods based on demand optimization	Journal of Industrial Engineering International
6	(Nikolaou et al., 2013)	A reverse logistics social responsibility evaluation framework based on the triple bottom line approach	Journal of Cleaner Production
7	(León Bravo et al., 2021)	A roadmap for sustainability assessment in the food supply chain	British Food Journal
8	(Sazvar et al., 2018)	A sustainable supply chain for organic, conventional agro-food products: The role of demand substitution, climate change and public health	Journal of Cleaner Production
9	(Seetharaman et al., 2022)	A Transition to a Circular Economic Environment: Food, Plastic, and the Fashion Industry	International Journal of Circular Economy and Waste Management (IJCEWM)
10	(Tiwari & Khan, 2019)	An action research approach for measurement of sustainability in a multi-echelon supply chain: Evidences from Indian sea food supply chains	Journal of Cleaner Production
11	(van Voorn et al., 2020)	An agent based model representation to assess resilience and efficiency of food supply chains	PLoS ONE
12	(Malagó et al., 2021)	An analytical framework to assess SDG targets within the context of WEFE nexus in the Mediterranean region	Resources, Conservation and Recycling
13	(J. L. Glover et al., 2014)	An Institutional Theory perspective on sustainable practices across the dairy supply chain	International Journal of Production Economics
14	(Azadnia & Ghadimi, 2018)	An integrated approach of fuzzy quality function deployment and fuzzy multi-objective programming to sustainable supplier selection and order allocation	Journal of Optimization in Industrial Engineering
15	(Seuring et al., 2019)	Analyzing base-of-the-pyramid projects through sustainable supply chain management	Journal of Cleaner Production
16	(Brunori et al., 2016)	Are local food chains more sustainable than global food chains? Considerations for Assessment	Sustainability (Switzerland)
17	(Kucukvar et al., 2019)	Assessing regional and global environmental footprints and value added of the largest food producers in the world	Resources, Conservation and Recycling
18	(Mercuri et al., 2021)	Blockchain Technology and Sustainable Business Models: A Case Study of Devoleum	Sustainability (Switzerland)
19	(Fracarolli Nunes et al., 2020)	Can we have it all? Sustainability trade-offs and cross-insurance mechanisms in supply chains	International Journal of Operations and Production Management
20	(de Vasconcelos et al., 2021)	Circular Economy and Sustainability in the Fresh Fruit Supply Chain: A Study across Brazil and the UK	Latin American Business Review
21	(Leon-Bravo, 2017)	Collaboration for sustainability in the food supply chain: A multi-stage study in Italy	Sustainability (Switzerland)
22	(Allaoui et al., 2019)	Decision support for collaboration planning in sustainable supply chains	Journal of Cleaner Production
23	(Golini et al., 2017)	Developing sustainability in the Italian meat supply chain: an empirical investigation	International Journal of Production Research

(*Continued*)

Table 4. (Continued).

Articles	Author/year	Title	Journal
24	(Yakavenka et al., 2020)	Development of a multi-objective model for the design of sustainable supply chains: the case of perishable food products	Annals of Operations Research
25	(Khan, Mathew, et al., 2022)	Disruption in food supply chain and undernourishment challenges: An empirical study in the context of Asian countries	International Journal of Logistics Research and Applications
26	(Stranieri et al., 2017)	Do motivations affect different voluntary traceability schemes? An empirical analysis among food manufacturers	Food Control
27	(Peano et al., 2015)	Evaluating the sustainability in complex agri-food systems: The SAEMETH framework	Sustainability (Switzerland)
28	(Roibás et al., 2015)	Evaluating the sustainability of Ecuadorian bananas: Carbon footprint, water usage and wealth distribution along the supply chain	Sustainable Production and Consumption
29	(J. Roy et al., 2020)	Evaluation and selection of third party logistics provider under sustainability perspectives: an interval valued fuzzy-rough approach	Annals of Operations Research
30	(Lin,2019)	Evaluation of decision-making for the optimal value of sustainable enterprise development under global 100 index thinking	Sustainability (Switzerland)
31	(Yu et al., 2022)	Evolutionary game analysis of green agricultural product supply chain financing system: COVID-19 pandemic	International Journal of Logistics Research and Applications
32	(Agyabeng-Mensah et al., 2020)	Examining the influence of internal green supply chain practices, green human resource management and supply chain environmental cooperation on firm performance	Supply Chain Management: An International Journal
33	(Medici et al., 2021)	Exploring the economic, social, and environmental dimensions of community-supported agriculture in Italy	Journal of Cleaner Production
34	(Sjauw-Koen-Fa et al., 2018)	Exploring the integration of business and CSR perspectives in smallholder souring: Black soybean in Indonesia and tomato in India	Journal of Agribusiness in Developing and Emerging Economies
35	(Pullman et al., 2009)	Food for thought: Social versus environmental sustainability practices and performance outcomes	Journal of supply chain management
36	(Ilbery & Maye, 2005)	Food supply chains and sustainability: Evidence from specialist food producers in the Scottish/English borders	Land Use Policy
37	(J. He et al., 2020)	How Can Manufacturers Promote Green Innovation in Food Supply Chain? Cost Sharing Strategy for Supplier Motivation	Frontiers in Psychology
38	(Wilhelm et al., 2016)	Implementing sustainability in multi-tier supply chains: Strategies and contingencies in managing sub-suppliers	International Journal of Production Economics
39	(M Segura et al., 2020)	Improving food supply chain management by a sustainable approach to supplier evaluation	Mathematics
40	(Merlino et al., 2020)	Innovation towards sustainable fresh-cut salad production: Are Italian consumers receptive?	AIMS Agriculture and Food
41	(Khan, Yu, et al., 2021)	Investigating the effects of the outbreak of COVID-19 on perishable food supply chains: an empirical study using PLS-SEM	The International Journal of Logistics Management
42	(Forsman-Hugg et al., 2013)	Key CSR dimensions for the food chain	British Food Journal
43	(Touboulic & Walker, 2015)	Love me, love me not: A nuanced view on collaboration in sustainable supply chains	Journal of Purchasing and Supply Management
44	(Kayikci et al., 2020)	Minimizing losses at red meat supply chain with circular and central slaughterhouse model	Journal of Enterprise Information Management
45	(Kazancoglu et al., 2018)	Minimizing losses in milk supply chain with sustainability: An example from an emerging economy	Resources, Conservation and Recycling

(*Continued*)

Table 4. (Continued).

Articles	Author/year	Title	Journal
46	(Nazam et al., 2020)	Modeling the key barriers of knowledge management adoption in sustainable supply chain	Journal of Enterprise Information Management
47	(Jouzdani & Govindan, 2021)	On the sustainable perishable food supply chain network design: A dairy products case to achieve sustainable development goals	Journal of Cleaner Production
48	(Garcia-Garcia et al., 2017)	Optimising Industrial Food Waste Management	Procedia Manufacturing
49	(Mancini et al., 2019)	Producers' and consumers' perception of the sustainability of short food supply chains: The case of Parmigiano Reggiano PDO	Sustainability (Switzerland)
50	(Verdecho et al., 2020)	Project portfolio selection for increasing sustainability in supply chains	Economics and Business Letters
51	(Shnayder et al., 2015)	Putting your money where your mouth is: Why sustainability reporting based on the triple bottom line can be misleading	PLoS ONE
52	(Segura et al., 2019)	Quantifying the sustainability of products and suppliers in food distribution companies	Sustainability (Switzerland)
53	(Bustos & Moors, 2018)	Reducing post-harvest food losses through innovative collaboration: Insights from the Colombian and Mexican avocado supply chains	Journal of Cleaner Production
54	(Pérez-Mesa et al., 2019)	Response of fresh food suppliers to sustainable supply chain management of large European retailers	Sustainability (Switzerland)
55	(Ramos et al., 2016)	SENSE tool: easy-to-use web-based tool to calculate food product environmental impact	The International Journal of Life Cycle Assessment
56	(Jarzębowski et al., 2020)	Short food supply chains (SFSC) as local and sustainable systems	Sustainability (Switzerland)
57	(Enjolras & Aubert, 2018)	Short food supply chains and the issue of sustainability: a case study of French fruit producers	International Journal of Retail & Distribution Management
58	(Matzembacher & Meira,2019)	Sustainability as business strategy in community supported agriculture: Social, environmental and economic benefits for producers and consumers	British Food Journal
59	(Abdella et al., 2020)	Sustainability assessment and modeling based on supervised machine learning techniques: The case for food consumption	Journal of Cleaner Production
60	(Erol et al., 2009)	Sustainability in the Turkish retailing industry	Sustainable Development
61	(Guliyeva & Lis, 2020)	Sustainability management of organic food organizations: A case study of Azerbaijan	Sustainability (Switzerland)
62	(Tsolakis et al., 2018)	Sustainability performance in food supply networks: Insights from the UK industry	Sustainability (Switzerland)
63	(Saputri et al., 2019)	Sustainable agri-food supply chain performance measurement model for GMO and Non-GMO using data envelopment analysis method	Applied Sciences (Switzerland)
64	(Allaoui et al., 2018)	Sustainable agro-food supply chain design using two-stage hybrid multi-objective decision-making approach	Computers and Operations Research
65	(Yakovleva et al., 2012)	Sustainable benchmarking of supply chains: The case of the food industry	International Journal of Production Research
66	(Cao et al., 2019)	Sustainable development of food processing enterprises in China	Sustainability (Switzerland)
67	(Khan, Zkik, et al., 2021)	Sustainable supplier selection for the cold supply chain (CSC) in the context of a developing country	Environment, Development and Sustainability
68	(Gold et al., 2013)	Sustainable supply chain management in 'Base of the Pyramid' food projects-A path to triple bottom line approaches for multinationals?	International Business Review
69	(Gómez-Luciano et al., 2018)	Sustainable supply chain management: Contributions of supplies markets	Journal of Cleaner Production
70	(Köhler & Pizzol, 2020)	Technology assessment of blockchain-based technologies in the food supply chain	Journal of Cleaner Production

(*Continued*)

Table 4. (Continued).

Articles	Author/year	Title	Journal
71	(Glover, 2020)	The dark side of sustainable dairy supply chains	International Journal of Operations and Production Management
72	(Nirino et al., 2019)	The impact of corporate social responsibility on firms' financial performance, evidence from the food and beverage industry	British Food Journal
73	(Vasileiou & Morris, 2006)	The sustainability of the supply chain for fresh potatoes in Britain	Supply Chain Management: An International Journal
74	(Pullman & Dillard, 2010)	Values based supply chain management and emergent organizational structures	International Journal of Operations and Production Management
75	(Pellegrini et al., 2020)	What are the conflicting tensions in an Italian cooperative and how do members manage them? Business goals', integrated management, and reduction of waste within a fruit and vegetables supply chain	Sustainability (Switzerland)

Table 5. All the journals in the database with the number of publications.

Jornal	Number of papers
Sustainability (Switzerland)	13
Journal of Cleaner Production	11
British Food Journal	4
Resources, Conservation and Recycling	3
International Journal of Operations and Production Management	3
International Journal of Production Research	2
PLoS ONE	2
Journal of Enterprise Information Management	2
Supply Chain Management: An International Journal	2
Annals of Operations Research	2
International Journal of Logistics Research and Applications	2
AIMS Agriculture and Food	2
International Journal of Production Economics	2
The International Journal of Logistics Management	1
Food Control	1
A proactive model in sustainable food supply chain: Insight from a case study	1
Management of Environmental Quality: An International Journal	1
Computers and Industrial Engineering	1
Mathematics	1
Journal of Modelling in Management	1
Journal of Purchasing and Supply Management	1
Journal of Agribusiness in Developing and Emerging Economies	1
Applied Sciences (Switzerland)	1
International Journal of Retail & Distribution Management	1
Latin American Business Review	1
Journal of Optimization in Industrial Engineering	1
Computers and Operations Research	1
Sustainable Development	1
International Business Review	1
Sustainable Production and Consumption	1
Land Use Policy	1
Economics and Business Letters	1
The International Journal of Life Cycle Assessment	1
Frontiers in Psychology	1
Journal of supply chain management	1
International Journal of Circular Economy and Waste Management (IJCEWM)	1
Journal of Industrial Engineering International	1
Environment, Development and Sustainability	1

workforce can increase Resilience. A diverse workforce with complementary skills and behaviors can better deal with uncertainty and signals an organization's social inclusion, fostering a long-term exchange relationship. On the other hand, diversification in employee characteristics can also lead to an increase in Unexpected variability, as differences can bring challenges to management and interpersonal relationships.

The *DT* and *DS* factors can amplify the complexity attribute Diversity of elements and increase Resilience. According to Chunsheng et al. (2019), the diversity of the portfolio of partners and suppliers in supply chains can increase the Diversity of elements with companies of different sizes and resources. In addition, diversifying available resources can increase Resilience at unexpected times.

When comparing the images in Figure 2, the factors with the highest score among the others in the increase in complexity were *LC, DT, LN*, and *DS*. Then, these factors were analyzed with the pillars of sustainability. The *LC* factor has a strong relationship with all pillars (environmental, social, and economic), and the *DT, LN*, and *DS* factors have a weak to moderate relationship with all sustainability pillars.

On the other hand, it was found that the *EV* and *PO* factors could reduce complexity. Thus, they were also analyzed with the pillars of sustainability. The *EV* factor increases complexity (Figure 2a-d) but also offers resources to reduce it (Figure e), being strong in the social and economic pillars. The *PO* factor strongly relates to the social pillar and reduces complexity.

Finally, it is possible to affirm that the 16 factors of this study have a strong relationship with all pillars of sustainability (TBL). More specifically, the LC factor stands out about the increase in complexity. The *EV* factor is pointed out in its reduction, which is strongly related to the social and economic pillars.

Note that in Figure 2, the attributes Large number of elements and Diversity of elements increase the complexity of the system through increasing all factors. The attribute Dynamically interacting elements reduces complexity by reducing *SR*. The attribute Unexpected variability reduces complexity by factors: *SR, PD, NS, EI*, and *CT*. Resilience is an attribute of complexity reduced by factors *IV, FP, EV, DP, DC*, and *CC*. Thus, the 16 factors mentioned in this study have, for the most part, a strong relationship with sustainability (TBL) and can generate an increase in the system's complexity. In this way, it is suggested that sustainability in the food supply chain requires methods that support managing its dynamic relationships. As each factor relates to a complexity attribute, and these relationships are primarily non-linear, small changes in one factor can has significant effects on different complexity attributes.

5. Conclusions

5.1. Main contributions

In this study, we conducted an SLR with 75 papers. The research connected sustainability in the food supply chain, analyzing the findings in light of complexity. Although the complexity perspective has been operationalized in other domains, it has not received the same attention from the literature on sustainability in the food supply chain. The research question guiding this study was: How does sustainability affect the complexity of food supply chains?

The results indicated that the SFSCM is a relevant research topic. The bibliometric analysis showed a growing trend in research on the subject in recent years. The journals that published the highest number of articles on the topic are related to the area of sustainability, which means that operations and supply chain journals may not be paying due attention to the importance of complexity in sustainable food supply chains.

In this research, 16 interrelated factors have been identified. These factors influence the complexity of the SFSCM according to the three pillars of sustainability. As the results suggest, there are differences between the factors that contribute to sustainability and affect complexity. These differences range from the relationship the factor has with each pillar of sustainability to whether this factor increases or decreases the system's complexity. These findings open up new avenues for theory as they help explain the difficulty in maintaining sustainability across the entire food supply chain. The research findings have implications for the SFSCM knowledge area. The results provide new insights into the relevant aspects of sustainability in the supply chain and how this impacts the complexity of the entire system.

Another relevant theoretical implication of this article is shown in the results related to the economic pillar. The study shows that none of the factors that contribute to TBL sustainability have a strong relationship only with the economic pillar. Thus, it is noted that economic factors also have social or environmental implications. Achieving sustainability in the food supply chain is a joint effort of the environmental, economic, and social pillars rather than the optimization of anyone in isolation.

Some managerial implications emerge from this study. First, managers must develop factors that minimize system complexity: *Slack resources (SR), Prevention of occupational and process health and safety hazards (PO), Natural resource management (NS), Exchange of information (EI), Clean Technologies (CT), Internal variability (IV), Food price (FP), External variability (EV), Diversity of consumers' profiles (DP), Uncertainty in the judgment because of the Diversity of criteria for waste and pollution assessment (DC) and Climate change (CC)*. On the other hand, they should pay attention to a Large number of elements and the Diversity of elements, all factors increasing complexity through these two attributes. Furthermore, understanding those factors contributing to sustainability and affect complexity can help clarify causal relationships between sustainability actions and increased system complexity.

5.2. Limitations

Some limitations of this research should be highlighted. First, in the eligibility phase, the titles and abstracts of the articles were read, and those that presented sustainability concepts related to the supply chain or its components and covered one or all of the pillars of sustainability (environmental, social, and economic) were selected. It excluded articles that used the concept of sustainability referring to corporate sustainability as a means of competitive advantage for the company, sustainable products instead of sustainable supply chains, articles that used the concept of sustainability as a synonym for reverse logistics without directly addressing social components, environmental, economic or sustainable, or who used it as a synonym for the circular economy, without directly addressing the social, environmental and economic components. In this way, it is possible that articles would be excluded after reading the title and abstract if they did not present important information related to the sustainability of the supply chain because the focus of the study was elsewhere. Second, the databases used may have overlooked relevant studies. The authors used five databases of academic articles. Although these databases contain the main publishers, the authors acknowledge that the search process could have omitted relevant searches due to limited access by the institutional portal. Third, there is a philosophical limitation to fully describing a complex system. Fourth, our model of relationships between factors influencing complexity has not been empirically tested.

5.3. Future studies

This study established a basis for an agenda for future research. The conception of complexity theoretical approaches: although we found many studies that related that the supply chain is complex, most did not consider the interactions with sustainability. Furthermore, future studies should empirically investigate how sustainability interacts with the set of complexity attributes to shed light on the general effects of complexity on sustainability and vice versa. These interactions are unlikely to be trivial and mixed impacts can be expected. Both large sample surveys and case-based research can be fruitful in this line of investigation.

Future studies should include developing methods for implementing sustainability actions appropriate to the different levels and nature of complexity in food supply chains focusing on food such as soy, corn, meat, and milk. As far as possible, it implies the need for a qualitative and/or quantitative assessment of the intensity of sustainability factors that affect complexity in each of the proposed food supply chains. Besides that, future studies could the development of empirically tested frameworks to define whether a methodological approach is suitable for the food in question. In addition, tools must be developed to consider sustainability factors that affect complexity attributes to design or improve food supply chains.

Disclosure statement

No potential conflict of interest was reported by the authors.

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