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REVIEW

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Is it possible to quantify the current resilience level of an agri-food system? A review of the literature

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Abstract

Nowadays being resilient is a requirement of all companies and more in general supply chains, as a consequence of the frequent disruptions which repeatedly affect systems and challenge markets from different sides. But how to state whether a company and its related supply chain are resilient or not? To address the present issue, a literature review was carried out on documents proposing quantitative tools or metrics for quantifying the resilience level of an agri-food supply chain, which is a specific field subjected to several threats and accordingly deserving attention. Due to the limited number of documents retrieved (i.e., 26 articles), stressing the gap to be filled in literature, mainly bibliometric analyses were performed on the sample, but contents were also deepened, resuming the different tools available at present. Results reflect the call for the development of models aiming at assessing the resilience of these systems before disruptions and non-controlled events occur; moreover, the industrial level turned out to be neglected, given the fact that all the studies deal with the farm stage (and in general agricultural activities).

Keywords: Agri-food supply chain, Resilience assessment, Literature review, Quantitative assessment, Resilience metric, Resilience model, Agriculture

Introduction

According to several accredited dictionaries, the term resilience can be mainly defined in three different fields: in material sciences it represents the ability of a material to absorb energy under elastic deformation and to recover its energy at removal of a load (Vegas and Martin del Yerro 2013); in psychology, instead, it refers to how individuals recover from or adapt to stress and restore mental, psychological and emotional balance (Bowling et al. 2021); again, in ecology it represents the persistence of relationships within an ecosystem after disturbance, and it is a measure of the ability of ecosystems to absorb changes of state variables (Standish et al. 2014). Starting from these definitions in these application fields, the term resilience was declined and adapted in other different contexts, including that general of supply chains, for which resilience is considered as the responsiveness of the supply chain itself to any non-controlled event which may challenge it (Clavijo-Buritica et al. 2023). More specifically, as the first authors that attributed

the definition of resilience to supply chains in 2004 stated (Kochan and Nowicki 2018), it refers to the ability of the system to return to its original state or move to a new more desirable one after being disturbed by any form of disruption (Christopher and Peck 2004). Starting from here there is a plethora of studies dealing with its definition, evolution and development, emphasizing the variability and the great factors affecting it (e.g., (Kochan and Nowicki 2018; Geske and Novoszel 2022; Simbizi et al. 2021)).

Undoubtedly, resilience represents one of the principal keywords associated with supply chains in the last decade, due to the several challenges they were subjected to; for instance, *in primis* the Covid-19 pandemic, but also the recent war between Russia and Ukraine which challenged economic systems and materials supply, the climate change that is actually further intensifying its impact, the water shortage in some geographical areas or the increasing world population requiring more food to be produced (Preite et al. 2023); and all the cascading effects deriving from these negative events. This is further stressed by the scientific activity focusing on this issue: a simple query on the Scopus database (https://www.scopus.com) having "resilience" and "supply chain" as keywords, at the beginning of year 2023 returns more than 3 thousand papers, half of which published in 2021 and 2022; this is surely a symptom of the relevance of the topic among the academic world. Clearly, aspects to be investigated and analyzed are manifold, as well as the fields of application.

This study originates from a practical need. Indeed, the authors of the present manuscript were required to quantitatively assess the as-is resilience level of an agri-food supply chain. In this field, in fact, resilience is an element of significant importance: as stressed by other authors, agri-food systems represent one of the major victims affected by the climate change (Bilali 2021; Borghesi et al. 2022), and they were damaged by the recent pandemic (Popescu and Popescu 2022); at the same time, they belong to one of the most relevant sector, since it guarantees the population's food security, is an important source of income and livelihoods and is a contributor to the national gross domestic product. The food production is suitable for feeding a third of the world population (Herman 2015), and above all for this reason being resilient is mandatory; as stated by Miranda et al. (2023), new business models for agri-food supply chains should allow to increase levels of resilience to mitigate the negative consequence of possible crises similar to those already caused by pandemics or wars.

As always happens the starting point is the literature analysis to understand whether previous studies were already carried out and to define the state-of-the-art and immediately, at the first impact, what emerged was that there was a huge number of heterogeneous documents resulting from literature apparently dealing with resilience (as also confirmed by the results from the Scopus search mentioned few lines above), whose main argument deflected from the mere resilience topic: in other words, the feeling was a sort of abuse of the keyword resilience. This fact further made the research difficult, as the number of resulting documents intensified the work and the efforts to be involved, and resulted in few pertinent studies. Moreover, another element arose is that quite often quantitative assessments of the agri-food supply chain resilience (AFSCR, in the following) are made a posteriori or while the disruption is manifesting, and accordingly can only reveal the resilience level after a disturbance has occurred (or in the meantime); with reference to that, sometimes the resilience assessment is simply derived from surveys proposed to practitioners

(e.g., (Hossard et al. 2021; Meldrum et al. 2018; Paas et al. 2021)), or there are some studies that provide a measure in terms of the average food price, of time/costs required to restore the situation (Proag 2014) or of failure in producing what was requested (Haqiqi and Bahalou Horeh 2021). But what about the as-is resilience level of a system, so before an unforeseen event occurs?

In addition, recalling the subdivision of a whole agri-food supply chain into three main phases, i.e., supply, production and distribution, if we consider with supply a phase in which the product is treated as raw material including activities such as cultivation or farming and with production the real industrial transformation as suggested by Tebaldi et al. (2021), the focus is only addressed toward the first one; indeed, no studies mentioning industrial plants or companies are addressed.

On the bases of these short premises, the aim of this paper is twofold: first of all, it presents the results from the literature analysis focusing on quantitative assessments of the AFSCR carried out at the beginning of 2023, whose initial research question was the following: how to measure the resilience of an agri-food supply chain? Second, this manuscript constitutes the call for the important development of quantitative models useful for managers and practitioners in order to assess the current resilience level of the supply chain they belong to, since prevention is better than cure. Indeed, having a structured tool that allows to derive the major areas in which the system is weak may support the decision management in understanding where the focus should be addressed. For instance, according to the opinion of the authors, the number of suppliers of a specific raw material can be considered a key indicator (e.g., from the side of a pasta producer, the wheat supply is essential, as is for the pasta sauce manufacturer the tomatoes); if the company in question has only a unique supplier for that basic material, this could constitute a warning, which could be detected by a model which considers the key elements to be monitored for ensuring an adequate resilience level. Ex-ante quantitative assessments are already proposed to deal with other food-related issues for their being useful tools to improve the understanding of dynamics and increase the evidence base underlying future actions (Mouratiadou et al. 2021); indeed, the numerical output is renowned for its being easily interpreted, comparable and immediate (Mikusova and Janeckova 2010).

This paper also responds to the call for more research in this area so as to design more efficient and resilient supply chains (Zhao et al. 2017), given the fact that nowadays food systems have no more to be designed only for economic efficiency as it happened in the past but must be re-evaluated for and according to their resilience (Stone and Rahimifard 2018).

The remainder of contents is organized as follows: Sect. "Methodology" proposes the methodology followed for carrying out the literature review as well as the analyses performed on the sample, both bibliometric and contents-related; Sect. "Results" deals with the results including the list of the tools found in the documents, followed by Sect. "Conclusions" presenting a brief discussion and the conclusions, including the relevant future research directions.

Methodology

The starting point for carrying out the literature review on quantitative assessments and models for the AFSCR were 11 queries launched in January 2023 on the two main scientific database, i.e., Scopus and Web of Knowledge, for collecting pertinent documents. The queries are listed in Table 1.

No temporal constraints were set so as to include all the possible sources; only journal articles and conference papers written in English language were considered, given the fact that English is considered the main language of scientific dissemination. After having removed duplicates, this first research returned a total of 184 documents.

The authors started a first screening for selecting those papers which may fit with the topic in question; indeed, as already stressed in the introduction section, quite often the word resilience is improperly used and several articles were returned from the queries but were completely out of scope (for instance, this is the case of Salazar et al. (2019) whose focus is on the behavior of a specific microbiota or of Gwadz et al. (2021) which deals with the resilience of people affected by HIV in the early phase of the recent pandemic). As additional exclusion criterion, also studies carried out in fields different from that of agri-food were excluded, as well as those for which no specific sector was mentioned (e.g., (Anderson et al. 2020) whose research was conducted in the aerospace sector, or (Neves Santos and Magrini 2018) which deals with biorefineries); this constraint may preclude other pertinent assessments in other fields, which could be then adapted in this specific context, but at this stage it was decided to study the topic in its specific application field. As inclusion criterium, only documents in which a clear quantitative assessment was proposed or implemented with a clear numerical output (e.g., a percentage, or a score) were considered, and this was the strongest restriction which let the sample be further reduced.

Table 1 Queries involved for retrieving documents

Progressive number	Query	No. of returned documents
1	title (resilience) AND title (assessment) AND title-abs-key (agri-food)	1
2	title (resilience) AND title (assessment) AND title-abs-key (food)	42
3	title (resilience) AND title (assessment) AND title-abs-key (food) AND title-abs-key (quantitative)	4
4	title (resilience) AND title (assessment) AND title-abs-key (agri-food) AND title-abs-key (quantitative)	0
5	title (resilience) AND title (assessment) AND title (agri-food) AND title (quantitative)	2
6	title (resilience) AND title (assessment) AND title (food) AND title (quantitative)	89
7	title (resilience) AND title (assessment) AND title (agriculture)	2
8	title-abs-key (resilience) AND title-abs-key (assessment) AND title-abs-key (agriculture) (search within results "quantitative")	51
9	title-abs-key (resilience) AND title-abs-key (assessing) AND title-abs-key (agriculture) (search within results "quantitative")	2
10	title-abs-key (resilience) AND title-abs-key (assessing) AND title-abs-key (agriculture) 238 (search within results "quantitative")	12
11	title-abs-key (resilience) AND title-abs-key (agri-food) 199 (search within results "quantitative assessment")	31

This first screening returned a total of 44 papers (so approximately 24% of the initial sample). These 44 documents were further analyzed through a comprehensive reading, and according to the abovementioned inclusion/exclusion criteria the final sample corresponds to 26 articles.

Figure 1 graphically resumes the followed procedure, while in the following Table 2, for completeness, readers can find the full list of the reviewed documents.

At first, for these 26 documents bibliometric parameters were investigated, namely their temporal evolution, their type of document (i.e., journal article or conference proceeding), research methodology, geography of the study (made both according to the affiliation of the first author and to the country in which the study was carried out), most productive authors and citations. Regarding contents, instead, the elements investigated recall a framework proposed by other researchers and mentioned in further studies (Meuwissen et al. 2019) developed for investigating the resilience of farming systems, and adapted for the purposes of the present literature review. In this framework, 5 key questions are to be addressed, below listed, including their adaptation in the present study:

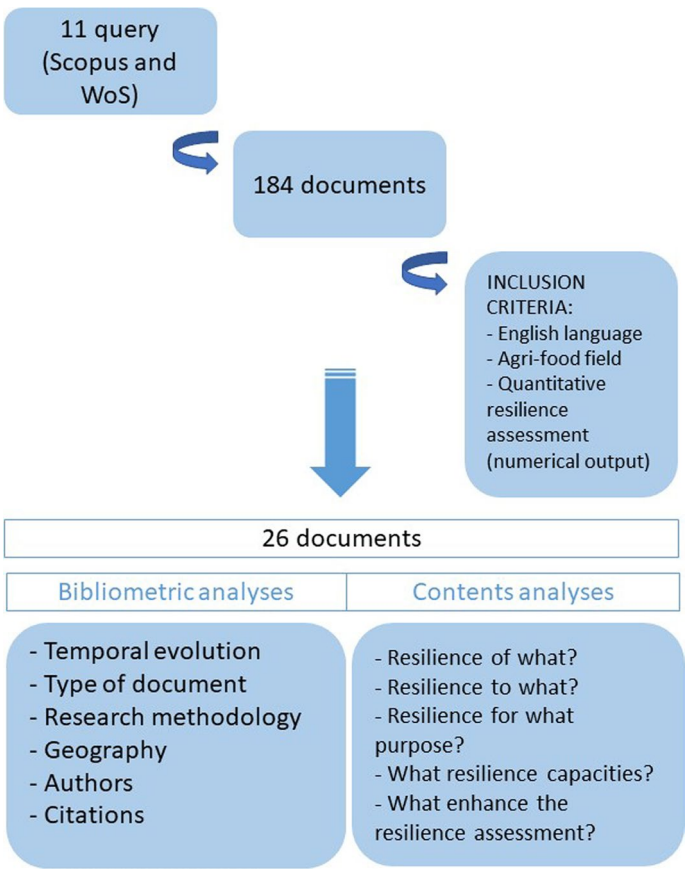

Fig. 1 Procedure for carrying out the present study

Table 2 List of the 26 reviewed papers, proposed in alphabetical order of the title

Progressive	Title	Year	Reference
1	A hybrid modeling approach for resilient agri-supply network design in emerging countries: Colombian coffee supply chain	2022	Clavijo-Buritica et al. (2023)
2	A multi-criteria approach for assessing the economic resilience of agriculture: The case of Lithuania	2021	Volkov et al. (2021)
3	Assessing the resilience of farming systems on the Saïs plain, Morocco	2021	Hossard et al. (2021)
4	Assessment of COVID-19 impacts on U.S. counties using the immediate impact model of local agricultural production (IMLAP)	2021	Haqiqi and Bahalou Horeh (2021)
5	Assessment of ecosystem resilience to hydroclimatic disturbances in India	2018	Sharma and Kumar Goyal (2018)
6	Assessment of the resilience of the agricultural landscapes and associated ecosystem services at multiple scales (a farm and landscape) in Kyrenia (Girne) Region of Northern Cyprus	2022	Cetinkaya Ciftcioglu (2022)
7	Building theory of agri-food supply chain resilience using total interpretive structural modeling and MICMAC analysis	2018	Zhao et al. (2018)
8	Caveat utilitor: A comparative assessment of resilience measurement approaches	2022	Upton et al. (2022)
9	Climate change and crop diversity: farmers' perceptions and adaptation on the Bolivian Altiplano	2018	Meldrum et al. (2018)
10	Climate change vulnerability and resilience: Current status and trends for Mexico	2010	Ibarraran Viniegra et al. (2010)
11	Cultivating climate resilience: A participatory assessment of organic and conventional rice systems in the Philippines (Renewable Agriculture and Food Systems (2018) 33:3 (225–237) https://doi.org/10.1017/S1742170517000709)	2018	Heckelman et al. (2018)
12	COVID-19 impacts on Flemish food supply chains and lessons for agri-food system resilience	2021	Coopmans et al. (2021)
13	Enhancing the resilience of the management of water resources in the agricultural supply chain	2021	Xu et al. (2021)
14	Indicators of sustainability to assess aquaculture systems	2018	Valenti et al. (2018)
15	Integrated valuation of alternative land use scenarios in the agricultural ecosystem of a watershed with limited available data, in the Pampas region of Argentina	2020	Maydana et al. (2020)
16	Involving resilience in assessment of the water–energy–food nexus for arid and semiarid regions	2022	Nunez-Lopez et al. (2022)
17	Multi-indicator sustainability assessment of global food systems	2018	Chaudhary et al. (2018)
18	Operationalizing food system resilience: An indicator-based assessment in agroindustrial, smallholder farming, and agroecological contexts in Bolivia and Kenya	2018	Jacobi et al. (2018)
19	Participatory assessment of sustainability and resilience of three specialized farming systems	2021	Paas et al. (2021)
20	Quantitative evaluation of the spatial resilience to the B. oleae pest in olive grove socio-ecological landscapes at different scales	2018	Rescia and Ortega (2018)
21	Resilience and equity: Quantifying the distributional effects of resilience-enhancing strategies in a smallholder agricultural system	2020	Williams et al. (2020)
22	Resilience assessment of centralized and distributed food systems	2022	Karan et al. (2023)
23	Resilience assessment of Swiss farming systems: Piloting the SHARP-tool in Vaud	2018	Diserens et al. (2018)

Table 2 (continued)

Progressive	Title	Year	Reference
24	Response and resilience of Asian agrifood systems to COVID-19: An assessment across twenty-five countries and four regional farming and food systems	2021	Dixon et al. (2021)
25	Squaring the Circle: Reconciling the Need for Rigor with the Reality on the Ground in Resilience Impact Assessment	2017	Béné et al. (2017)
26	What determines farmers' resilience toward ENSO-related drought? An empirical assessment in Central Sulawesi, Indonesia	2008	Keil et al. (2008)

(1) *Resilience of what?* To reply this question, the subject of the resilience assessment under investigation in each of the 26 document is defined (i.e., general AFSC, a country, resilience of water management etc.);
(2) *Resilience to what?* This point refers to the challenges the subject of resilience defined in the first point is subject to; in other words, the type of disruption undermining a balanced situation;
(3) *Resilience for what purpose?* In the original framework, at this stage it was recalled the fact that farming systems' function can be divided into the provision of private and public goods: private goods include the production of food and other bio-based resources but also ensuring a reasonable livelihood for people involved in farming, while public goods comprise maintaining natural resources in good condition, animal welfare and ensuring that rural areas are attractive places for residence and tourism. In this analysis, this is translated into recognizing which dimension of resilience is addressed: economical (referring to private goods), environmental or social (referring to public goods);
(4) *What resilience capacities?* The three capacities of resilience under stake in this fourth question are those of robustness, adaptability, transformability. Other authors as well refer to these capacities (e.g., (Paas et al. 2021; Bertolozzi-Caredio et al. 2022; Zawalinska et al. 2022)); some others, instead, similarly refer to the resilience capacities as anticipatory, coping and responsive (e.g., (Coopmans et al. 2021)). What these capacities have in common is the timing they manifest: robustness and anticipatory capacities occur before a disruption happens; adaptability and coping during the negative event and similarly capacities of transformability and responsive after. In the present research this information was translated into the moment in which the resilience assessment was performed: pre, in and post disruption occurrence;
(5) *What enhance resilience?* This corresponds to the last question of the original framework, but according to the opinion of the authors, given the aim of the present manuscript, this question was re-interpreted into the following: what enhance the resilience *assessment*? And the reply is simply the summary of the tools and methods identified in the 26 screened documents, which is one of the contribution of the present manuscript.

The software Microsoft Excel™ was implemented for supporting these analyses.

For concluding this section, the authors are aware of the fact that the sample is constituted by a limited number of documents; however, other literature analyses rely on reduced samples (e.g., (Tebaldi et al. 2021) or (Bigliardi et al. 2023)), given the fact that this can be considered a result itself as well; it also follows that results cannot be generalized and no inferential statistics can be applied.

Results

As already stated, after the second screening papers have significantly reduced in numerical terms, and only 26 scientific documents were included in the sample. Results are proposed in the subsections that follow: the first is dedicated to the bibliometric analyses, the second to the contents and the last third summarizes the quantitative AFSCR assessments and replies to the last fifth question of the abovementioned framework.

Bibliometric analyses

The temporal distribution of the reviewed documents is proposed in Fig. 2, below.

As it is possible to deduce from the graph, the topic in question is mainly investigated in the last five years (as partially expected), starting from 2018 which is the most productive. After the pandemic year as well, i.e., 2020, a considerable number of articles was recorded (15, so approximatively half of the sample). From the first document in 2008, however, there is a long period of almost ten years in which no study specifically dealt with a quantitative assessment of the AFSCR. Overall, it is not possible to derive a specific trend for this argument as production over time is extremely heterogeneous and the number of documents is limited; it can only be stated that in numerical terms documents are timidly growing.

As far as the type of document is concerned, they are all from scientific international journals; no conference proceeding was recorded, probably symptom of the fact that, when discussed, the topic is worth of scientific journals rather than a conference act. Going into the detail of the journals, it is worth mentioning Agricultural Systems by Elsevier (4 publications), and Ecological Indicators (Elsevier, again), Environment, Development and Sustainability (Springer) and Sustainability (MDPI), all with two contributions.

Another descriptive parameter investigated was the research methodology implemented for carrying out the study; specifically, this classification was made according to the guidelines proposed in Seuring and Muller (2008), which identify five different

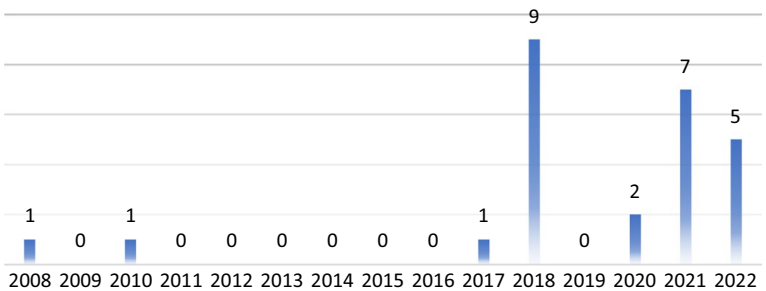

Fig. 2 Temporal evolution of the reviewed documents

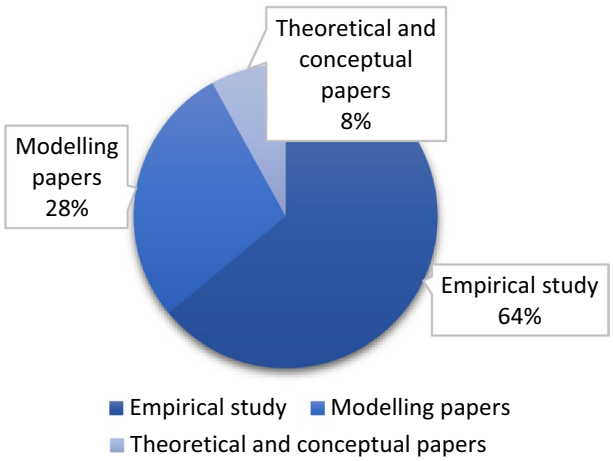

Fig. 3 Research methodology of the 26 papers

Table 3 Results from the geographical analysis according to the affiliation of the first author

Country	Nationality of the first author	Country	Nationality of the first author
Argentina	1	Italy	1
Australia	1	Lithuania	1
Belgium	1	Mexico	2
Brazil	1	Netherlands	1
Canada	1	Portugal	1
China	1	Spain	1
Colombia	1	Switzerland	3
France	1	Turkey	1
Germany	1	UK	1
India	1	USA	4

methodologies: empirical surveys, case studies, theoretical and conceptual papers, modeling papers and literature reviews. First of all note that in line with the topic treated, as well as with the inclusion criterium of proposing numerical assessment of resilience, no literature review was recorded in the sample, while in most cases we deal with empirical studies, analyzing collected data from real contexts or by means of questionnaire surveys. The resulting classification is proposed in the pie chart of Fig. 3.

As far as the geography is concerned, the analysis was carried out in a twofold way: indeed, while performing the first screening, it emerged that quite often the geography of the first author did not match with the country of the study, and quite often as well the affiliation of the first author corresponded to a western state, while the analyses and the research were carried out in Asiatic or African regions (i.e., developing countries); according to that, both the geographies were investigated.

The first table and figure (i.e., Table 3 and Fig. 4) refer to the classification depending on the affiliation of the first author, while the following (i.e., Table 4 and Fig. 5) to the country in which the study was carried out.

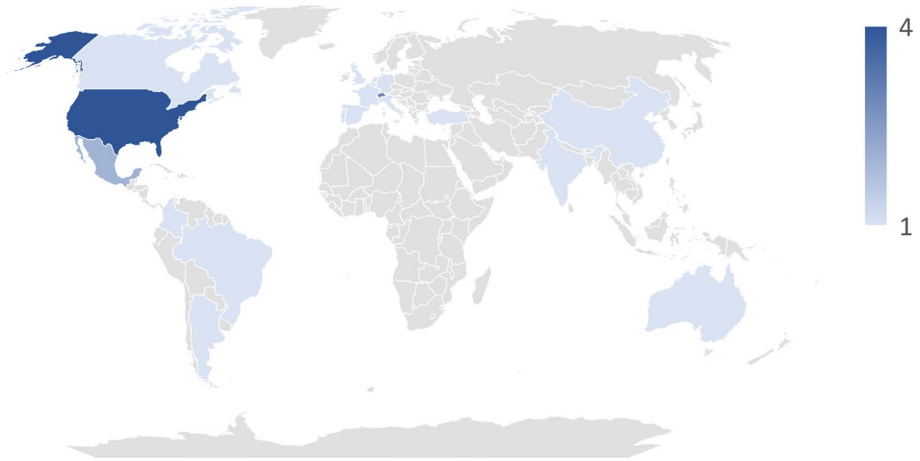

Fig. 4 Maps of the studies according to the geographical origin of the first author

Table 4 Results from the geographical analysis according to the country in which the study was carried out

Country	Country of the resilience assessment	Country	Country of the resilience assessment
Argentina	1	Kenya	1
Asia	1	Lithuania	1
Bangladesh	1	Mexico	2
Belgium	2	Netherlands	1
Bolivia	2	Niger	1
China	1	Spain	1
Colombia	1	Switzerland	1
Cyprus	1	USA	2
India	1	Worldwide	1
Indonesia	1	No specific country	2
Italy	1		

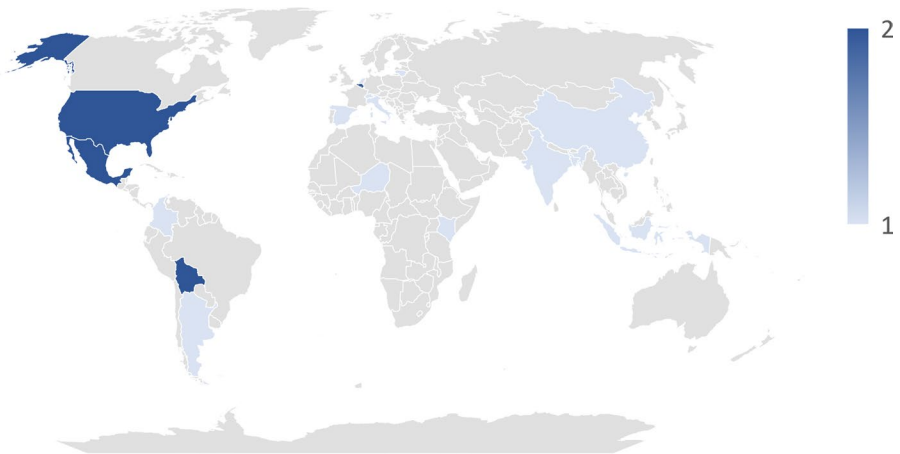

Fig. 5 Maps of the studies according to the country in which the study was carried out

Overall, from the first classification 20 countries were found; from the second, instead, 18 (plus a study referring in general to the Asiatic region, i.e., (Dixon et al. 2021) and one implemented in 156 countries labeled worldwide, i.e., (Chaudhary et al. 2018)). What at first stands out is that, when shifting from the results deriving from the nationality of the first author to those returned from the country in which the assessment was performed, some countries disappear (i.e., Australia, Brazil, Canada, France, Germany, Portugal, Turkey and United Kingdom), while some others appear, namely Bangladesh, Bolivia, Cyprus, Indonesia, Kenya and Niger. In other words, it is possible to notice an albeit weak trend highlighting that more developed countries perform their resilience-related studies in poor and less developed ones; this is supported, for instance, by Upton et al. (2022), whose first author is form the USA, but the study was then carried out in both Ethiopia and Niger; by Jacobi et al. (2018) whose first author comes from Switzerland, and the research took place in Bolivia and Kenya; or again by Meldrum et al. (2018) whose research center of the first author is Italian but the study was developed in Bolivia. A possible explanation, given the fact that some of these studies address the resilience of African families, is that these regions are particularly affected by the climate change in the guise of drought, and accordingly this fact could have attracted researchers. As expected, the two papers for which no specific country was involved for the research are the two articles belonging to the theoretical and conceptual papers group with reference to their methodology (i.e., (Zhao et al. 2018) and (Valenti et al. 2018)). Overall, the only two notably countries are the USA which contributed with 4 documents, and Switzerland (3 articles); as far as the research territory, instead, it can be noted that some developing countries such as Bangladesh, Indonesia or Niger are not represented by any authors, supporting the sentence stated few lines above.

Other two bibliometric parameters investigated are the presence of an author in more publications, and the citations trend. Regarding the first, out of 26 documents a total of 157 different authors was recorded.

Only one of them contributed with two studies, namely Isabeau Coopmans from the KU Leuven (Belgium) and their two empirical studies published both in 2021 respectively deal with a survey aimed at assessing the resilience of Flemish food supply chain in the immediate post Covid-19 pandemic (Coopmans et al. 2021) and with a participatory assessment on the resilience and sustainability of three farming systems focused on three different products, i.e., hazelnuts, potatoes and a dairy (Paas et al. 2021).

Overall, most of the documents have 3, 4 or 5 authors (respectively, 6 papers, 5 and 4); one single paper has only one author (i.e., (Cetinkaya Ciftcioglu 2022)), and 4 documents have a number of contributions equal or greater than 8. It is definitely worth nothing a paper with 45 authors (i.e., (Dixon et al. 2021)).

As far as citations are concerned, which may reflect the interest of the topic among the academic community, 10 documents do not have any citation (recently published); 8 documents are within the range of 1–25 mentioning in other studies, 5 between 30–50, and finally there are three studies worth of noting for their resonance: the first, with 87 mentioning deals with the resilience assessment of households toward droughts (i.e., social resilience) (Keil et al. 2008); note that this is the oldest document of the sample (it was published 15 years ago), and surely this may have impacted on this result since clearly for more recent papers it is difficult to reach such numbers. The other two

documents published five years ago in 2018 are both focused on a multi-indicators sustainability assessment, in the first case of aquaculture systems (Valenti et al. 2018), while in the second of global food systems (Chaudhary et al. 2018); respectively, they are mentioned in other documents 107 and 243 times at the time this research was conducted.

Contents analyses

After the round of bibliometric analyses, contents were addressed. Recalling the order of the questions of the starting framework (Meuwissen et al. 2019), the subsections that follow propose the replies.

Resilience of what?

At first, the subject of the resilience assessment of each document was identified. Table 5 illustrates outcomes. Note that a single document (i.e., (Maydana et al. 2020)) compares twice since two issues are addressed, namely the resilience of both soil and water subjects.

Overall, in most cases the subject of resilience is the general AFSC, and it is worth noting that it is mostly referred to what has been defined in the introduction the supply level, i.e., agricultural and farming activities; indeed, the only document in which the agroindustry is mentioned is (Jacobi et al. 2018), revealing as already stated a gap which should be filled. It is also worth of mention the fact that in four documents the resilience of households it quantified; the peculiarities of these four documents is that all these empirical studies are survey-based and carried out in less developed countries, i.e., Bangladesh (Béné et al. 2017), Ethiopia (Upton et al. 2022; Williams et al. 2020), Indonesia (Keil et al. 2008) and Niger (Upton et al. 2022). Another interesting common characteristic is that, exception for one document (i.e., (Béné et al. 2017)), in the remaining three the disruption affecting families and toward which the resilience level is determined is the climate change, and more specifically the already mentioned droughts.

Table 5 Resilience of what? Results from the subjects of the resilience assessment

Subject of the resilience assessment	References
Agri-food supply chain (general)/food systems	Clavijo-Buritica et al. (2023) Hossard et al. (2021), Paas et al. (2021), Haqiqi and Bahalou Horeh (2021), Volkov et al. (2021), Zhao et al. (2018), Heckelman et al. (2018), Coopmans et al. (2021), Jacobi et al. (2018), Karan et al. (2023), Diserens et al. (2018), Dixon et al. (2021)
Households	Upton et al. (2022), Williams et al. (2020), Béné et al. (2017), Keil et al. (2008)
Soil—landscape	Cetinkaya Ciftcioglu (2022), Maydana et al. (2020), Rescia and Ortega (2018)
Country	Ibarraran Viniegra et al. (2010), Chaudhary et al. (2018)
Water management—water	Xu et al. (2021), Maydana et al. (2020)
Crops	Meldrum et al. (2018)
Aquaculture system	Valenti et al. (2018)
Ecosystem (e.g., forestry)	Sharma and Kumar Goyal (2018)
Water–energy–food nexus	Nunez-Lopez et al. (2022)

Resilience to what?

To reply to the second question, the type of disruption or negative event which challenges the system and accordingly may affect the equilibrium was investigated: in 11 documents out of 26 no reference to a specific disturbance was mentioned; in the remaining sample, instead, the majority of cases (i.e., 11) deals with the climate change and the concerns that derive, such as droughts (e.g., (Sharma and Kumar Goyal 2018)) or water shortage (e.g., (Xu et al. 2021)); only three studies treated the Covid-19 issue (i.e., (Haqiqi and Bahalou Horeh 2021; Coopmans et al. 2021; Dixon et al. 2021)), while in one unique paper the topic of pest infections which could affect plants is addressed (i.e., (Rescia and Ortega 2018)). To be honest, it was expected a greater impact from the pandemic side, having passed three years. The pie chart of Fig. 6 graphically resumes these results.

Resilience for what purpose?

Regarding the dimensions of the resilience, recalling the triple bottom line (TBL) concept related to sustainability (Alhaddi 2015) and adapted to that of public and private goods for addressing the third question, outcomes are below proposed, in Fig. 7.

Most of the papers (i.e., 11) considers all the three dimensions of resilience, as it happens for the sustainability concept. When deepening the analysis of the single pillars, instead, the main outcome reveals that in the majority of documents (i.e., 8) the economic aspect is investigated, and it does not surprise at all; in fact, when referring to the AFSCR, it is meant the ability of a system to recover after disturbances implicitly referring to its system in terms of productivity, and accordingly an economic-related issue. As also stressed in the introduction section, in fact, in several cases the resilience is a posteriori evaluated in terms of non-production, time or costs employed for restoring the equilibrium or food price, and accordingly in economic terms. It is equally unsurprising that in the four documents whose focus is on the social aspect the subject of the resilience assessment are the households, and is mainly addressed to a food security assessment. For concluding this aspect, when referring to the three documents focusing

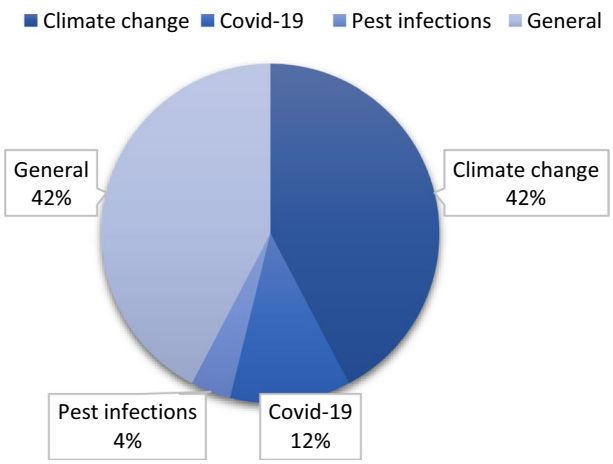

Fig. 6 Disruptions under study in the 26 documents of the sample

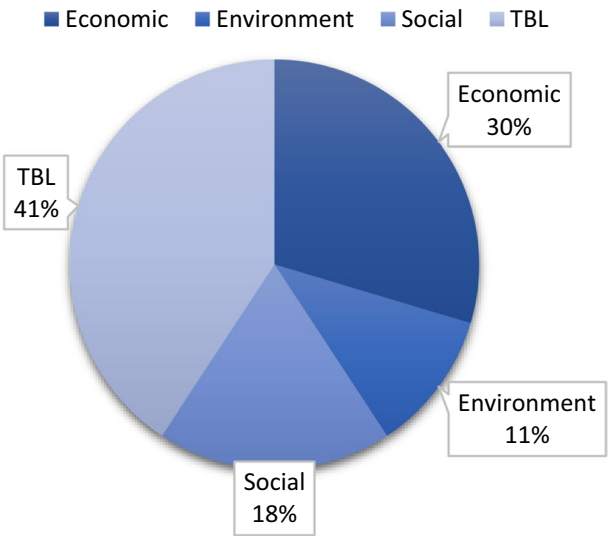

Fig. 7 Dimension of resilience investigated in the 26 documents

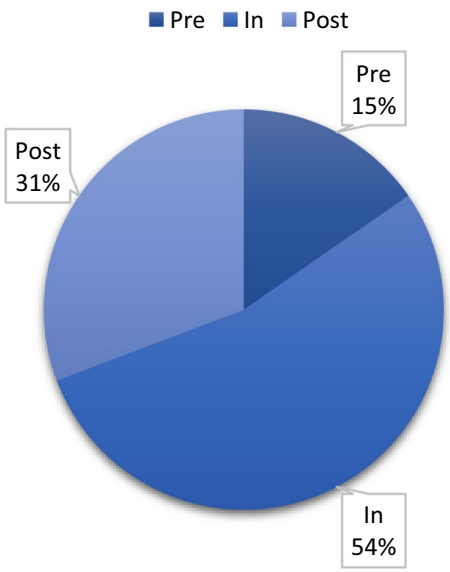

Fig. 8 Temporal time of the resilience assessment

on the mere environmental dimension, research whose subject of resilience is a natural resource (e.g., water, soil or landscape) are recalled.

What resilience capacities?

As far as the moment in which the study was carried out and implicitly referring to the abovementioned capacities and recalling the proposed subdivision into pre, in and post resilience assessment, numerical outcomes are proposed below, in Fig. 8. For let the readers better understanding how this classification was carried out, for each group an example is provided: (Clavijo-Buritica et al. 2023) fits in the "pre" group since this work is based on a simulation study which simulates the behavior of

the network, and the disruption has not yet occurred; this second study (Chaudhary et al. 2018), instead, regards the assessment of the as is situation of a system during the disruption, while this third (Coopmans et al. 2021) investigated the resilience after a disruption manifested (in this specific case after the Covid-19 pandemic).

Most of the documents under investigation (i.e., 14) analyzes the as is impact on the subject in question; note that all the three documents dealing with the Covid-19 pandemic, as expected, are studies aimed at assessing post effects. It is important to stress, going back to the origin of the present study, that for an as-is assessment of the AFSCR the pre phase is relevant, corresponding to the above mentioned anticipatory capacity, representing the robustness of the system as a whole.

What enhance the resilience assessment?

The last subsection of the results is dedicated to summarize the quantitative assessments which were derived from the 26 documents, and aimed at replying the fifth final question of the initial framework. This represents one of the contribution of the paper, since interested researchers or practitioners may refer to this summary for their scope and needs.

As emerged, in several cases the resilience is computed on the bases of a questionnaire survey result, for instance according to an achieved score; according to that, at first documents in which the assessment is based on a survey score achieved by respondents and interested parties are recalled and detailed in Table 6. The grading scale is clearly different depending on the study.

In the abovementioned cases, the resilience level is simply determined according to the responses of the surveyed participants to the issues posed to them. The surveys are significantly different, as well as are their aims and the indicators considered, as deductible from the last column referring to their description. However, surely a weakness of such investigations is that replies (and accordingly scores) are subjective: the level of perception can vary from respondent to respondent, and may not really reflect the real status.

In other documents, instead, specific indexes or ad hoc models were used or derived and implemented for computing the resilience level. For completeness and for the interest of readers and practitioners, they are resumed in the table below (Table7).

The findings proposed in the two tables above are definitely heterogeneous: sometimes they refer to a determined subject, to a specific dimension, sometimes to a model or to an index; accordingly, their application field may vary as well and it is difficult to derive common characteristics or limits, since each of them has its own. They only share the fact that a numerical output measuring a determined resilience dimension is derived. It is interesting to note that among the papers addressing a multi-dimensional assessment of sustainability (Valenti et al. 2018; Maydana et al. 2020; Chaudhary et al. 2018), resilience is considered among the factors affecting the sustainability level of a system, as also previously stressed by other authors (e.g., (Javed Iqbal et al. 2022)); thus the reason for their inclusion. According to their needs, readers are invited to refer to the specific manuscripts for deepening the models.

Table 6 Documents whose resilience level is derived from surveys results

Reference	Resilience subject	Resilience dimension	Description
Hossard et al. (2021)	AFSC	TBL	On the bases of 8 performances indicators (i.e., land; labor; income; yields; family assets; market access and commercialization; irrigation and policies) through a participatory assessment the most resilient farm types were assessed
Meldrum et al. (2018)	Crops	TBL	Assessment of the role of crop diversity in farmers' adaptation actions; investigation on how farmers' use of diversity in adaptation is related to their perceptions of crop and variety tolerances and other environmental, social, and economic factors on the bases of a community resilience self-assessment
Paas et al. (2021)	AFSC	TBL	Participatory assessment for defining the perceived resilience of three farm systems (i.e., starch potatoes, dairy and hazelnut production) on the bases of a developed framework named Framework of Participatory Impact Assessment for Sustainable and Resilient FARMing systems (FoPIA-SURE-Farm) which includes some activities and their relative achievable score
Coopmans et al. (2021)	AFSC	Economic	Questionnaire sent to farmers to assess how the Covid-19 crises impacted from a business perspective and whether farmers resorted to available resilience capacities; 32 variables with their related measurement are involved
Jacobi et al. (2018)	AFSC	Social-environmental	Indicator survey-based assessment of the social-ecological resilience on the bases of buffer capacity, self-organization, capacity of learning and adaptation. 16 indicators and their rating criteria are proposed
Cetinkaya Ciftcioglu (2022)	Landscape	TBL	Assessment of the resilience of the agricultural landscapes and associated ecosystem built on 21 elements, and for each of them a resilience indicator assessment was associated
Dixon et al. (2021)	AFSC	TBL	Response and resilience to Covid-19 shock assessment by the degree of initial recovery of 5 domains: productivity, economic, natural resources, human conditions and social capital

Table 6 (continued)

Reference	Resilience subject	Resilience dimension	Description
Heckelman et al. (2018), Diserens et al. (2018)	AFSC	TBL	SHARP (Self-evaluation and Holistic Assessment of Climate Resilience of Farmers and Pastoralists) tool implemented for assessing the climate resilience of farmers respectively implemented in Philippines (Heckelman et al. 2018) and Switzerland (Diserens et al. 2018). It is a survey-based digital instrument developed by FAO (https://www.fao.org/in-action/sharp/sharp-tool/en/) constituted by 33 modules related to different aspects of the household and farm system; the application automatically calculates the compound resilience scores per module, and an overall score
Béné et al. (2017)	Households	Social	Resilience impact assessment on the bases of a set of indicators constituting a framework

Conclusions

In this manuscript outcomes from a literature analysis carried out on documents dealing with quantitative assessments of AFSCR are proposed, so as to reply to the original research question to be addressed: how to measure the resilience of an agri-food supply chain? Actually, we could not reply at all. Surely the reduced number of documents, namely 26, attracted the attention, being considered a first symptom of the fact that probably the topic is poorly treated, and this was confirmed.

Going in order, at first the temporal evolution of the journal studies was investigated, showing a timidly growing trend starting from year 2018, after approximately ten silent years from the first paper of the sample. The reason can be attributed to the fact that, at present, harmful events impacting supply chains are unfortunately increasing, both in number and in forms, and force to face new challenges.

The first bibliometric analyses let emerge the fact that, as expected and in line with the topic, the most common methodology is that of empirical studies, and with reference to the geography sometimes there is a mismatch between the affiliation of the authors and the country in which the study is then developed, and this happens quite often when dealing with social resilience of households, being families located in less developed countries. USA and Switzerland stand out for their scientific production in terms of number of publications. However, the feeling is that now also developed (e.g., European or North American) countries were bent for several reasons not previously considered; as a consequence more studies are expected to assess their attitude and behavior.

As far as contents are concerned, the subject of the resilience assessment turned out to be in most cases the general AFSC, with a specific focus at the farm level; indeed, no mentioning to production or transformation of food (i.e., to the industry) was found. According to the opinion of the authors, this could be actually due to the fact that, so far, resilience was mainly associated with environmental issues such as the climate change, whose primary and direct impact is on agricultural productivity; as a consequence of a pandemic and a recent war that no one would have imaged, the equilibrium

Table 7 Indexes/models for computing resilience

Reference	Resilience subject	Resilience dimension	Index/model
Upton et al. (2022)	Households	Social (Food security)	Resilience Capacity Index (RCI) derived from the method RIMA II (Resilience Indicators for Measurement and Analysis) developed by FAO (F. a. A. Organization 2016)
Upton et al. (2022)	Households	Social (Food security)	RCI developed by TANGO International (Smith and Frankenberger 2018; Smith et al. 2022)
Upton et al. (2022)	Households	Social (Food security)	RCI developed by Cissé and Barret (Cissé and Barret 2018)
Keil et al. (2008)	Households	Social (Food security)	Drought Resilience Index
Williams et al. (2020)	Households	Social (Food security)	Agent-based model for determining two measures of resilience: poverty reduction and shock absorbance
Chaudhary et al. (2018)	Country	TBL	Notre Dame Global Adaptation Initiative (ND-GAIN) Country Index, calculated based on the status of 45 different factors (Chen et al. 2015)
Chaudhary et al. (2018)	Country	TBL	Shannon Diversity of Food Production (expected contribution to a country's resilience by having more than just a few crops being produced) (Remans et al. 2014)
Ibarraran Viniegra et al. (2010)	Country	TBL	Vulnerability and Resilience Indicators Model (VRIM)
Valenti et al. (2018)	Aquaculture System	Economic	Three resilience included among the sustainability indicators: Risk Rate, Diversity of Products and Diversity of Markets
Maydana et al. (2020)	Water—soil (land)	Environment	Vulnerability and resilience assessment of water and soil quality indicators
Xu et al. (2021)	Water management	TBL	14 factors affecting the resilience of water management from society, economy, environment, institution and crop characteristics dimensions; an final index is constructed
Rescia and Ortega (2018)	Landscape	Environment	Spatial resilience index for pest infections prevention based on landscape indicators
Sharma and Kumar Goyal (2018)	Ecosystem	Environment	Ecosystem resilience assessed on the bases of the water use efficiency (WUE) indicator
Nunez-Lopez et al. (2022)	Water-energy-food nexus	Economic	Resilience index for the provision of functional services
Clavijo-Buritica et al. (2023)	AFSC	Economic	Index for defining the resilience of an AFSC network
Haqiqi and Bahalou Horeh (2021)	AFSC	Economic	Resilience computed in terms of missed production on the bases of forecasts

Table 7 (continued)

Reference	Resilience subject	Resilience dimension	Index/model
Zhao et al. (2018)	AFCS	Economic	Total Interpretive Structural Modeling (TISM) model of resilience factors
Volkov et al. (2021)	AFCS	Economic + Social	Index composed of three components: production of food at affordable prices, assurance of farm viability, provision of employment opportunities with decent income for agricultural workers
Karan et al. (2023)	AFCS	Economic	Resilience computed as costs that would occur in case of manpower, energy or water shortages

of companies as well started to waver; this surely reveals a gap which should be filled. Families as well quite often are under exam, specifically in terms of food security and accordingly the social side of resilience.

Several documents do not refer to a specific disruption, but among those in which it is manifested the climate change is recalled, probably as already emphasized given the fact that so far it was considered the main negative event; more into detail, when dealing with social resilience effects of droughts are referred. A greater component from the recent Covid-19 pandemic was expected, but in only few documents it was mentioned; undoubtedly, effects are still being felt. With reference to the resilience dimensions, it was noted that in most cases the economic aspect is predominant, supporting the definition of resilience from the managerial point of view; however, among literature a great attention to a social resilience as well was found, while the environmental aspect turned out to be the less debated but this outcome as well is in line with the resilience definition.

Overall, the main issue returned from the present research is that, at present, a structured analytic model to be used both from researchers and practitioners for assessing the resilience level of an AFSC does not exist; and in fact this paper represents the call for future research on the development of models for this purpose, both at farm and industry stage. Indeed, existing general evaluations as anticipated in the introduction section, mainly refer to post (or also in) effect assessments so as to reply to the question addressing if the system was resilient or not. But the as-is resilience level so as to prevent a disruption may be useful to highlight where the efforts should be addressed for increasing the robustness of a system and being able to face any event. This last statement may be interpreted in contrast to the reply to the fourth question referring to the moment in which the assessment was carried out, as it emerged that in the majority of documents the in-resilience was investigated; however, in resilience means that the disruption has already occurred and started to impact the system, and accordingly its potential shortcomings could have already manifested.

As a final remark, results from this scientific review should give pause for thought on the usage of the term resilience among the scientific community: by involving pertinent keywords, starting from a total of 184 documents, only 26 turned out to be really suitable. We are aware of the fact that quite often this happens when reviewing, but we

all know that this particular word, resilience, is currently in fashion. Resilience can be everything and nothing. The authors wish for a conscious use of the term with its real meaning.

Surely a limit of this research is represented by one of the inclusion criterium depicted in the methodology section, which stated that only assessments in the agri-food field could be included; as already declared in the methodology section in other fields, some methods or tools could have been already developed and implemented, and may be adapted to this field. In this regard, expanding the search in other contexts in terms of literature analysis represents a future directions which the authors surely will deepen. Another limit already mentioned is the scarce number of reviewed documents, which impacted in terms of analyses that could be performed on the sample and on the general statistics which could be applied. Other research, moreover, may include investigations of the social resilience of households in western well and are not limited to the emerging ones. As last limitations, it is worth noting that only documents written in English language were considered, and this may have caused the exclusion of articles not respecting this criterium; moreover, only Scopus and WoS database were involved in the research, neglecting some documents which may be found in other minor database such as Google Scholar.

Finally, for the future, as the main aim of this paper stresses, quantitative models for the assessment of the AFSCR are expected, including more contributions from the scientific community.

Abbreviations

AFSCR	Agri-food supply chain resilience
e.g.	*Exempli gratia* (for example)
FoPIA-SURE-Farm	Framework of Participatory Impact Assessment for Sustainable and Resilient FARMing systems
i.e.	*id est* (that is)
ND-GAIN	Notre Dame Global Adaptation Initiative
RCI	Resilience Capacity Index
RIMA	Resilience Indicators for Measurement and Analysis
SHARP	Self-evaluation and Holistic Assessment of Climate Resilience of Farmers and Pastoralists
TBL	Triple bottom line
TISM	Total Interpretive Structural Modeling
VRIM	Vulnerability and Resilience Indicators Model
WUE	Water use efficiency

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Author contributions
LT contributed to conceptualization, writing—original draft, writing—review and editing, methodology, validation, investigation, data curation, formal analysis. GV contributed to conceptualization, funding acquisition, writing—review and editing, supervision, methodology, visualization, validation, project administration. All authors read and approved the final manuscript.

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Availability of data and materials
Not applicable.

Declarations

Competing interests
The authors declare that they have no conflict of interest.

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