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Reorganization and resilience of food supply chains according to current international crisis scenario

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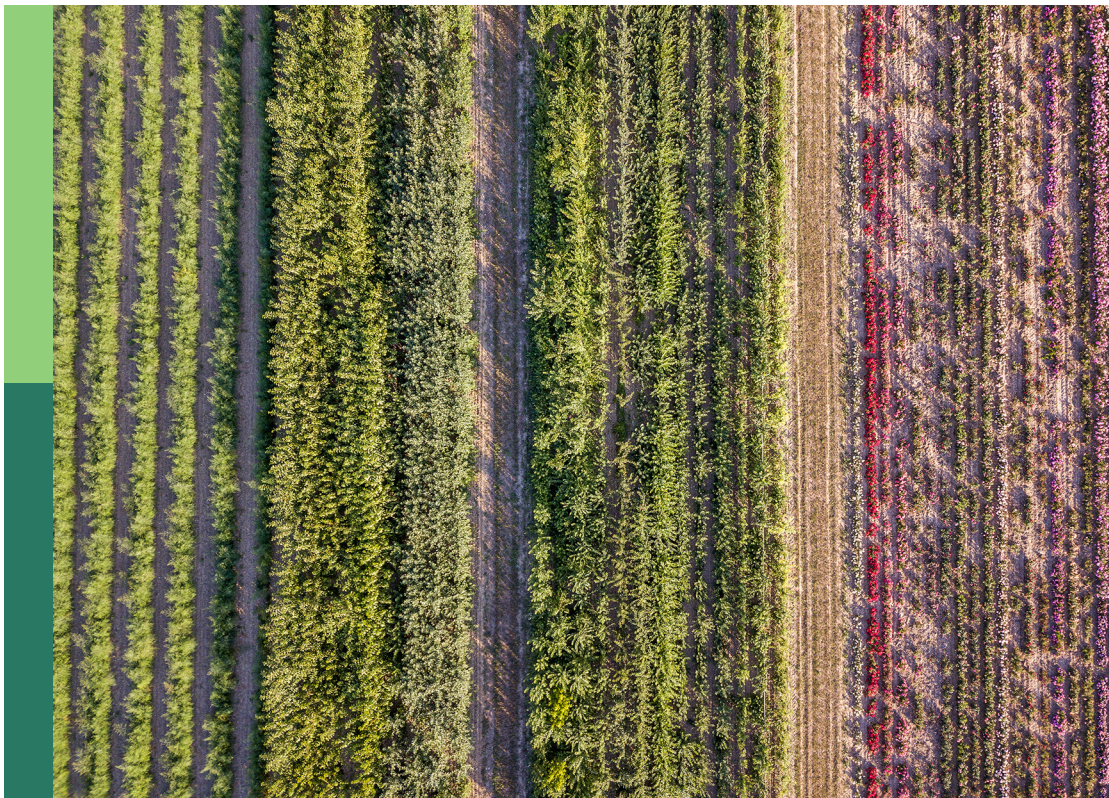

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Reorganization and resilience of food supply chains according to current international crisis scenario

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SYSTEMATIC REVIEW
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Food Policy Councils: A 20—Year Scoping Review (1999–2019)

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The proliferation of food policy councils (FPCs) in the past two decades has been accompanied by increasing academic interest and a growing number of research studies. Given the rapid interest and growth in the number of FPCs, their expanding geographic distribution, and the research on their activities, there is a need to assess the current state of knowledge on FPCs, gaps in that knowledge, and directions for future research. To address this need, we undertook a scoping review of the scholarly literature published on FPCs over the past two decades. The review identified four main themes in the FPC research—(1) Activities of FPCs; (2) Organizational dimensions; (3) Challenges; and, (4) Facilitators. We also note a significant sub-theme related to equity and diversity, race and class representation in FPCs. These themes frame a growing body of knowledge on FPCs along with key gaps in the current body of literature, which may help to direct research on these organizations for those interested in approaches to food systems change and cross-sectoral collaborative approaches to social-ecological governance.

Keywords: food policy councils, food policy, food systems, food movements, local food systems

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INTRODUCTION

In the past two decades, cities and regions across North America, Europe, the United Kingdom, and Australia have established food policy councils (FPCs) as an approach to addressing the multitude of issues that impact a community's food systems (from production and harvesting to consumption and waste management). FPCs can be defined as collaborative, membership-driven organizations that bring together stakeholders across private (e.g., small businesses, industry associations), public (e.g., government, public health, postsecondary institutions), and community (e.g., non-profits and charitable organizations) sectors to examine opportunities to implement integrated strategies for improving local and regional food systems. Key characteristics of FPCs–which differentiate them from other food systems organizations–are: (1) their use of a cross-sectoral committee to guide decisions and activities; and, (2) their use of a food systems approach (i.e. they focus on a variety of food issues and are not limited to one specific area of concern such as nutrition or agriculture).

The first FPC was established in 1982 in Knoxville Tennessee, with a few additional FPCs emerging throughout the 1990s. The initial creation was spurred by events such as the World Fair (hosted in Knoxville in 1982) and the United States Conference of Mayors (1984–1985) which urged municipal leaders to become more involved in developing and shaping policy around food issues. Other catalyzing moments included the development of the Ottawa Charter for Health Promotion in 1986 and the World Health Organization's *Healthy Cities* program. Throughout the 1980s, the significant rise in the demand for emergency food due to increased poverty–paralleled by drastic cuts in social services, forced cities to consider how to address a mounting food security crisis (Riches, 2018). By the early 2000s, many FPCs were established and by 2007, there were about 44 of these organizations distributed primarily across North America, with a few in Europe and Australia

(Schiff, 2007). By 2020 FPCs had proliferated: the Food Policy Networks project (operated through the Johns Hopkins Center for a Livable Future) identified over 350 FPCs across North America [Centre for a Livable Future, (n.d.)]. Most FPCs operate at local/municipal level with a few working at a regional or state/provincial scale. In 2021, the Canadian federal government created a National Food Policy Advisory Council to support cross-sectoral collaboration and engagement at a national level and to support the implementation of the new Food Policy for Canada.

There were a few studies of early FPCs in the 1980s and 90s in the U.S. and Canada (Clancy, 1988; Dahlberg, 1994a,b; Yeatman, 1994; Gottlieb and Fisher, 1995; Webb et al., 1998) and Australia (Yeatman, 1995; Hawe and Stickney, 1997). The proliferation of FPCs in the past two decades has been accompanied by increasing academic interest and a growing number of research studies. Given the rapid interest and growth in the number of FPCs, their expanding geographic distribution, and the research on their activities, we identified a need to systematically assess the current state of knowledge on FPCs and gaps in that knowledge. As such, we implemented a scoping review methodology to systematically assess the scholarly literature published on FPCs over the past two decades (1999–2019).

METHODS

We utilized the five-stage process for conducting scoping reviews as outlined by Arksey and O'Malley (2005). Below, we discuss the five stages and describe our specific approach.

Research Question

Three research questions guided this scoping review:

a) What are the major themes in research on FPCs in the past two decades (i.e., published between 1999–2019)?
b) What methods have been employed in the study of FPCs in the past two decades?
c) What gaps and directions for further research are suggested by the research on FPCs?

Literature Search Strategy

Our initial search included five databases for identification of peer-reviewed journal articles: The Web of Science, Food Science Source, AGRICOLA, FSTA, and Greenfile. To search for chapters in academic books, we utilized Omni library portals. We also included publications from the Johns Hopkins Annotated Bibliography on Existing, Emerging, and Needed Research on Food Policy Groups (Santo et al., 2017). Databases were searched using the keywords "food policy" AND "council" or "committee" or "association" or "coalition" or "alliance" or "network". The search was limited to literature published between 1999 and 2019.

Study Selection Criteria

We engaged in three stages of review (title review, abstract review, full content screening) to refine the results to our specific topic. In the title review stage, titles were included if they mentioned food policy, FPCs, or synonymic terms such as food policy groups, associations, councils, etc. Additionally, titles with related concepts such as food security, food democracy, wellness committees, and urban food systems merited further review, and were forwarded to abstract screening. The abstract review stage focused on identifying articles that discussed FPCs as defined by our definition which is found in the first paragraph of this article. Abstract review screened out those articles which might have focused on organizations that did not fit with the FPC definition–such as food systems non-profits that do not use a cross-sectoral council to guide their activities or government committees that are focused narrowly on one specific aspect of the food system. Full text screening focused on identifying articles where FPCs were the primary/exclusive focus. This stage screened out articles where FPCs were only briefly discussed or were review articles that did not present empirical research findings. This resulted in the final list that was used for content analysis to answer the research questions.

Data Charting

Data was captured in a Microsoft Excel workbook with two spreadsheets. The first spreadsheet included all articles identified in the initial search. This sheet tracked: author; year; title; citation; database/source. Following title and abstract screening, a secondary sheet included those articles that had passed the initial screening process. This sheet documented: study location; synopses; major findings for each publication. A third sheet (with the same fields as the second sheet) was created for the final list, which included all articles identified as relevant after full content review.

Summarizing and Report Results

All three authors of this article were involved with analysis and reporting. All authors reviewed all articles in the final list using an inductive approach to interpretive content analysis (Drisko and Maschi, 2016) to identify key themes related to our three research questions. This analysis was guided by the following focus as defined by our research questions: thematic organization of the existing literature, description of methods used to study FPCS, identify gaps and potential direction for future FPC research. The authors met to merge the results of individual inductive analysis into a single coding scheme. This was accomplished by identifying common themes identified in the individual inductive analyses and applying codes (thematic titles) which captured those common themes. The codes that emerged through merging of the individual inductive interpretive analysis included:

- Research Question 1: impacts / effectiveness; organizational dimensions; FPC activities
- Research Question 2: geographic scale; scope; methods
- Research Question 3: researcher identified gaps and recommendations.

Each of these codes also contained sub-codes which are discussed in detail in the results section. We also included a code for a small amount of data which could not be categorized within these themes. We then utilized this coding scheme to review all publications in the final list and to categorize data. We also analyzed results for any additional potential gaps in research that are not identified in the existing literature.

RESULTS

Our initial search yielded 2,239 unique peer-reviewed journal articles, 578 book chapters, and an additional 16 articles/chapters from the Johns Hopkins database. Following full content screening our final list yielded a total of 25 articles. Five of these articles were published between 1999 and 2009 when the number of FPCs was still relatively small—44 FPCs in North America as per Schiff (2007). The increase in studies on FPCs between 2009 and 2019 may be related to the rapid increase in the number of these organizations during that time period.

The scoping review search strategy and selection process are summarized in **Figure 1**. The 25 articles which met the scoping review criteria are accompanied by an asterisk (*) in the reference list at the end of the article. For the purposes of this article, we refer to all articles/chapters as "articles" in the findings and discussion.

The interpretive content analysis resulted in coding structure around four key themes in the research on FPCs in the past 20 years: (1) Activities of FPCs; (2) Organizational dimensions; (3) Challenges; and, (4) Facilitators. A theme related to "methods employed in the study of FPCs" is included in our findings and "researcher recommendations" is included in our final discussion section. We note that this analysis was not analyzing FPCs themselves but rather was analyzing the ways in which the FPC literature (from empirical studies) discusses and analyzes FPCs. In other words–the purpose of this article was not to provide a detailed description or definition of FPCs. The purpose of this work was to thematically organize literature on FPCs to identify what is known and how this reveals gaps in knowledge and directions for future research.

FINDINGS

Methods Employed in the Study of FPCs

As mentioned above, codes included documentation of geographic scale, scope, and methods. In relation to methods, of the 25 articles/chapters included, the majority (17) used a case study methodology. Many case studies used mixed methods which included semi structured interviews, participant observation, field notes and document review. Other methods included structured surveys or large numbers of FPCs and multi-site comparative case studies.

In terms of geographic scale, 12 articles/chapters exclusively examined FPCs operating at a municipal/local level. Three focused exclusively on FPCs operating on a regional or state/provincial scale. The remaining 10 examined FPCs operating at different levels – i.e. included examination of FPCs at municipal, regional, and state levels in one study. In terms of geographic scope, most articles (17) reported on research conducted in the United States. Three articles reported on research conducted in Western European countries, one article on research in Australia, and five from Canada. Two articles compared FPCs in different countries. Thirteen articles focused on a single FPC, while the others included between two and 56 FPCs in their research.

Activities of FPCs–What FPCs Do

Much of the research on FPCs focused on an examination of what FPCs do and specifically on their various activities. As the very nomenclature suggests a focus on policy (change) there is indeed a considerable amount of literature focusing on the policy work of FPCs. There is however also significant documentation of a wide range of other kinds of activities that go well beyond policy-specific work. In this subsection, we describe the ways in which FPC activities are documented and discussed in the articles.

Policy Specific Activities

Early literature on FPCs (Dahlberg, 1994a,b; Yeatman, 1994) indicated that impacting and influencing food related policy at a municipal, regional, or state level is a key priority for many FPCs–this theme was also evident in our review and analysis of the FPC literature. This might include policies that relate to food directly (e.g., retail zoning, food related funding, food safety bylaws, etc.) or indirectly (e.g., transportation, use of public space, etc.). In the articles reviewed, FPC policy work primarily included activities such as drafting resolutions, reports, and proposals for and with governments (Lang et al., 2005; Blay-Palmer, 2009; Scherb et al., 2012; Coplen and Cuneo, 2015; Siddiki et al., 2015; Clark, 2018; Koski et al., 2018). Other policy activities included advocating for food-related issues (Blay-Palmer, 2009; Purifoy, 2014), creating legislation to create an FPC within government (De Marco et al., 2017) and working to amend zoning laws (McClintock et al., 2012). Many of the articles on municipal FPCs (10 of 12) include some focus on policy change to support urban agriculture.

While many FPCs engage in policy work, some articles (4) noted FPCs that do not prioritize this type of work. The articles in this review reported that some FPCs have members that (despite the nomenclature) are not directly interested in policy work and prefer to focus on project development and implementation. Newer FPCs sometimes have concerns that their recent emergence—being a new entity with lower levels of recognition among policymakers and less political capital—was a potential hindrance to their impact on policymaking (Sieveking, 2019). Similarly, McCartan and Palermo (2017) found that some FPCs viewed policy change as a long-term goal that required a more established council to have an impact (McCartan and Palermo, 2017). For some FPCs, policy work was simply not a part of their goals (Packer, 2014).

Other Activities

For many FPCs, policy work is a priority, however most articles described FPCs pursuing non-policy initiatives. Gupta et al. (2018) note, "research makes it clear that the FPC label is being applied to collaborations that engage in a diverse and wide-ranging set of activities, not all of which involve…policies" (p. 13). Schiff (2008) categorized the various types of non-policy work that FPCs engaged in, including: implementing food (nutrition; urban food production; other (farm and fisheries) production; distribution) programs; creating and facilitating a network for food systems organizations; facilitating program implementation for food systems organizations, and; education on sustainable food systems.

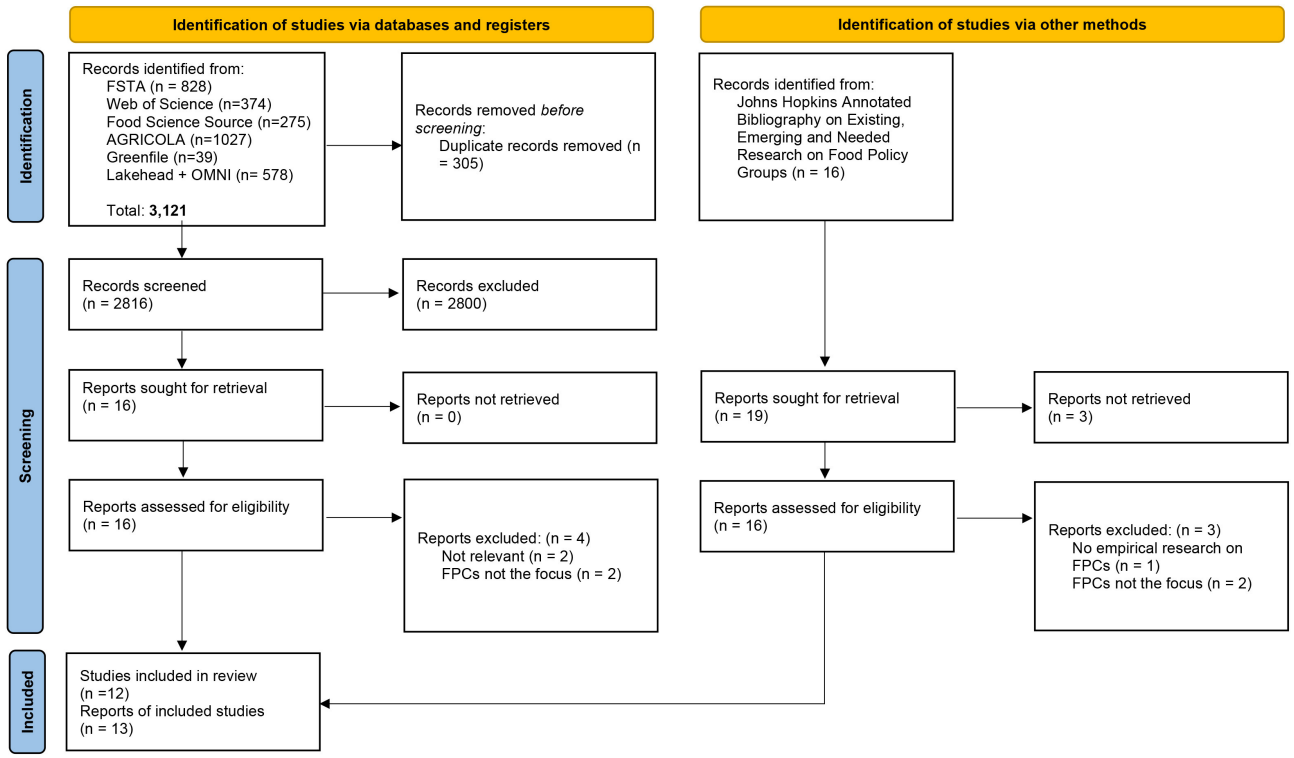

FIGURE 1 | Details of scoping review and citation selection process. Adapted from: Page et al. (2021).

Supporting urban agriculture was a theme of several (5) articles. Blay-Palmer (2009) described the work of the Toronto Food Policy Council (TFPC), that included the creation of more opportunities for producers to sell their food, leading the implementation of urban agriculture projects such as rooftop gardens, and urban apiaries, and demonstrating the importance of urban agriculture for the city council (Blay-Palmer, 2009). Other articles describe similar urban agriculture initiatives undertaken by the Oakland FPC (McClintock et al., 2012), Ghent FPC (Prové et al., 2019), Portland Multnomah FPC (Coplen and Cuneo, 2015) and many others (Scherb et al., 2012).

Purifoy (2014) highlighted other, diverse non-policy activities of several FPCs–describing FPCs as ideal institutions to integrate action on food, environment, and social justice issues. These activities included the creation of opportunities for green grocers in New Orleans, sustainable agriculture on public lands in Colorado and New York, and farm to school programs by FPCs in New Mexico and Mississippi. Sands et al. (2016) described the role of the Holyoke Food and Fitness Policy Council in supporting school food programs, which fostered public awareness of local food issues by working with community members and made significant improvements to the quality of food served in local schools.

As Schiff (2008) notes, many FPCs focus on education as a key activity and outcome of their work. This is echoed in other articles, such as Packer (2014) who noted that the Rhode Island FPC participated in regional research and action groups with the goal of food systems education. Other research points to FPC work on educating and raising awareness among policymakers about interconnected food system issues. This was identified by Walsh et al. (2015) in their study of the Cleveland–Cuyahoga County Food Policy Coalition, as well as by Sieveking (2019) in the study of the Oldenburg FPC. The Oldenburg FPC also had a strong focus on community education and awareness and supported initiatives such as "Political Soup Pots" where community members could gather to discuss food systems issues and educational activities in schools (Sieveking, 2019).

Organizational Dimensions–Effects on FPC Impact and Effectiveness

Many of the articles reviewed focused on analysis of the organizational dimensions of FPCs. By *organizational dimensions* we refer to the ways in which FPCs are structured and governed. This literature was often accompanied by a focus on how organizational dimensions affected the activities of FPCs or how they impacted the effectiveness of FPCs in achieving their stated goals. The literature on FPC organizational dimensions included themes related to memberships and partnerships, relationships with government, and internal governance. We also note that, within the discussions of membership and partnerships, there was a sub–theme that emerged focused on equity, diversity, race and class.

Partnerships/Membership

Every article we reviewed mentioned the partnerships and memberships that make up the FPCs. Diversity in partnerships/membership was portrayed in two ways: (1) sector diversity and (2) social (race and class) diversity.

Many (12) articles described a deliberate effort from FPCs to ensure that a diversity of sectors were represented. Most of these articles (8) noted that members were appointed to ensure representation from across the food system and from the public, private, and charitable sectors (Blay-Palmer, 2009; Scherb et al., 2012; McCartan and Palermo, 2017; Clark, 2018; Koski et al., 2018; Baldy and Kruse, 2019; Bassarab et al., 2019; Sieveking, 2019). For example, in a study of 10 FPCs, Gupta et al. (2018) noted that all had involvement from local government employees. The most frequently represented agencies included Cooperative Extension, public health, environmental health, and the Agricultural Commissioner Office.

In addition to discussions of diversity in membership across food systems sectors, some articles (5) discussed other elements of membership diversity–particularly in relation to race and class representation. More specifically, some articles indicated that many FPCs are predominantly composed of white, middle-class professionals from similar socioeconomic and educational backgrounds (Packer, 2014; Sands et al., 2016). This issue is further exacerbated because the individuals and communities that are most directly affected by food system issues are sometimes the ones most absent in FPC membership (Sands et al., 2016; Boden and Hoover, 2018; Bassarab et al., 2019). As Packer (2014) highlighted, this lack of diversity and representation in FPC membership can create hotbeds for negative stereotypes, and deficit-based framing of low-income and food-insecure individuals. During the launch of the RIFPC, the First Lady of Rhode Island "publicly hailed the council's… 'teaching people on SNAP how to eat healthy"' (p. 13). As Packer (2014) notes, such problematic proclamations betray widely held beliefs that people in receipt of SNAP[1] benefits do not (know how to) eat "healthy" and require instruction from those more privileged, educated, or even enlightened" (p. 13) thus perpetuating negative stereotypes. Additionally, members of the RIFPC used deficit-based framing, through "negative, pitying terms: hunger, discrimination, inaccessibility, etc." (Packer, 2014, p. 15). These examples point to a potential for implicit and explicit bias among members of FPCs, which may further alienate racialized or marginalized individuals from joining, thus perpetuating already existing barriers for membership diversity.

These issues with membership stand in contrast to the priorities and stated goals of many FPCs, which often include addressing inequity within food systems (Blay-Palmer, 2009; Packer, 2014; Siddiki et al., 2015; Sands et al., 2016; Boden and Hoover, 2018; Clark, 2018; Bassarab et al., 2019). Several articles indicated that some FPCs have recently included mandates or activities which focus on equity. Examples include the RIFPC which aims to achieve equitable food access regardless of income or race (Packer, 2014) and the Chicago Food Policy Advisory Council, which has joined a project which works toward "dismantling racism and empowering low-income and communities of color through sustainable and local agriculture" (Purifoy, 2014, p. 397). As Kessler (2019) writes, "without confronting the equity component, councils are prone to reinforce inequitable structures" (p. 49).

Overall, creating a diverse FPC has been described as a contributor to success (Clancy et al., 2008; Schiff, 2008; Dharmawan, 2015; De Marco et al., 2017) with benefits to internal and external networks; however, it appears to be a goal that many groups struggle to achieve. The existing membership structures serve to alienate others, limiting the council's ability to represent the community, and therefore decreasing its impact (Packer, 2014). McCullagh and Santo (2014) note,

> Applied to FPCs, "meaningful inclusion" of diverse community residents is not simply an invitation to participate, but a practice that ensures that all participants feel comfortable and supported in making contributions and that their opinions are listened to and respected… (p. 28).

The absence of these important voices creates several challenges for FPCs, specifically the potential for a lack of ideological diversity, questions around equity and a limited understanding of the needs of those most vulnerable within the community (Sands et al., 2016; Boden and Hoover, 2018; Bassarab et al., 2019). The articles reviewed in our study suggest that in order to create meaningful change, many FPCs must change their governance structures and membership policies to enable greater diversity and work toward dismantling racism in the food system. The strategies to make such changes are not described in the literature and point to a potentially important area for further research.

Diversity within FPCs has been important for creating room for critical analysis, spurring innovation through diverse perspectives, and increasing social capital (; Walsh et al., 2015; Ilieva, 2016; McCartan and Palermo, 2017). Despite the evidence demonstrating the value of diversity, many of the articles reviewed indicated that FPCs often struggle to create a diverse membership. This has been particularly noted in terms of struggles to represent a broader range of race, class, and other socio-economic dimensions among members (Sands et al., 2016; Boden and Hoover, 2018; Bassarab et al., 2019).

Relationships With Government (and Bureaucracies)

Twenty of the articles we reviewed discussed the engagement of state actors in FPCs. Some of these articles discussed FPCs as being embedded within government offices or with direct links to government (Clancy et al., 2008; Mendes, 2008; Blay-Palmer, 2009; Coplen and Cuneo, 2015; Boden and Hoover, 2018; Bassarab et al., 2019). Some of the articles discussed directives or policies which mandated the inclusion of government representatives (Clayton et al., 2015; Siddiki et al., 2015; De Marco et al., 2017; Bassarab et al., 2019) while others noted the benefits of having paid staff funded directly through government (McCartan and Palermo, 2017).

[1]SNAP is the Supplemental Nutrition Assistance Program – a federal program of the United States government which assists low – income families with the cost of purchasing healthy foods.

From a different perspective, some articles discussed ways that FPCs were intentionally established outside of government or developed to ensure distance from government reach (Clancy et al., 2008; Packer, 2014; Boden and Hoover, 2018; Bassarab et al., 2019). Bringing these two extremes (government based or non–government) together, Schiff (2008) noted that a "hybrid" model includes "some formal relationship with government through funding, resources, or otherwise while maintaining some NGO or non-profit status. In their research, Gupta et al. (2018) echoed this noting that:

> all but one of the 10 councils [studied] is organized as a multisector community collaborative, rather than as an independent non-profit organization or a government advisory body. Each includes local government personnel as members and most depend on government resources for their operations (p. 11).

Baldy and Kruse (2019) discussed two main ways that government actors were involved with FPCs, first as initiators of processes (e.g., introduce particular topics), and second as shapers of process (e.g., deciding who is involved, creating transparency within the process). Research findings from Bassarab et al. (2019) note that "membership and relationship to government have more bearing on the policy priorities (activities) of an FPC than the organizational structure" (p. 39).

Internal Governance

Seven articles discussed various internal governance arrangements such as formalized decision-making processes. Some of these articles discussed consensus decision-making processes implemented by FPCs to mitigate power imbalances (Packer, 2014; Clark, 2018). Other research indicated that FPCs developed processes and procedures to ensure greater democratic engagement such as Terms of Reference that were reviewed regularly, member surveys, committee structures, holding public meetings and sharing of meeting minutes (Sands et al., 2016; McCartan and Palermo, 2017; Boden and Hoover, 2018; Prové et al., 2019; Sieveking, 2019).

Challenges–Factors That Create Barriers to FPC Effectiveness

Most (19) articles described several different types of barriers that FPCs experience that impede their ability to achieve their goals (i.e., impede their effectiveness)[2]. We found four distinct categories of barriers described in the articles that we reviewed: membership and structural issues; resource issues; political issues; setting priorities.

Membership and Structural Issues

In terms of membership and structural issues, several (8) articles reported diversity and lack thereof, as a major barrier to effectiveness (as discussed above). These articles mainly focused on diversity issues from an equity or community representation perspective (Packer, 2014; Sands et al., 2016; Boden and Hoover, 2018). Some research pointed to difficulties of FPCs in engaging citizens (Sands et al., 2016; Boden and Hoover, 2018; Baldy and Kruse, 2019) and maintaining engagement in sub-committee work for volunteer members (Sieveking, 2019). Koski et al. (2018) identified engagement challenges when FPCs were too large–which could lead to marginalization of unique perspectives and disagreements on priorities 2018. Two articles pointed to lack of food system knowledge as a challenge for FPCs. This included lack of knowledge about the local food system of the FPC (Baldy and Kruse, 2019) as well as lack of knowledge about utilizing a food systems perspective (Sieveking, 2019). Another major challenge identified in the literature on FPCs is related to lack of leadership. This can be an issue when the FPC lacks leadership overall (Clancy et al., 2008; Scherb et al., 2012) or when there is a lack of leadership or champions for particular issues (Schiff and Brunger, 2013). On a related note, Scherb et al. (2012) and Sands et al. (2016) noted that some FPCs can also face challenges when members disagree about leadership, council structure or priorities.

Resource and Capacity Issues

The literature on barriers also noted that FPCs face several resource and capacity issues, some of which may be the most significant in terms of impeding the ability to achieve their specific goals. Resource/capacity barriers were noted in 11 articles. For example, funding is a major issue faced by many FPCs. As Bassarab et al. (2019, p. 36) described: "FPCs are woefully underfunded; 68% operate on an annual budget of $10,000 or less (35% have no funding). 12% have an annual budget over $100,000." Several articles noted that some FPCs lack core funding–i.e. for staff, which is a significant barrier (Clancy et al., 2008; Schiff, 2008; Schiff and Brunger, 2013; Sands et al., 2016; Sieveking, 2019). Koski et al. (2018) described this specifically as a challenge for non-profit FPCs. Even for those FPCs that do have funding, the literature noted that there are often still monetary challenges. McCartan and Palermo (2017) identified issues related to lack of long-term funding–such as not being able to plan long term projects. Alternatively, some articles described FPCs that have core funding (even long-term core funding) but do not have funding for individual projects and face difficulty obtaining the funding needed to achieve their objectives (Schiff and Brunger, 2013; McCartan and Palermo, 2017; Prové et al., 2019).

Another resource issue described in the literature is lack of time. Research by Scherb et al. (2012) found that this is particularly the case when FPCs have been legislatively created or are dependent on a limited funding time frame. Mendes (2008) indicated that, as a result, FPCs can be forced to trade-off between quick wins and longer-term investment in policy change processes. An additional resource issue identified in the literature was related to training. While only one article touched on this issue (Scherb et al., 2012) with a focus specifically on lack of training in policy change processes, we note this may be an underlying challenge not yet identified among other FPCs.

[2]For the purposes of this article, we define "effectiveness" as FPCs' ability to achieve their goals and objectives. This may be characterized in terms of program or policy goals or in terms of organizational goals such as achieving organizational stability.

Political Issues

The literature also identifies a range of political challenges faced by FPCs. There are two primary political issues: political turnover and formal association with government. Political turnover–due to political/electoral cycles–is an issue identified in several studies, often due to concerns about loss of support for the FPC as political leaders and the political climate (Clancy et al., 2008; Schiff, 2008; Blay-Palmer, 2009; Scherb et al., 2012; De Marco et al., 2017). Some studies expand on the associated issues which include a constant need to educate new political leaders, bureaucrats, other community leaders (Clancy et al., 2008; Schiff, 2008; Blay-Palmer, 2009). This is due to the lack of understanding among some new leaders about the interconnectedness of food issues and need for FPCs (Schiff, 2008; Blay-Palmer, 2009).

The second political issue identified in the literature is that formal associations with government can also create a range of challenges. While Schiff (2008) and others noted that FPCs can face difficulty accomplishing policy goals if they do not have strong relationship with government–there is other research which indicates challenges due to government affiliation. Coplen and Cuneo (2015) conducted an in-depth examination of dissolution of a government-based council and identified numerous issues related to its government affiliation. Other research has identified that having government employees on a council can be a barrier because they may not be allowed to do policy work (Scherb et al., 2012) or need to get approval for certain activities which slows down progress (Siddiki et al., 2015). As Siddiki et al. (2015, p. 544) described, "A lot of members, because of their a?liations, cannot engage in advocacy activity, which impacts what the council can actually do in garnering public support for policy recommendations." Scherb et al. (2012) also identified that members might lack trust in governments which can lead to internal conflict or slow progress. Government councils can also be less connected and less responsive to community needs (Walsh et al., 2015). It is important to note that being situated within government or having government members can provide many benefits (these are discussed in the section on facilitators below).

Setting Priorities

A final area of challenges that we identified in the literature was related to defining priorities and conducting strategic planning. Scherb et al. (2012) indicated that there can be significant issues when FPCs have trouble defining or agreeing on priorities. As Koski et al. (2018) describe, this may be particularly challenging for FPCs with larger memberships. De Marco et al. (2017) identified that agreement on priorities can be difficult when diverse representatives may not understand other members' motivators and drawbacks to involvement on specific issues. Related to this is the challenge faced when members have different stances on particular issues. Scherb et al. (2012) also found that there may be different or even opposing perspectives on a policy or other issue that the FPC is attempting to address–this can lead to stagnation in agreeing on achieving objectives. Finally, Prové et al. (2019) identified an issue that, while not mentioned elsewhere, may be understudied and significant for other FPCs as well. They found that FPCs focusing at a specific scale (whether neighborhood, municipality, regional or state) may miss opportunities, fail to address important issues, or encounter challenges that could have been avoided if the focus was at a different scale, or even multiple scales.

Facilitators–Factors That Support FPC Effectiveness

In addition to barriers, almost all (23) of the articles discussed factors or approaches that may support FPC effectiveness. These factors included include distinct approaches to: organizational structure; membership; and strategic planning. There is also some literature on how to successfully form a FPC, which we include here as well.

FPC Establishment

Two of the articles we reviewed spoke directly about how to effectively form an FPC. While there is not an extensive literature on this topic, it is nonetheless important, since many FPCs in their formative stages look for such direction and guidance. De Marco and colleagues (2017) noted four factors which support successful formation of a FPC. Those included: (1) stakeholder involvement; (2) diverse partnerships; (3) stake-holder ability to compromise; and (4) conducive political setting (De Marco et al., 2017). Schiff and Brunger (2013) also discussed the formation of an FPC and noted that widespread education and awareness raising about food issues in a community (such as through the creation of a community food plan) can help to build support for and interest in the FPC concept among politicians and community members.

Structural

The literature discusses a number of approaches to structuring an FPC that can be important for supporting on-going effectiveness–this was a theme in seven of the articles reviewed. Several of these studies identified the importance of processes that would support open communications and transparency in decision making processes (Coplen and Cuneo, 2015; Baldy and Kruse, 2019; Sieveking, 2019). Other studies identified the importance of having staff (Clancy et al., 2008; Schiff, 2008) as well as a strong, long-term commitment and engagement from staff and members (Clancy et al., 2008; Blay-Palmer, 2009; McClintock et al., 2012). Finally, Coplen and Cuneo (2015) indicated that strategic planning and evaluation could be very important for FPCs to ensure that structures and processes can be responsive to changing needs.

Membership

Membership can be an impediment (as discussed above) but is also identified in many (13) articles as a core strength of FPCs. Several (10) studies discussed the ways in which membership can be mobilized for greatest effectiveness. In this literature, diversity in representation and community engagement were widely cited as key factors for FPC effectiveness (Clancy et al., 2008; Mendes, 2008; Schiff, 2008; McClintock et al., 2012; Coplen and Cuneo, 2015; Sands et al., 2016; Gupta et al., 2018). Purifoy (2014) found that having local residents as members can help maintain legitimacy and support with municipalities and

organizations. Additionally, research by McCartan and Palermo (2017) revealed that having members from a diverse range of sectors helps to extend the reach, influence, and resources of the FPC networks. Similarly, other research found that FPCs may see more success when they consciously focus on internal and external partnerships and seek out key partners/members in private and public sectors (Mendes, 2008; Clayton et al., 2015; Walsh et al., 2015; Sands et al., 2016).

Strong leadership within the membership was another strongly cited factor for success–appearing in 11 of the articles. This included the importance of including and engaging local "experts" or "champions" and links to government (Clancy et al., 2008; Schiff, 2008; Gupta et al., 2018). Researchers reported that these types of partnerships and links can help gain legitimacy, political capital, and maintain links with people in government with decision and policy-making capacity and power (Packer, 2014; Clayton et al., 2015; Walsh et al., 2015; Boden and Hoover, 2018; Bassarab et al., 2019) and with the private sector (Schiff and Brunger, 2013; Clayton et al., 2015). Baldy and Kruse (2019) argue that state actors are pivotal for affecting change through participation processes that aim to implement food policy measures. However as noted in the section on challenges, links with government can also come with pitfalls. For this reason, Gupta et al. (2018) recommend FPCs maintaining some degree of autonomy in priority setting and decision-making capacities (Gupta et al., 2018). They suggest that FPCs might be more effective if housed outside of government:

> Councils housed outside of the government…can engage in strategic temporary alliances or partnerships with specific agencies that align with their particular campaign goals at the time without needing to comply with or adhere to the mission of any particular government agency over the long-term. Positive working relationships with government entities, therefore, do not necessarily need to be formalized and/or institutionalized to lead to successful policy outcomes or to build trust and legitimacy (p. 23).

Strategic Planning

The literature also includes some discussion of the ways in which FPCs can approach their activities and plan their work, that might lead to the greatest effectiveness in achieving goals. Some studies identified that background research and planning, while lengthening the process, may be critical to being successful for specific projects and goals (McClintock et al., 2012; Coplen and Cuneo, 2015). Other studies discuss the importance of collaboration, and of engaging members in planning and implementing projects (Schiff, 2008; McCartan and Palermo, 2017). It should be noted however that other articles and earlier FPC research has found that putting pressure on members to be involved in project implementation can also be a drawback (Schiff, 2007; Sieveking, 2019). This occurs when members might have limited time or capacity to take on that work. Several studies identified the importance of both internal (within the FPC) and external education and awareness raising about projects (Clancy et al., 2008; Schiff, 2008; Schiff and Brunger, 2013; Walsh et al., 2015; Baldy and Kruse, 2019; Sieveking, 2019). Internal learning can help to build excitement and buy-in around projects while external education can build more widespread community support and bring additional resources to projects. Some research also suggests the importance of focusing on community needs (Walsh et al., 2015), having priorities that are flexible according to opportunities, financial or otherwise (Schiff and Brunger, 2013), and looking for "quick wins" that can help to build confidence in the FPC. Finally, Schiff and Brunger (2013) note that celebrating success is important for building and maintaining morale and support for the FPC.

Gaps and Future Research Directions

Our review of the literature on FPCs also considered the directions for future research suggested in this literature. Four themes emerged from this analysis: (1) Methodological gaps; (2) Evaluation needs; (3) Impact of FPC activities; (4) FPCs' role in democratic decision making.

Methodological Gaps

A significant set of gaps that we identified was related to the methods employed in the studies of FPCs. Almost all the studies of FPCs (21 articles) used a case study approach, with primarily qualitative (interviews, focus groups, document review) methods. There were only two studies (Scherb et al., 2012; Bassarab et al., 2019) that used quantitative methods. Those studies surveyed FPCs at a national level and used descriptive statistics to analyze data related to policy activities, policy priorities, and the influence of organizational structure and membership on policy work.

While qualitative and case study approaches yield important and in-depth information, we suggest that there is a need for more diverse methods and greater application of quantitative, multi-site, and mixed methods in the study of FPCs. There is a particular lack of the application of quantitative methods to add to the evaluation and in-depth understanding of single FPCs at a local level. Since much FPC research has focused on case study approaches, there may be a need for a more standardized and generic framework through which to describe the characteristics and activities of individual FPCs. Such approaches might add significantly to answering some of the outstanding questions related to FPCs as described below such as those related to strategic evaluation and impact of FPC activities. Multisite comparative, longitudinal, and quantitative approaches would be well suited to linking different aspects of organizational functioning with success/failure of FPCs. Social network analysis might also be a valuable methodological tool to consider for investigations related to FPCs membership, partnerships, and related impacts (Levkoe et al., 2021).

Another important consideration in future evaluation of FPC literature may be a consideration of the theoretical orientations employed by researchers in the formulation of research questions and methodologies. Future examination of the FPC literature might investigate theoretical frameworks through which FPCs are examined. It may also be important for further empirical studies on FPCs to examine these frameworks and discuss explicit orientation of their research within existing theory on FPCs.

There are also significant geographic gaps in the study of FPCs, with most research focused on FPCs in the U.S. There

is little research on FPCs in other countries such as Canada, Australia, the U.K. other European countries, and in the Global South. Some of the articles that we reviewed noted this gap and suggested a need for more examination of FPCs in other countries (Baldy and Kruse, 2019). We also suggest a need for more research that can implement a geographical approach to understanding FPCs. This could include research which examines the experiences of FPCs within and between countries in different types of geographies and geo-political contexts, for example, rural vs. urban, local vs. regional levels, and across different national contexts.

Strategic Evaluation

An additional and related methodological gap is the lack of strategic formative and program evaluations conducted on/with FPCs. When the FPC movement was in its infancy, such evaluations were seen as a potential threat to their ongoing growth and the establishment of new FPCs (Schiff, 2007). Now that many FPCs are well established and widespread, we suggest that researchers and FPCs should consider regular, formal program evaluations (of FPC structure and activities) to support continuous improvement. This may help to further future research directions identified in several of the articles that we reviewed. Many authors called for systematic evaluations of FPCs' influence on policy, other impacts on local food systems, and the relationship between these efforts and the organizational dimensions. There were also articles that called for changes to governance structures to allow for greater equity and diversity in FPC membership, though there were not suggestions on how to achieve this. We suggest that more research may be needed on governance structures that are successful in supporting diverse councils and addressing / dismantling racism in the food system. Implementing regular evaluations might also prevent many of the issues (even dissolution) of FPCs that were described in the literature by providing FPCs with information on what is working, and what could be changed to improve their functioning. Such evaluations should look to program evaluation methodology (Newcomer et al., 2015) and incorporate both quantitative and qualitative approaches to assessing challenges, successes, and opportunities. Such work may in fact add further legitimacy and demonstrate the importance of FPCs in supporting the move toward healthy, sustainable and equitable food systems.

Impact of FPC Activities

Many articles suggested a need more research on and documentation of the impact of FPC activities (e.g., are FPCs achieving goals for food systems change?). This could apply broadly to any activities that FPCs are engaged with–as McCartan and Palermo (2017) suggest, there is a need to understand the extent to which FPCs influence local food systems. This will contribute to a greater understanding of work being undertaken within local food systems, which may lead to a greater proliferation of FPCs and create meaningful change within the broader food system.

Several articles focused specifically on policy work. There were several suggestions for further analysis of FPCs' success in influencing policy and policy-making processes. This was accompanied by an interest in understanding whether FPC policy activities result in food systems change, as Bassarab et al. (2019) described:

> Since our analysis did not explore FPC policy out-comes, we are left with further questions around the goal of food democracy—that is, if and how FPC policy outcomes yield transformative food systems change" (p. 40).

FPCs and Democratic Processes

Several articles paid particular attention to FPCs as a form of democratic institution—representing a new avenue for democratic decision—making about food issues. This was discussed in the context of the FPCs inclusion of state and non–state actors in decision–and policy–making processes (Baldy and Kruse, 2019). It was also discussed in terms of FPCs engagement with deliberative processes–with a few authors suggesting direct links to theories of deliberative democracy and the emergent theory of food democracy (Sieveking, 2019). These authors suggested a need for further definition of the concept of "food democracy" as well as clearer links between this theory and the concept of deliberative democracy (e.g., a demonstration of the ways in which FPCs embody and contribute to deliberative democratic processes).

These calls for more research documenting FPCs' connections to food democracy and deliberative democracy also led to suggestions for further investigation on the importance of citizen engagement in FPC activities. FPCs were described in many instances as a tool for empowering citizens and increasing citizen engagement—however, many authors pointed to a need for more research on the importance and impact of citizen involvement (Baldy and Kruse, 2019; Bassarab et al., 2019; Sieveking, 2019).

These suggestions also tied into the need for further investigation into diversity in council membership. Boden and Hoover (2018) offer the suggestion that further attention is needed to diversity in council membership—particularly in order to address race, class, and other equity issues related to food systems and food democracy. Our analysis also found that there was little connection to a broader literature (and social movements) on racism and dismantling racism, White privilege, and privilege of the Global North in food systems (Schiff and Levkoe, 2014; Holt-Giménez, 2015). We suggest that analyzing FPCs against the backdrop of these movements may provide additional insights into the activities, successes, and challenges of FPCs.

CONCLUSIONS

In the past two decades, the number of FPCs has grown dramatically. Alongside this growth, there has been increasing academic interest in FPCs–what they do, how they do it, and what challenges and successes they encounter in their work. Given the rapid growth in FPC numbers and academic interest, our scoping review aimed to systematically analyze this growing body of literature to identify future directions for research. As such it sought to address the questions: What are the major themes in

research on FPCs in the past two decades (i.e., published between 1999 and 2019)? What methods have been employed in the study of FPCs in the past two decades? What gaps and directions for further research are suggested by the research on FPCs?

We identified four main themes (and several sub–themes) in the FPC research in the past two decades: (1) Activities of FPCs; (2) Organizational dimensions; (3) Challenges; and, (4) Facilitators. We also noted a significant sub-theme related to equity and diversity, race and class representation in FPCs. These themes frame a growing body of knowledge on FPCs which may aid these organizations, those interested in approaches to food systems change, and those interested in cross-sectoral collaborative approaches to food systems and sustainability governance. We also identified four key gaps described in the current body of literature which might provide direction for future research on FPCs. These include needs to: broaden methodological approaches, support strategic evaluation, evaluate the impact of FPC activities and document links to deliberative and food democracy. This evaluation may provide direction for ongoing impact in FPC research and evaluation.

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The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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The impacts of sustainable industrial revolution (IR) on the profitability of Hungarian food companies

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There is growing literature on the concept and objectives of corporate sustainability (CS), but less attention is paid to a comprehensive approach to economic, social and ecological factors and industrial revolution (IR). Specifically, this paper contributes to the academic debate on the relationship between CS and IR in agri-food economics using firm-level data. The study used quantitative pathway models to measure the extent to which technologies affect the development of social, ecological and economic factors in Hungarian food manufacturing companies. The research was conducted using partial least squares path modeling (PLS-PM) and categorical principal component analysis (CATPCA) to calculate the direct and indirect effects of IR technologies on profitability outcomes. This study has shown that the livable and sustainable path hypotheses can be confirmed. Consequently, the food manufacturing businesses whose managers think along the viable and sustainable lines tend to be more profitable. However, the ecological and economic factors strengthened the positive impact of the social dimension on food corporate profitability. Decision-makers should not wait for a pie in the sky for emerging sustainability but consciously embrace the CS issues that only provide a direction for the changes.

KEYWORDS

sustainable development, industrial revolution (IR), path models (PLS-PM), agri-food analysis, financial performance

Introduction

In recent years, there has been an increasing interest in Industrial Revolutions (IR), for instance, 4IR as a technological revolution aimed at achieving greater efficiency and increased productivity in the global marketplace (Lee and Trimi, 2018), initially as a high-tech strategy of the German government (Cugno et al., 2021). 5IR complements the existing Industry 4.0 paradigm by using research and innovation to drive the transition

to, for example, sustainable, human-centered and resilient industries (Breque et al., 2021).From a conceptual perspective, Breque et al. (2021) defined 5IR as something that "… recognizes the power of industry to achieve social goals beyond job creation and growth, and to become a resilient provider of prosperity by respecting the limits of the planet and putting the wellbeing of industrial workers at the heart of the production process." 5IR technologies serve people and societies, which means that humans are not machined; the technology used in manufacturing adapts to the needs and diversity of industrial workers (Lu et al., 2021).

The Covid-19 pandemic and current geopolitical shifts have highlighted the need to rethink existing types of drivers and barriers, e.g., working conditions, compliance with legislation and adaptation to sustainable strategies to overcome the challenges in the food industries (Kamble et al., 2018). The agri-food sector, more than any other sector, is characterized by a high dependence on natural resources and has a significant impact on the ecosystem, and its companies are highly exposed to the expectations of civil society and policies (Hartmann, 2011). These policies have also amplified the vulnerabilities of food manufacturing enterprises, i.e., fragile strategic supply chains and the need to find innovations to address resilience (Ibn-Mohammed et al., 2021).

Corporate Sustainability (CS) has become a vital component of the complementary causality between business performance, economic, environmental and social dimensions (Tomšič et al., 2015). While the linkage between CS and its driving forces and barriers has been investigated (Bojnec and Tomšič, 2020), there is still a significant research gap when considering the relationship between enterprise performance and sustainability in association with the mediating role of IR. Although there are existing research frameworks and findings on sustainable IR (Młody and Weinert, 2020), most studies explored the concept (Ejsmont et al., 2020). Specifically, this paper contributes to the academic debate on the relationship between CS and IR in agri-food economics using micro- and firm-level data.

The major objective of this study was to investigate to the theoretical framework and modelling of CS and IR interactions by analyzing the impact of sustainable technology implementation on profitability business performance. This study follows a cross-country-specific design in the case of Hungarian food manufacturing companies. It uses an in-depth CATPCA and a PLS-PM approach to analyze the direct and indirect impacts of the IR technologies affect the development of social, ecological and economic factors on corporate performance. This study aims to understand the growing area of research better by exploring the interactions between IR and corporate incomes from a sustainable perspective. Data for this study were collected using 2020-2021 surveys.

The study is structured as follows. This paper begins by reviewing the literature on sustainable concepts and their linkage to IR. It will then go on to designing the data materials. The third section concerns the methodology used for answering the hypotheses described. The fourth section presents the findings of the research. Finally, the conclusion gives a summary and limitations of the findings.

Literature overview

A large and growing body of literature has investigated the concept of Sustainable Development (SD) (Basiago, 1995; Pope et al., 2004; Schoolman et al., 2011; Boyer et al., 2016). Much of the current literature pays particular attention to encompassing economic, social, and ecological (environmental) factors and goals. This threefold approach places sustainability at their intersection (Giddings et al., 2002). According to McKenzie (2004), social development depends on economic and ecological development, and social sustainability is an aspect of development that is on a par with environmental or economic sustainability. However, the three-pillars concept of sustainability is far from being the dominant interpretation in the literature, and its precise meaning has been disputed.

Brown et al. (1987) conducted preliminary work on SD and identified the three contexts in which the concept of sustainability provides a paradigmatic framework. The social perspective focuses on the satisfaction of basic human needs, the ecological on the continued productivity of ecosystems and the protection of scarce resources and biodiversity, and the economic constraints imposed by a sustainable society on economic growth (Eisenmenger et al., 2020). The institutionalizing of SD continued with the "1992 Rio Process". Central to this was the publication of the 'Rio Declaration' consisting of 27 principles intended to guide future agendas (Purvis et al., 2019). Following the 2012 World Summit, an Open Working Group was established to develop the UN's Sustainable Development Goals (SDGs) to integrate sustainable development's economic, social and ecological dimensions (United Nations, 2015). More specifically, SDG 9 focuses on promoting sustainable industrialization and encouraging innovation.

IR technologies and their role in sustainability can differ significantly, especially in the context of different industries. In particular, IR is the challenge of moving from conventional technology to smart systems without limiting the sustainability of the industrial economy by addressing all three dimensions and their interconnections in a balanced way (Rosati and Faria, 2019). The sustainable IR transition for small and med-size enterprises (SMEs) can start with digitizing certain operations to support lean manufacturing systems (Ghobakhloo and Fathi, 2020). The green supply chain framework driven by IR technologies directly influences consumer behavior, working processes and transport in sustainable logistics (Sun et al., 2022). IR uses new technologies such as 3D printing, robotics and automated guided vehicles to achieve the optimal solution under

different production and sales constraints to maximize corporate profits (Tsai and Lu, 2018). Together, these studies provide insights into the importance of IR and the digitization of the entire value chain (Nhamo et al., 2020).

The evidence presented by Chinese SMEs in the field of precision agriculture confirms that the use of IR technologies has benefits across the three sustainable dimensions (Müller and Voigt, 2018). However, there are different views in the literature on long-term environmental sustainability. The ecological (ECOL) aspect requires agri-food companies to produce quality products and services at the lowest cost and to package them in reusable materials to avoid polluting nature (Coelho et al., 2020). Food companies, logistics providers, retailers and consumers must work together to achieve sustainable solutions to reduce the costs of production, packaging and transport to ensure environmental advances (Bradu et al., 2022). Proper packaging facilitates transportation, and customers will be willing to pay a high price for goods and services that support a green environment, resulting in fewer greenhouse gas emissions (GHGs) and a positive impact on reducing global warming and supporting the expected positive impacts through financial initiatives (Bonilla et al., 2018). The ecological nature of the green technologies, combined with the IR phases, leads to an increase in energy efficiency and a reduction in production waste, but an increase in electrical waste and energy consumption (Yu et al., 2022).

One of the fiercest debates has been about the impact of IR technologies on self-employment. IR is closely related to social (SOC) sustainability because firms offer better working conditions for workers, health and safety are prioritized (Adamik and Nowicki, 2018), and workers can even work from home, ensuring flexibility and reducing pollution (Ahn and Kim, 2017). Others argue that it means greater efficiency in energy use, as workers spend less time at the company, resulting in lower cost production (Jankalová and Jankal, 2018). The argument against home working is that it simply means passing on utility costs to workers' households (Barbieri et al., 2021). Moreover, self-employment can reduce worker productivity and motivation (Patanjali and Bhatta, 2022). New technologies have a negative impact on the labor market because they can lead to job losses, thereby reducing demand, and new technologies can completely undermine economic development (Sachs et al., 2015). Conversely, new technologies make it easier to keep jobs, and employment is expected to overgrow among companies in related food industries. Acemoglu and Restrepo (2018) stated that IR tools are not eliminating but redefining the workplace, and machines are taking over basic daily tasks, allowing workers to focus on activities that require creativity. Technological innovation has a positive impact not only on employment but also on efficient production methods. Indeed, if green products are produced at lower costs, there will be greater demand for new green jobs (van Vuuren et al., 2017).

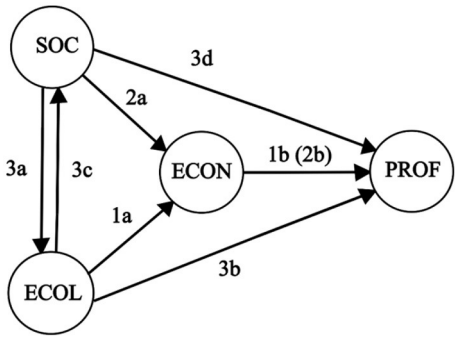

FIGURE 1
Proposed conceptual framework. ECON: economic, ECOL: ecological, SOC: social and PROF: profitability. The numbers (e.g., 1a, 1b, 2a, 2b, 3a, 3b, 3c and 3d) represent the different SD paths based on McKenzie (2004).

The economic (ECON) context that should be considered for integrating IR with SD is that companies must conserve available resources to maximize profits and ensure adequate returns for stakeholders. The essence of economic sustainability means that companies need to focus not only on short-term but also on long-term goals so that customers are satisfied with their current purchases (Cox and Pezzullo, 2017). Digital technology adopters expect to make scarce material and energy savings, increase capacity utilization and bring new products to market faster to meet changing demand, thereby creating the essential capabilities needed to exploit the potential of 5IR (Burmeister et al., 2016). The use of big data has supported managers in studying internal and external factors and failures to impact productivity, efficiency and competitiveness by improving business processes (Shahid and Sheikh, 2021). While companies are investing in or planning to invest in, for example, big data, computer modeling and simulations are optimistic about their prospects for returns (Anwar et al., 2018).

The paradoxical nature of corporate sustainability (CS) is the need to simultaneously consider social, ecological and commercial aspects (Luo et al., 2020). The essential principle of CS is that it takes a complex approach to economic development, social needs and ecological requirements into account (Hahn et al., 2018). The primary research objective of the analysis is to find explanations for how each sustainable development path can contribute to higher corporate profitability (PROF), either indirectly or directly, through IR technologies in the case of food manufacturing companies. Typical corporate performance indicators include profit margin and return, sales and annual growth ratios (Pache and Santos, 2013). Figure 1 shows the proposed conceptual framework.

The "livable path" is one in which the ecological footprint, i.e., the environmental burden, is kept low in line with

future economic development and environmentally responsible companies tend to be more profitable (Wu et al., 2022). However, traditional economic approaches underestimate the risks from climate change and overestimate the costs of the low-carbon transition, as they do not consider the cumulative gains from path-dependent innovations (Ekins and Zenghelis, 2021).

H1: The sustainable economic factor mediates the impact of the ecological dimension on food corporate profitability (livable path).

The "fair way", where decent work ensures economic growth, means overconsumption of resources and the depletion of the future. Researchers have generally used synergistic increases in economic and social performance to represent the success of sustainability. However, economic and social aspirations can be detrimental to each other in the short term (Margolis and Walsh, 2003), and impacts on social or environmental performance are assumed to occur only after a long time (Miron-Spektor et al., 2018).

H2: The sustainable economic factor mediates the impact of the social dimension on food corporate profitability (fair path).

The 'tolerable path' is one in which accessible food and clean water are accompanied by renewable energy affordable for the entire society (McKenzie, 2004). de Amorim et al. (2018) pointed out that water, energy and food are interdependent and essential resources that require sustainable, integrated and intelligent management. The nexus is increasingly seen as a promising approach to address the leadership gaps to the manufacturers in addressing complex and interconnected resource management challenges for enterprises (Pahl-Wostl, 2019).

H3a: The sustainable ecological factor mediates the impact of the social dimension on profitability. Thus, H3b: The social factor mediates the impact of the ecological dimension on corporate profits (tolerable path).

The common area of the three factors (Sustainable path) must be consciously addressed to change the status quo (Hahn et al., 2018). A paradoxical approach to CS explicitly acknowledges the tensions between different desirable but sometimes conflicting sustainability goals (Hahn and Aragón-Correa, 2015). This pragmatic approach allows corporate decision-makers to balance the simultaneous pursuit of competing goals (Schad et al., 2016). Furthermore, it allows for business contributions to sustainable development, as environmental and social considerations are not seen as goals but merely as a means to maximize corporate profits (Schreck, 2011). In this case, firms are making financial revenue and taking environmental and social concerns into account.

TABLE 1 Summary of sustainable development paths related to IR and the hypotheses.

Paths	Description	Hypotheses
Livable	ECOL->ECON->PROF (1a and 1b)	H1
Fair	SOC->ECON->PROF (2a and 2b)	H2
Tolerable	SOC->ECOL->PROF (3a and 3b)	H3a
	ECOL->SOC->PROF (3c and 3d)	H3b
Sustainable	SOC->ECOL->ECON->PROF (3a, 1a and 1b)	H4a
	ECOL->SOC->ECON->PROF (3c, 2a and 2b)	H4b

Source: Authors' compilation.

H4a: The sustainable ecological and economic factors mediate the impact of the social dimension on food corporate returns. Besides, H4b: The social and economic factors mediate the impact of the ecological dimension on food corporate profitability (sustainable path).

Table 1 summarises the SD pathways associated with IR and corporate profitability, and formulates the following hypotheses based on the indirect (mediation) effects:

Materials and methods

This research was carried out using quantitative pathway models, and a primary questionnaire was used as a research tool to investigate Hungarian food manufacturing businesses following the COVID-19 outbreak. The investigation was conducted typically through online professional events, telephone, and face-to-face inquiries. The surveys were conducted at the beginning of 2020, while the data refer to a two-year period spanning from 2020 to 2021. The composition and structure of the questions were based on the literature collected and on preliminary consultations with the CEOs of the 5 selected food companies and their suggestions. A comprehensive literature review of the variable operationalization was conducted based on ecological (Tang et al., 2016; Bonilla et al., 2018; Gielen et al., 2019), social (Sachs et al., 2015; Jankalová and Jankal, 2018), economic (Westerman et al., 2012; Cox and Pezzullo, 2017) and profitability (Bughin, 2016) dimensions. Some dimensions and items were piloted and feedback, grammatical errors and misunderstandings were corrected. The surveys were then collected with the help of senior and middle managers and IT specialists.

Data design

A Voluntary Questionnaire Was Developed to Measure the Extent to Which IR Technologies Affect the Development of Social, Ecological and Economic Factors in Hungarian Food

TABLE 2 Sources and abbreviations of sustainable development items and profitability indicators.

Factors	Descriptions	Abbreviations	Source
Ecological(ECOL)	Equipment to reduce air pollution	ECOL1	Tang et al. (2016), Bonilla et al. (2018), Gielen et al. (2019)
	Renewable energy use (solar panels)	ECOL2	
	Reducing energy costs	ECOL3	
	Rapidly biodegradable materials (packaging)	ECOL4	
	Increased recycling of products	ECOL5	
	Increase in electronic data storage	ECOL6	
	Promoting a green environment	ECOL7	
	Recycling reduces deforestation	ECOL8	
Social(SOC)	Creation of new jobs	SOC1	Sachs et al. (2015), Jankalová and Jankal (2018)
	Global poverty reduction	SOC2	
	Robots and machines support workers	SOC3	
	Robots displace manual labor	SOC4	
	New types of competencies needed	SOC5	
	Reducing unemployment	SOC6	
	Reducing gender inequality	SOC7	
	Increase in homeworking	SOC8	
Economic(ECON))	Reduction in production costs	ECON1	Westerman et al. (2012), Cox and Pezzullo (2017)
	Influencing legal regulations	ECON2	
	Increasing productivity	ECON3	
	Producing quality products	ECON4	
	Investment support, tax breaks	ECON5	
	Increasing economic disparities	ECON6	
	It makes a business more competitive	ECON7	
	Reduce issues and increase efficiency	ECON8	
Profitability(PROF)	Return on Assets	ROA	Bughin (2016)
	Return on Equity	ROE	
	Return on Sales	ROS	
	Return on Investment	ROI	

Source: Authors' compilation.

Manufacturing Companies. A Total of 24 Elements, Each Containing eight Selected Environmental, Economic, and Social Aspects, Are Measured on an Ordinal Scale. Each Item Was Measured on a Five-Point Likert Scale, Where 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree. For the Corporate Return (Profitability) Indicators Were Transformed as Follows: Below 0, 0–5, 5–15, 15–30 and Above 30%. The list and sources of items are shown in Table 2.

Hungarian food industry

Based on KSH (2020) report, the industry contributed 24.3% of the gross value added to the economy in Hungary. It ranks fourth in terms of manufacturing industry share in the EU behind Slovenia (23%), the Czech Republic (24%), and Ireland (38%), making it one of the most industrialized EU countries. Manufacturing, which accounts for around 96 per cent of total production, experienced a 6.0% decline. However, transportation decreased by 11.2%, but less for food, drink, and tobacco (up 0.8 and 1.0%). In 2020, production was growing steadily for seven years, and the pandemic has only partially impacted certain areas. The most significant shortfall was caused by the disappearance of demand generated by tourism and hospitality. Domestic sales, which account for 59% of the total, remained unchanged from the previous year, while export, which account for 41% of the total, rose by 3.4%. The negative impact of the epidemic was most pronounced in meat processing, preserving and preparations, which accounts for almost a quarter of production, and the beverages, which fall by almost the same amount (5.8 and 5.9%). In the poultry and pig sectors, production was also negatively affected by avian influenza and African swine fever. In addition, the production of bakery products, pasta and other food products (such as confectionery) also fell (by 3.4% and 2.3%).

In 2020, there were only 1157 (TEÁOR-10) food companies. However, most did not respond to the questions, citing confidential company information. After the survey, 276 respondents completed the questionnaire, which was reduced to 259 during the data cleaning process, with no missing data or registry errors. In order to have sufficient data for the analysis, 223 or more measurements are needed to have a confidence level of 95% that the real value is within ±5.9% of the surveyed value (Kirby et al., 2002). The sample size is sufficient for further analysis on partial least squares, as at least 200 individuals are needed (Pérez and Esposito, 2010).

Most responses came from meat processing and canning (97), followed by bakery and pasta (60) and then from fruit and vegetable processing and preservation companies (46). The fewest responses came from companies involved in fish processing and preservation, as well as in the production of vegetable and animal oil, since very few manufacturers in Hungary carry out their main activities in this field. 44% of the food companies are aware of and implement IR tools. While 54% of respondents do not intend to make substantial investments, and they hope to maintain the status quo by adjusting to market demands. Keeping up with new developments and inventions is critical for the group of inventors, which accounts for 38.9% of those active in the Hungarian market for more than 5–10 years. Most laggards are new businesses that lack the resources to grow to the appropriate size (Erdei et al., 2021).

Applied methods

The research was conducted using partial least squares path modeling (PLS-PM) and categorical principal component analysis (CATPCA). CATPCA was used to highlight the hypothetical model structure using the principals' function of the gifi package in R 3.4.4 software (R Core Team, 2022; RStudio Team, 2022). The primary aim of the analysis was to combine all the elements (items) in the same block into a single common principal component and then calculate the correlation between each principal component. CATPCA involves a technique called optimal scaling, whereby numerical values are assigned to each category and applied for further evaluation. Different levels of measurement (e.g., nominal and ordinal scales) can be used in the assessment without restriction, and values are assigned using an iterative method called Alternating Least Squares (Linting et al., 2007). Kaiser Meier Oldkin's (KMO) measure of sampling adequacy was also used to assess the reliability of each principal component by the KMO function of the "psych" package of the R 3.4.4 software (Kaiser and Rice, 1974).

The partial least squares path model (PLS-PM) was used in the next step to fit the hypotheses. In regression models, multicollinearity is often a problem, removing highly correlated variables and losing information (Chin, 1998). Despite multicollinearity, the PLS technique can detect a system of structured mediating effects with multiple manifest variables (Tenenhaus et al., 2005). Ramli et al. (2018) stated that the PLS approach may be a better alternative to clustering methods, especially in the case of many categorical predictors and multicollinearity.

In this research, a reflective modeling approach was used for latent constructs like ecological, economic and social factors and a formative modeling approach was used for the profitability indicators. Reflective modeling means that the latent construct exists independently of the measures, the causality runs from the construct to the indicators, and the elements do not substantially change the content validity of the construct, whereas in formative models the indicators are combinations that form the composite latent variable. (Sarstedt et al., 2016). In order to verify the modeling approach, principal component analysis was used for testing the formative model and factor analysis was used for testing the reflective model. Principal component analysis and factor analysis were performed using the "principals" and "fa" functions of the "psych" package in R 3.4.4 software (R Core Team, 2022; RStudio Team, 2022).

Cronbach's alpha can be used for checking the internal consistency of indicators for each latent variable (Alpha $>$ 0.7) (Cronbach, 1951). The bootstrapping technique proposed by Chin (1998) was used to validate the model with 500 replicates. The model's overall fit was measured using the Goodness of Fit (GoF) test, where a GoF above 0.6 indicates an excellent model fit (Tenenhaus et al., 2005). Dillon Goldstein's rho indexes tested the blocks' composite reliability (CR). The identified dimensions should have a value above the recommended 0.7, and factor loadings should exceed 0.6–0.7 (Hair et al., 2016). R^2 values were calculated to assess the quality of the structural model, where values of 0.02, 0.15, and 0.35 are classified as small, medium or large effects (Cohen, 1988). The Fornell and Larcker criterion was used to check the discriminant power of the model. In addition, the average variance extracted (AVE $>$ 0.5) was used to assess discriminant validity in the study (Fornell and Larcker, 1981). Model fitting and estimates were performed using the'plspm' package in R 3.4.4 (Kaiser and Rice, 1974).

Results

As a first step, four blocks were examined, i.e., ecological, social, economic and business profitability performance (Table 3). The Cronbach's Alpha Value of the Scale Items Is High and Acceptable, Especially for the Ecological Factor (0.930). The Descriptive Statistics and the Cross and Factor Loadings Are Examined After the Exclusion. The two Highest Values per Block Were Obtained for ECOL5 and ECOL6; SOC4 and SOC5; ECON4 and ECON7. Only Those With a Value of Around 0.7 or More Were Kept. Therefore, the Final Path Model Excluded ECOL3, SOC1 SOC7 and ROI. After Exclusion, Almost all Other Loadings in the Final Model Improved. The

TABLE 3 Descriptive statistics, loadings, and composite reliability of the items.

Latent variable (Cronbach's alpha)	Manifest variables	Mean/median	Factor loading before exclusion*	Factor loading after exclusion*	Cross loadings with PROF
Ecological (ECOL)					
(0.938)	ECOL1	3.75/4	0.792	0.791	0.459
	ECOL2	3.85/4	0.852	0.859	0.521
	ECOL3	3.42/4	0.622	-	
	ECOL4	3.91/4	0.976	0.977	0.638
	ECOL5	3.91/4	0.975	0.977	0.640
	ECOL6	3.94/5	0.967	0.969	0.645
	ECOL7	3.93/4	0.939	0.943	0.581
	ECOL8	3.92/4	0.938	0.943	0.582
Social (SOC)					
(0.813)	SOC1	3.57/4	0.686	-	
	SOC2	2.71/3	0.707	0.733	0.408
	SOC3	2.90/3	0.749	0.780	0.359
	SOC4	3.14/3	0.813	0.833	0.416
	SOC5	3.91/4	0.827	0.815	0.580
	SOC6	3.07/3	0.700	0.738	0.329
	SOC7	2.64/2	0.517	-	
	SOC8	3.57/4	0.715	0.724	0.356
Economic (ECON)					
(0.789)	ECON1	3.76/4	0.717	0.717	0.541
	ECON2	2.88/3	0.700	0.700	0.368
	ECON3	3.81/4	0.786	0.783	0.514
	ECON4	4.12/4	0.871	0.871	0.555
	ECON5	3.21/3	0.744	0.744	0.419
	ECON6	2.92/3	0.771	0.774	0.462
	ECON7	4.08/4	0.878	0.878	0.609
	ECON8	4.00/4	0.773	0.773	0.525
Profitability (PROF)					
(0.789)	ROA	2.99/3	0.879	0.875	0.875
	ROE	3.05/3	0.801	0.800	0.800
	ROS	3.19/3	0.892	0.917	0.917
	ROI	2.98/3	0.780	-	

*ECOL3, SOC1 and SOC7 should be omitted from the final model due to low factor loadings before exclusion, but PROF4 should be omitted from the final model after exclusion of ECOL3, SOC1, SOC7 due to low factor loading (0.340).
Source: Authors' compilation.

Ecological Dimension (ECOL) Is Best Described by "Recycling" and "Packaging" Items (0.977). The Latent Social Variable (SOC) Is Mainly Correlated With "Robots Displace Manual Labor" (0.833), While the Economic Variable (ECON) Is Best Correlated With "Producing Quality Products" (0.871) and "Competitiveness" (0.878). Cross Loadings Are Lower for all Items Compared to PROF.

In the Subsequent Analysis Stage, a Preliminary CATPCA Analysis Was Carried out on all the Items in the Same Block to Reduce the Dataset and Generate Latent Variables. Table 4 Presents the Reliability Measures and Pearson Correlations Between the Principal Components. The Lower Triangular Matrix Shows the Correlation Coefficients, While the Upper one Shows the Corresponding *p*-Values in Parentheses. On the one Hand, the Total Measure of Sampling Adequacy (MSA) Values Measured by KMOs Were Higher Than the Required Value of 0.7. On the Other Hand, the Explained Variances (%) Were Above the Required Level of 50 %. The Best Correlation Between ECOL and ECON (0.721) Was Found, but ECOL Was Also Strongly Correlated With the SOC (0.613). Regarding the Correlation With PROF, the Best Relationship Was Found Between ECON and PROF (0.374).

Based on the results of the CATPCA analysis and the literature review, the following path model could be constructed (see Figure 2). Figure 2 shows the parameter estimates of the models.

A bootstrap simulation was used to validate the parameters estimated by the mean and standard errors of the path coefficients. Only path coefficients with a standard error of 50% or less of the mean were considered statistically significant. Not all relationships were significant, as formerly assumed based on the CATPCA results. The PLS-PM model considered the direct relationship between ECON and PROF, and the path coefficients of ECOL, SOC to PROF irrelevant based on the *p*-values, pseudo t-statistics, and standard errors. The sustainable economic dimension positively impacts on corporate business returns. In other words, the effects of increased IR factors tend to be resulted in more profitable food manufacturing companies.

TABLE 4 Squared correlations of CATPCA components.

Block	ECOL	SOC	ECON	PROF
ECOL	-	(<0.001)	(<0.001)	(<0.001)
SOC	0.613	-	(<0.001)	(<0.001)
ECON	0.721	0.516	-	(<0.001)
PROF	0.350	0.279	0.374	-
MSA*	0.860	0.824	0.761	0.878
ExplainedVariance (%)	79.8	52.8	61.85	71.18

*MSA, measure of sampling adequacy (Kaiser-Meier-Oldkin value).
Source: Authors' compilation.

Likewise, the clearest direct relationship is found between SOC and ECOL ($B = 0.822$; SE = 0.070; t = 11.74; p < 0.001), and reciprocal ($B = 0.816$; SE = 0.073; t = 11.18; p < 0.001). However, ECOL will also be strongly directly related to ECON ($B = 0.806$; SE = 0.111; t = 7.26; p < 0.001), which has a positive impact on business profitability ($B = 0.381$; SE = 0.226; $t = 1.69$; $p = 0.047$).

The overall model showed an excellent global fit, and the internal and external model quality was excellent, as the GoF was 0.649. The main diagonal of the numbered columns of the matrix is shown in Table 5. The AVE values are in italics, which express the percentage of the variance of the items explained by a given latent variable (LV). The squared Pearson correlation coefficients are given below the main diagonal. In contrast, the correlation coefficients' significances (i.e., *p*-values in parentheses) are shown above the main diagonal. It is evident from the AVE values that each LV explained at least 50% of the variance of the items on average. Discriminant validity was also satisfactory, as the correlations for each LV were lower than the AVE values. The proportion of variance explained by the coefficient of determination (R^2) in these regressions was significant. R^2 values were large, the Dillon-Goldstein rho was above 0.7, and the AVE (Average Variance Extracted) values were also acceptable and more significant than 0.5. The last two columns of Table 5 justified the modeling approach. The reflective model was tested throughout a factor analysis, while a principal component analysis tested the formative one. The explained variances of creating a single factor or component were not significantly different except in the Profitability latent variable case. On the other hand, when the model was run with

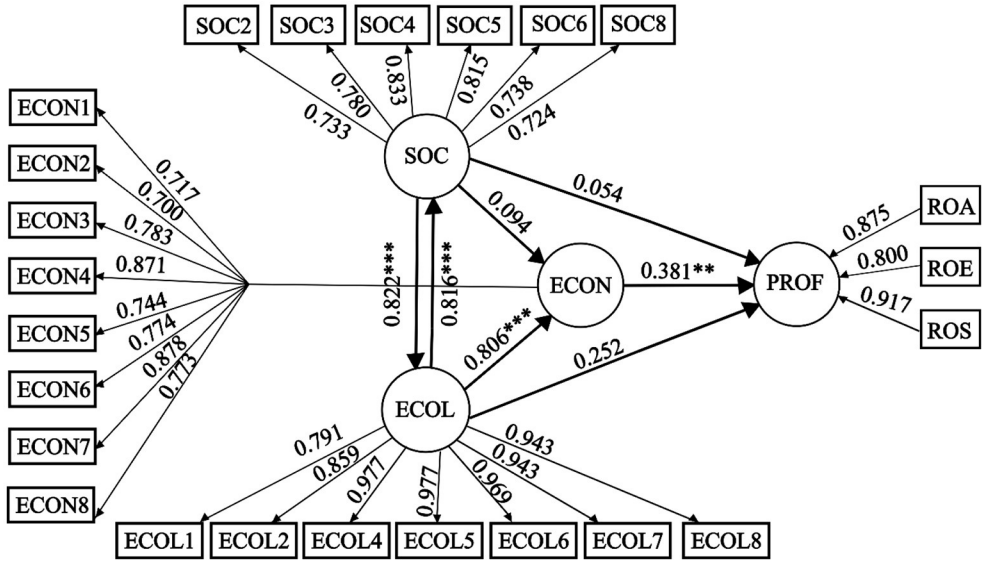

FIGURE 2
The final path model and coefficient estimates. **: $p < 0.05$.***: $p < 0.001$. *Source*: Authors' compilation.

TABLE 5 Reliability measures of PLS-PM components.

Latent variable	ECOL	SOC	ECON	PROF	R^2	DG rho*	Reflective model test** (variance%)	Formative model test*** (variance%)
ECOL	**0.856**	(<0.001)	(<0.001)	(<0.001)	0.676	0.950	64	68
SOC	0.666	**0.598**	(<0.001)	(<0.001)	0.666	0.867	37	43
ECON	0.779	0.565	**0.611**	(<0.001)	0.782	0.844	35	41
PROF	0.399	0.298	0.415	**0.591**	0.434	-	49	61

*DG rho: Dillon–Goldstein's rho is used to measure the composite reliability. **Proportion of variance from a factor analysis using one factor; ***Proportion of variance from a simple principal component analysis using one component.
Source: Authors' compilation. The primary diagonal of the matrix's numbered columns is highlighted in bold.

TABLE 6 Total, direct, and indirect effects of the path models.

Relationship	Direct path coefficient	Indirect path coefficient	Total effects	Std. error	t statistic	p value
SOC->ECOL	0.822***		0.822***	0.070	11.743	<0.001
ECOL->SOC	0.816***		0.816***	0.073	11.178	<0.001
ECOL->ECON	0.806***	0.077	0.883***	0.075	11.773	<0.001
ECOL->PROF	0.252	0.754***	1.007***	0.170	5.924	<0.001
SOC->ECON	0.094	0.726***	0.820***	0.075	10.933	<0.001
SOC->PROF	0.054	0.557***	0.610***	0.135	4.519	<0.001
ECON->PROF	0.381**		0.381**	0.226	1.686	0.047

***$p < 0.001$; **$p < 0.05$. Std. errors were estimated using the bootstrap validation.
Source: Authors' compilation.

only formative relationships, the goodness and interpretability were decreased to a large extent.

The main advantage of PLS-PM is the ability to distinguish between direct, indirect and aggregate (total) effects on the outcome variable, i.e., corporate profitability (Table 6). Examining the direct and indirect relationships revealed that ECOL and SOC indirectly affect PROF, and the direct effects were insignificant. The strongest relationship of total effect was found between ECOL and ECON (total = 0.883; SE = 0.075; $t = 11.77$; $p < 0.001$). Among the factors influencing PROF, ECOL had the largest total effect (total = 1.007; SE = 0.170; $t = 5.92$; $p < 0.001$), followed by SOC (total = 0.610; SE = 0.135; $t = 4.52$; $p < 0.001$) and ECON (total = 0.381; SE = 0.226; $t = 1.69$; $p = 0.047$). Regarding percentages, ECOL has a 66% effect on profitability, while SOC and ECON have a 24% and 9% influence, respectively.

Table 7 shows that only hypotheses H1 and H4a are supported in order at the 5% significance level. Rucker et al. (1986) showed that the smaller the sample, the more appropriate it is to set a more stringent p-value. Only the livable path (ECOL-ECON) and a sustainable path (SOC-ECOL-ECON) significantly impacted corporate profitability (PROF). Consequently, the food producing businesses whose managers think along the viable and sustainable path tend to be more profitable. The livable path or indirect (mediating) effects of economic (ECON) factors strengthened the positive (0.307*** = 0.806 × 0.381) effect on profitability. Also, the latent economic variable fully mediates (strengthens) the ecological factor's (ECOL) effect on profitability (PROF). It plays an intermediate role in the positive relationship between the independent and dependent variables. H1 accepted. Thus, the sustainable path hypotheses focus on how the independent (sustainable IR specific) factors affect the dependent variable (profitability) through one or more potential intervening variables or mediators. Only the positive impact of social variables (SOC) on corporate profitability is fully mediated and strengthened by the ECOL and ECON IR dimensions (0.252 = 0.822*0.806*0.381). However, the direct effect of social factors on profitability is insignificant, whereas the indirect effect of SOC and PROF was substantial. H4a is accepted, and H4b should be rejected.

Discussion

The primary objective was to identify the direct and indirect impacts of sustainable dimensions, i.e., ecological, economic,

TABLE 7 Total, direct, and indirect effects of the path models related to SD and hypotheses.

Name	Paths	Coefficient	Std. Error	t statistic	p value	Hypotheses
Livable	ECOL-ECON-PROF	0.307**	0.157	1.952	0.026	H1 accepted
Fair	SOC-ECON-PROF	0.036	0.207	0.173	0.431	H2 rejected
Tolerable	SOC-ECOL-PROF	0.207	0.136	1.527	0.064	H3a rejected
	ECOL-SOC-PROF	0.044	0.079	0.558	0.289	H3b rejected
Sustainable	SOC-ECOL-ECON-PROF	0.252***	0.129	1.957	0.026	H4a accepted
	ECOL-SOC-ECON-PROF	0.029	0.138	0.211	0.417	H4b rejected

***$p < 0.001$; **$p < 0.05$. Std. errors were estimated using the bootstrap validation.
Source: Authors' compilation.

and social factors that can contribute to increased corporate profitability through IR technologies.

The study found that the economic IR dimension positively impacts corporate profitability. Another important finding was that ecological factors substantially effect on profitability, while social and economic factors have fewer impacts than environmental ones. Interestingly, in all cases of this study, only the livable path and one sustainable path significantly impacted food corporate profitability. In other words, food manufacturing businesses whose managers think along these lines tend to be more profitable. The economic factor positively mediates the impacts of the environmental dimension on corporate returns. Furthermore, the ecological and economic factors strengthened the positive impact of the social dimension on corporate profitability. In summary, the sustainable IR approach proposed in this analysis is an original and useful tool for the evaluation of food corporate performance in three dimensions: economic, social and environmental. However, with small sample size, caution must be applied, as the findings might not be transferable to entire industries.

There are several possible explanations for these results. The findings further support the idea of the circular economy that ensures an equal distribution of resources so that companies operate efficiently and effectively, the environment is preserved and is able to regenerate for the future (Jørgensen and Pedersen, 2018). Sustainability and ecological impact have become increasingly critical differentiating factors between competing products and services. Consumer Social Responsibility (CSR) initiatives with green, healthy products and services can have an impact on business processes, such as the entire supply chain processes and product life-cycles (Nazzaro et al., 2020). The circular economy aims to increase productivity through more efficient use of natural resources and ecosystems to keep products at their highest value (Pajula et al., 2017).

The findings of the study provide useful implications for theorists, policy makers and practitioners alike, as they contribute to the debate on the role of the IR in considering sustainability in the success of agri-food companies. The CS concerns, which may conflict with corporate profitability objectives, are not ignored. Instead, conflicting sustainability factors are juxtaposed without highlighting one as the 'better solution' (Hahn et al., 2018). Results keeps the door open to the performance paradox and serves as a call for simultaneous action on various economic, social and environmental issues. The paradoxical approach does not mean that firms abandon the profit-driven strategy. Instead, paradox resolution refers to a deliberate iteration between alternatives to gain equal attention over time (Smith and Lewis, 2011). The paradoxical perspective creates scope for meaningful corporate contributions to sustainable development by purposefully balancing and combining instrumental (IR) initiatives where companies addressing environmental and social issues bring business benefits (Hahn et al., 2016).

CS paradox perspective also suggest that society, businesses, logistics providers and consumers must work together to achieve sustainable outcomes that improve overall financial, social, economic and environmental performance (Agyabeng-Mensah et al., 2020). A possible explanation for these results could be that sustainability enhances operating performance, efficiency and effectiveness, minimizes resource use and costs, and benefits society by offering less harmful products and (ICT) services in the most diminutive possible form (Biagi and Falk, 2017). Tsai (2018) has developed a model using 5IR techniques of green production planning and control to maximize profits and reduce carbon emissions, recycling and waste reuse through activity-based costing, which has already been proven in paper, printing and textiles industries, but is also promising in the food sector.

The present results are significant in at least two major respects. Firstly, ecological factors may play a more crucial role in the profitability of the food industry than in other industries, as the sector is highly vulnerable to scarcity of natural and food resources due to climate change (Leisner, 2020). Involving farmers in sustainable agricultural practices and applying food innovations can contribute to resilient economic and employment recovery, avoiding land abandonment and environmental degradation (Pancino et al., 2019). Further factors, e.g., sustainable, innovative approaches, can be integrated to allow food plants to use waste to feed the energy

system, such as coal-fired power plants, instead of further deforestation (Chen et al., 2020). On the other hand, the focus shift from technology-driven advancement to a human-centric approach is one of the most substantial paradigmatic transitions defining 5IR (Breque et al., 2021). It implies that the food manufacturing sector must consider societal restrictions relating to a healthy and safe working environment, respect for human rights, and the qualifications needed for employees. The evolving position of the industrial worker and the narrative surrounding them suggest that the employer is interested in investing in their workforce's talents, skills, and general wellbeing to meet their goals for profitability. Measures of the social dimension of the path models focus on human-machine interactions such as employment, poverty and gender equality and do not take into account the importance of food security issues. However, social IR dimension has crucial impact on profitability by providing affordable access to certain foods and services to achieve competitiveness by making production processes more efficient and improving economic performance and market position (Stanco et al., 2020). Consequently, sustainable IR will bring positive results, both in terms of consumer reactions and of producers, who will pay more attention to working conditions and the quality, wholeness and origin of food (Vermeir et al., 2020). Some of other findings relate specifically to the different accounting standards and legal regimes that significantly impact companies' investment opportunities. For instance, corporate taxation incentives, preferential loans and subsidies contribute even more to encouraging food producing companies and accomplishing higher revenues (Kostakis et al., 2016).

Further research is needed to examine how should managers make decisions to balance the different dimensions of sustainability in IR investments to stay profitable. This empirical framework provides guidance for research on how sustainable venture capital can help startups and nascent entrepreneurs succeed. Sustainable entrepreneurs seek to address economic prosperity, social justice and ecological resilience through entrepreneurial behavior (Bocken, 2015). Sustainable entrepreneurship is about preserving nature, ecosystems and communities while creating benefits for individuals, the economy and society (Rosário et al., 2022).

Conclusions

The present study was designed to determine the impacts of sustainable IR factors from economic, social and ecological perspectives in the food production sector, where appropriate supply utilization and minimal adverse environmental impacts are crucial for the future. The main objective of the study was to propose explanations for analyzing how each sustainability pathways can contribute to higher corporate profitability.

This research was conducted with quantitative models using partial least squares path modeling (PLS-PM) and categorical principal component analysis (CATPCA). The advantage of CATPCA implies an optimal scaling technique, whereby numerical values are assigned to each category and applied for further evaluation. PLS-PM is mainly used to develop theories for exploratory research (Henseler et al., 2016). The method is recommended for cases such as lower sample size requirements, easier testing of direct and mediating (indirect) relationships and built-in ability to handle formative indicators (Sarstedt et al., 2016).

The present study makes several noteworthy contributions to the CS literature. This study has shown that the livable and sustainable path hypotheses can be confirmed. However, the economic dimension of sustainable IR impacts positively and significantly on corporate profitability. The ecological and economic factors mediate and strengthen the positive impact of the social dimension on corporate profitability. Contrary to previous approaches (Yolles, 2018), it is not only the natural environment that determines the structure and functioning of society, and the economy must respond to it. The results suggest that this sustainable path is one where the environment and the economy determine the functioning of societies. Together, these results suggest that sustainability through IR plays a crucial role in improving food manufacturing companies' profitability. However, decision-makers should not wait for sustainability to emerge but consciously embrace it. The transition into sustainability is a long journey, full of questions, but it provides a direction for the necessary changes (Kot et al., 2019).

The results support the idea that sustainable development requires responsible financial management for changes in the global food systems, affecting farmers, food supply chains, production companies, different food production systems and local ecologies, and the diversity of food traditions and cultures (Bhat and Jõudu, 2019). Another crucial practical implication confirms that adopting IR tools support improved business performance (Kovacs and Kot, 2016; Rajnoha et al., 2017). Internet of Things (IoT), e.g., Big Data, RFID, helps managers study internal and external factors that significantly impact sales and profits (Nagy et al., 2018). For similar efforts (see SOC, ECOL linkage), by extending paths from multiple directions and path models, the techniques used in this paper can be applied to other indirect links in any field of the social sciences.

Finally, several limitations need to be considered. First, the study is limited by the lack of information on the Hungarian sectoral case, which restricts the generalizability of the results. The omitted variables bias is a major limitation of this study, as the variables included in the models reflect only subjective selections and do not provide a complete picture of IR sustainability factors. We urge researchers to evaluate additional interactions in the context of agri-food industry, such as hunger reduction, water pollution, and soil degradation, as vital social and ecological factors related to

food security and climate change. In the future, researchers should look at organizations from different industries to better understand the dimensions of sustainability and the impact of technological changes. The data collection method used in this study was an opinion-based survey, which suffers from the potential problem of common method bias, which describes measurement error exacerbated by the conscious perceptions of respondents who choose to provide only positive responses (Chang et al., 2010). The most crucial concern is that the study used a cross-sectional approach, which limits the conclusions that can be drawn. The effects of food and energy crises caused by the current war conflicts are not reflected. The current study has only examined the profitability performance and expected returns of food manufacturing companies. More research is required to determine the usefulness of such vital financial indicators as liquidity, efficiency and leverage.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

Conceptualisation: DM. Methodology and software: SK. Validation: EE. Resources: ZB. Writing—review and editing: NE. Visualization and funding acquisition: JO. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted without any commercial or financial relationships construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.1034010/full#supplementary-material

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Purchasing behavior in rural areas for food products during the COVID-19 pandemic

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Introduction: Most previous studies have investigated consumer purchasing behavior for food products in urban areas during the COVID-19 pandemic. In contrast, the present study is one of the very few to investigate consumer purchasing behavior for food products within rural areas.

Methods: To this end, research was conducted in Sicily taking as a case study a rural municipality whose population was subjected to a lockdown regime to contain the spread of the virus. The choice of carrying out the research in a rural rather than an urban area contributed to the emergence of new aspects concerning consumer behavior in rural areas during the COVID-19 emergency.

Results and discussion: The research reveals that the amount of money spent on food purchases, as well as the amount of food purchased, increased during the lockdown. In general, the research shows that COVID-19 impacted the purchasing behavior of consumers in rural areas even though they showed a high resilience and adaptation to the health emergency situation caused by the pandemic.

KEYWORDS

consumer behavior, food purchasing, economic sustainability, COVID-19, rural areas

Introduction

When the first cases of COVID-19 were detected in Italy in 2020, all media broadcast images of empty shelves and supermarkets being stormed by consumers. Panic buying was an extremely frequent event, leading to disruptions in the food supply chain (Yuen et al., 2020; Bentall et al., 2021; Kassas and Nayga, 2021; Cerroni et al., 2022). Fear of disruptions and lockdown restrictions caused a change in consumer purchasing behavior that led to an increase in food stocks and the amount of food purchased (Sim et al., 2020; Janssen et al., 2021). These behavioral changes can also be attributed to a feeling of insecurity that pervaded public opinion during that period (Farr-Wharton et al., 2014; During, 2016; Sturiale et al., 2022).

In addition, the containment measures envisaged by the Italian government to stem the contagion confined people indoors, causing an increase in the use of online sales platforms (McKinsey and Company, 2020a; Montanino et al., 2020). Even small neighborhood shops equipped themselves with their own platforms or used social media, such as Facebook and WhatsApp, to sell their products (Scuderi et al., 2022). In this regard, the pandemic has caused drastic changes in both sales and purchasing patterns (Zarbà et al., 2022) but, however, it is not yet sufficiently clear whether the post-COVID-19 situation will still be the same and whether online platforms will continue to be preferred by consumers. A recent market study showed that 61% of respondents said they would continue to shop online even after the pandemic (McKinsey and Company, 2020b).

During the lockdown, there was an increase in purchases of certain food categories, such as pasta, rice, sugar, eggs, and flour (Zinola, 2020; Fang et al., 2022). In addition, due to the closure of restaurants, there was a change in habits that pushed consumers to rediscover a passion for home cooking, almost as a psychologically positive response to the economic crisis caused by COVID-19 (Coop 2020 Report, 2020).

Another interesting aspect noted during the lockdown period concerns behaviors toward food waste. Residential lifestyles, panic buying, and restrictions to curb contagion are also possible causes of changing purchasing behavior in relation to food waste (Pappalardo et al., 2020). It is well-known that food waste is an extremely important issue, especially since it is one of the main causes of global warming (Scherhaufer et al., 2018; Pappalardo et al., 2022). Landfilled food waste emits toxic substances that also affect groundwater (Tonini et al., 2018). Previous studies have also shown that the tendency to waste food varies between segments of the population (Setti et al., 2016) and depends on consumers' purchasing habits (Lazell, 2016). Scalvedi and Rossi (2019) have reported a typical attention of the Italian people to waste production, although unfortunately it does not correspond to proper management. However, although the pandemic contributed to an increase in panic buying (Wang et al., 2020), it is possible that consumers decreased food waste even though purchasing more food. This could be due to the increased focus consumers place on food waste in emergency situations, such as COVID-19 (Scuderi et al., 2016; Shiller, 2019).

Despite the numerous studies done on consumer food purchasing behaviors during the COVID-19 pandemic, some aspects remain underexplored even though they are potentially interesting in understanding how consumers react to emergency moments. One of the still under-explored aspects concerns the food purchasing behaviors of consumers living in rural areas during the COVID-19 pandemic. Almost always, studies conducted on this topic have not focused specifically on rural areas despite the fact that it is plausible to assume that the lifestyle habits of people living in rural areas differ from those living in metropolitan areas. This aspect may have relevant implications when intervention strategies have to be planned to cope with periods of crisis since the degree of resilience of rural areas may depend on different factors than urban areas.

With this in mind, the objective of our survey was to observe the food purchasing behaviors of people living in rural areas during the lockdown period, when the maximum regulatory restrictions were imposed to contain COVID-19 infection. This represents a novel aspect in the scientific literature, since previous studies on this topic have not specifically focused on purchasing behaviors of people living in rural areas, but more generally on consumers living in metropolitan areas (e.g., Harrison et al., 2022), or belonging to specific population groups (e.g., Drichoutis and Nayga, 2022), or even on purchasing and consumption behaviors of specific food products (e.g., Malone et al., 2021). However, focusing on rural areas could bring out peculiar characteristics such as the different living habits of people living in those areas, knowledge of which could be useful in addressing emergencies measures consistent with the socio-economic context of rural areas (Bellia et al., 2015; Chenarides et al., 2020; Ingrassia et al., 2022a). Specifically, our survey was conducted in a small rural municipality (Capizzi) located in Sicily (Italy) whose population was subjected to the lockdown regime at the beginning of 2021 due to the high number of COVID-19 cases in the municipality. The results of our survey can provide useful insights for policy makers, particularly regarding the behaviors of rural people and the resulting strategies to be adopted to better manage emergency periods in rural areas (Safonte et al., 2018).

Materials and methods

The survey was conducted on a representative random sample of 207 residents in the municipality of Capizzi, which is a small rural municipality located in Sicily (Italy). The interviews were conducted during the lockdown period to which the population of Capizzi was subjected in January 2021. Due to restrictions imposed by the governmental authorities, the online Google Forms platform was used for data acquisition.

Specifically, the sample of consumers interviewed was first contacted by telephone to be invited to answer an online questionnaire in an accurate and thoughtful manner. Some screening questions were first asked by phone, namely whether they were of legal age (more than 18-year-old) and whether they were the person responsible for purchases within the household.

After obtaining positive answers to these questions and consent to complete the survey, each participant was sent the online questionnaire also containing socio-demographic questions such as gender, age, marital status, number of children, number of people with a job in the household, level of education, and net annual income.

Subsequently, questions on purchasing behavior were asked to consumers in relation to the COVID-19 emergency situation and the establishment of the so-called "Red Zone" (lockdown) within the municipality of Capizzi.

Specifically, respondents were asked a set of qualitative questions about whether their purchasing behavior, food expenditures, waste productions and other food-related behaviors had changed during the COVID-19 pandemic. These qualitative questions were grouped in the following four categories: (1) Structure of preferences (i.e., types of food purchases), (2) shopping behaviors (i.e., frequency of food purchases, amount of food purchased, food expenditure, and food stocked at house), (3) behavioral drivers (i.e., drivers underlying shopping behaviors), and (4) socio-demographic characteristics.

Participants were asked through five points Likert-scales questions to elicit whether their purchasing behaviors changed during the lockdown. This format has already been used in previous studies examining consumer behaviors during the COVID-19 pandemic to increase the significance of qualitative and quantitative information (Pappalardo et al., 2020; Goswami and Chouhan, 2021; Amicarelli et al., 2022). In particular, participants answered on a scale from 1 (significantly reduced) to 5 (significantly increased). Respondents were also asked to report the extent to which they agreed to a set of statements regarding possible reasons behind the reported change in food purchasing behaviors. An example of a statement is: "*My food waste production was reduced because I wanted to ease the work of people in the waste collection.*" Again, they had the option to choose on scale from 1 (do not agree at all) to 5 (completely agree).

Results

The summary of the main socio-demographic characteristics of the interviewed sample is reported in Table 1. A total of 74.4% of the consumers who participated in the survey declared themselves to be female, and 25.6% declared themselves to be male. It is evident that in the rural area of reference, that is the municipality of Capizzi, women are mainly involved in household shopping. The average age of the consumers involves was 41.5 years. The majority of the respondents answered that they are married (64.3%), and 34.3% of the respondents stated that they had two children living in their household. The average number of people with a paid job in the household of the respondents was 1.5 members. Furthermore, 47.5% of the respondents stated that they had a diploma as their educational qualification. Finally, 72.5% of the survey participants stated that they had a low income (<20,000 euros per year).

TABLE 1 Main socio-demographic characteristics of the interviewed sample.

Variables	
Gender (%)	
Female	74.4
Male	25.6
Age (years)	
Years	41.5
Civil status (%)	
Married	64.3
Cohabitant	8.7
Single	19.3
Divorced	2.9
Widower	4.8
Cohabiting children (members %)	
No children	31.9
One child	21.7
Two children	34.3
Three children	10.6
Four children	1.0
More than four children	0.5
Number of persons in paid employment	
Median	1.5
Education level (%)	
Primary school	2.9
Middle school	27.5
Diploma	47.3
Degree	18.8
Postgraduate	3.4
Income (euro %)	
<20,000	72.5
20,000 to 39,999	20.3
40,000 to 59,999	4.8
60,000 to 79,999	1.0
80,000 to 99,999	1.4
<100.000	0.0

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

Frequency of visits to the supermarket

The majority of the sample surveyed (48.3%) stated that the frequency of visits to the supermarket was unchanged during the lockdown. Examination of Table 2 also shows that the number of consumers who increased the frequency of visits to the supermarket was slightly higher than those who decreased the number of visits during the lockdown.

This almost equal distribution between those who have increased their purchase frequency and those who have decreased is shown in Table 3 shows that 56.9% increased the

TABLE 2 Summary statistics regarding purchasing purchases (on a scale of 1–5).

Variable	Frequency	%
Significantly reduced	7	3.4
Slightly decreased	42	20.3
Unchanged	100	48.3
Slightly increased	50	24.2
Significantly increased	8	3.9
Total	207	100

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

TABLE 3 Summary statistics of the main reasons for increasing purchasing frequency.

Motivation to increase frequency	Percentage of agreement
The amount of food I eat has increased since the start of the pandemic	56.9
The likelihood of contracting the coronavirus in supermarkets is low	19.0
I fear that there will be interruptions in food supply	20.7
I cook more and order less take-away food than before	60.3
I tend to accumulate more food reserves	63.8

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

frequency because the amount of food consumed increased during the lockdown. Moreover, total of 60.3% stated that they increased the frequency of visits to the supermarket because they preferred to cook more at home and order less take-away food, and 63.8% of the respondents stated that they increased their food stocks at home. In contrast, the main reason for the decrease in the frequency of shopping at supermarkets has been the fear of contracting the virus and becoming infected.

Purchased quantity of specific food items

Regarding the types of foodstuffs purchased during the lockdown, Table 4 shows that flour was the product whose quantity increased more than any other product (48.8%). It is not easy to find a precise reason for this result, but it is probably due to a greater availability of time spent at home by the population with the ability to prepare homemade flour-based foods.

On the other hand, the product type with the smallest increase was "ready meals" (4.8%). For this type of good, 56.5% of consumers stated that the quantity purchased of ready meals

TABLE 4 Summary of changes in the quantity of specific foodstuffs.

Variable	Decreased (%)	Unchanged (%)	Increased (%)
Pasta	5.3	67.1	27.5
Rice	11.6	80.7	7.7
Flour	4.3	47.3	48.3
Oil and vinegar	8.2	72.9	18.8
Bread	7.7	63.3	29.0
Meat, fish, eggs	7.7	61.8	30.4
Milk	6.3	62.3	31.4
Frozen foods	14.0	60.4	25.6
Canned foods	16.9	68.1	15.0
Ready-made dishes	38.6	56.5	4.8
Vegetables and fruit	6.3	60.9	32.9
Snacks and biscuits	13.0	60.4	26.6
Organic products	16.9	68.1	15.0
Gluten-free products	26.6	66.2	7.2
Bottled water	8.2	61.8	30.0
Non-alcoholic drinks	17.9	67.6	14.5
Alcoholic drinks	29.5	63.8	6.8

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

TABLE 5 Summary statistics of the amount of money spent on food purchases.

Variable	Frequency	%
Decreased	23	11.1
Unchanged	91	44.0
Increased	93	44.9
Total	207	100

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

was unchanged, while 38.6% replied that it had "decreased." This result may be attributable to the new residential lifestyle that consumers have to adopt during the lockdown period. This seems to be a potential interesting result and probably due to the context in which the survey was carried out and that is a rural area where both due to established habits and the lack of an adequate supply of ready foods, the use of them was found to be uncommon. Another interesting result is the percentage of consumers (32.9%) who responded that they had increased the amount of fruit and vegetables they bought, probably because these foods are recognized as having important health values.

Amount of money spent on food purchases

During a lockdown period, consumers can only move within the municipality to make food purchases. This leads to an

TABLE 6 Summary statistics of the main reasons for the increase in the amount of money spent on shopping.

Variable	Disagree	Indifferent	Agree
I tend to buy more food	18.3	25.8	55.9
I cook less and order more take-away food	79.6	9.7	10.8
I tend to buy more ready-made meals	80.6	10.8	8.6
Prices have risen	15.1	15.1	69.9
I tend to stock more food	7.5	26.9	65.9

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

TABLE 7 Summary statistics of food stored at home.

Variable	Frequency	%
Decreased	7	3.4
Unchanged	110	53.1
Increased	90	43.5
Total	207	100

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

increase in domestic demand and a likely increase in food prices. To find out whether prices had increased, consumers were asked whether the amount of money spent on food purchases during the lockdown had decreased, remained the same, or increased. It was found that the amount of money spent had increased for 44.9% of consumers (Table 5).

The main reasons for increasing the amount of money spent on food were (Table 6): "I tend to buy more food" for 55.9% of the consumers; 69.9% responded that prices had increased; and 65.9% agreed with the statement "I tend to stock more food." The consumers who stated that the amount of money spent on food had increased disagreed with the following statements: "I cook less and order more take-away food" (79.6%); and "I tend to buy more ready meals" (80.6%).

Quantity of food stored at home

Table 7 shows that, for 53.1% of the consumers, the amount of food stored at home as a reserve remained unchanged during the lockdown. However, the percentage of consumers who answered that the amount of food kept in reserve increased was 43.5%, while that for those who answered that the amount of food kept in reserve decreased was only 3.4%.

Among the main reasons for increasing food stocks at home during the lockdown, 80% of the respondents answered that "I tend to buy more food," while 61.1% stated that they shopped more online and were concerned about possible problems with food supply (Table 8).

TABLE 8 Summary statistics of the main reasons for increased food storage at home.

Variable	Disagree	Indifferent	Agree
I tend to buy more food	7.8	12.2	80.0
I tend to eat more	27.8	30.0	42.2
I tend to shop more online	20.0	18.9	61.1
I tend to be preoccupied with food supply problems	11.1	27.8	61.1

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

Food shortages

A total of 58% of the respondents reported noticing shortages of food products during the lockdown, with the products most in short supply being flour (85.8% of respondents) and vegetables and fruits (44.2%; Table 9). Significant shortages were also found for pasta, milk, and frozen food. No shortages were found in the supply of products such as rice, water, and various beverages. This question was answered by 58% of consumers who had previously stated that they had noticed food shortages.

Quantity of food wasted

Concerning the amount of food wasted during the lockdown, 68.6% of the respondents stated that this amount remained unchanged. However, a significant result was that 24.6% of the participants stated that they had decreased the amount of food not consumed and thrown away. Only 6.8% stated that they had increased food waste during the lockdown (Table 10).

Concerning the main motivation for decreasing food waste (Table 11), 91.8% of those who had previously stated that the amount of food waste had decreased stated that they were paying more attention to these aspects because they were experiencing a period of emergency. Other reasons for decreasing food waste were not to add more pressure to the food management system (77.6%) and to buy less perishable food (73.5%). This latter result seems at odds with a previous finding that respondents were buying more fruit. Actually, the purchase of perishable foods such as fruit might actually be associated with the consumption of foods that have potential positive health benefits, and this is important in times of health emergencies. However, buying

TABLE 9 Summary statistics of percentages regarding shortages of specific food products.

Variable	Yes (%)	No (%)
Pasta	32.5	67.5
Rice	5.0	95.0
Flour	85.8	14.2
Oil and vinegar	20.8	79.2
Bread	19.2	80.8
Meat, fish, eggs	20.0	80.0
Milk	36.7	63.3
Frozen foods	33.6	66.4
Canned foods	23.3	76.7
Ready-made dishes	24.2	75.8
Vegetables and fruit	44.2	55.8
Snacks and biscuits	21.7	78.3
Organic products	25.8	74.2
Gluten-free products	15.0	85.0
Bottled water	15.0	85.0
Non-alcoholic drinks	7.5	92.5
Alcoholic drinks	7.5	92.5

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

TABLE 10 Summary statistics of the amount of food wasted and thrown away.

Variable	Frequency	%
Decreased	51	24.6
Unchanged	142	68.6
Increased	14	6.8
Total	207	100.0

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

TABLE 11 Summary statistics of the main reasons for the decrease in the amount of food wasted and thrown away.

Motivation to increase frequency	%
I want to facilitate the work of people involved in waste collection	70.6
I pay more attention because we are living in a time of emergency	91.8
I buy less perishable food such as salads and fruit	73.5
I don't want to add more pressure to the food management system	77.6

The data were collected during a lockdown period, i.e., during the establishment of the "Red Zone" in the village of Capizzi, in January 2021.

more perishable foods (e.g., fruit) does not necessarily imply an increase in food waste, which instead is reduced due to the uncertainty caused by the emergency, the risk of not being able to go to the supermarket, the risk of incurring economic hardship such as job loss and finally the need to stay in good health status.

This question was answered by 24.6% of the consumers who had previously stated that they had reduced food waste.

Discussion and concluding remarks

The data collected provide a sufficiently comprehensive view of what happened during the lockdown within a small rural community. To the best of our knowledge, our study is the first that specifically focussed on the purchasing behaviors of consumers living in rural areas during the emergence of COVID-19 when severe movement restrictions and great uncertainty existed among the population (Prescott et al., 2020).

Overall, our findings contrast with previous studies conducted in metropolitan areas (Chenarides et al., 2020) suggesting that the pandemic condition may not have had significant effects on food purchasing behaviors among consumers that live in rural areas compared with those live in metropolitan areas. The lockdown has led to an increase in time spent at home and thus the ability to prepare food without excessive reliance on outside ready-to-eat food purchases. Moreover, in contrast with previous studies (Sim et al., 2020; Kassas and Nayga, 2021), we did not observe any significant panic buying phenomenon since the frequency with which consumers went to the supermarket to buy food remained for the most part "unchanged," as well as the amount of food purchased. Actually, other previous studies had also noted that the phenomenon of panic buying is more pronounced in urban than in rural areas (Bentall et al., 2021). Consequently, our results seem to confirm this trend although the causes that might explain this result are not well-understood and would merit further investigation in future specific surveys. Perhaps, one possible cause could lie in the lower-middle income level that makes it more difficult to increase shopping if not even in the smaller social context that make more reassuring relations between consumers and small local retailers. However, like in the previous studies (Chenarides et al., 2020; Janssen et al., 2021; Fang et al., 2022), our findings showed that the main motivation for increased food stocks at home was the fear of food supply chain disruptions and the tendency to buy more food staying at home.

Among food items, there was an increase in the purchase of flour and, quite surprisingly, decrease in the purchase of ready meals. The decrease in ready meals purchases seems to partly contradict what has been observed in previous studies but refereed to other socio-economic contexts (e.g., urban areas; e.g., Chenarides et al., 2020; Janssen et al., 2021). However, this result could be explained by the lifestyle habits that especially in rural areas enhance the role of preparing food at home even by resorting to traditional recipes

and eating habits. In other words, consumers in a time of crisis rediscovered their passion for cooking and combined it with proper application of expert advice that indicated better chances of defense against the virus in correlation with proper nutrition.

Instead, there was an increase in the amount of money spent on food, but this result is due to rising prices caused by an increase in demand of food products. However, like in the previous studies our findings showed that the main motivations for increased the amount of money spent on shopping was the tendency to buy and store more food at home (Ingrassia et al., 2022b).

Another interesting aspects regards the behaviors about food waste. Our findings showed that although the amount of food wasted and thrown away remained unchanged for the majority of respondents, a significant percentage of participants reported an increase in awareness about this issue. This result confirms what has already been observed in previous studies (Pappalardo et al., 2020; Cerroni et al., 2022), as living in times of emergency probably increases social awareness toward certain behaviors such as reducing food waste. Moreover, this result confirms what Scalvedi and Rossi (2019) stated about the attention that Italians people typically show on food waste issue.

In conclusion, it can be said that the situation that arose in rural areas like the municipality of Capizzi in Sicily during the lockdown of COVID-19 pandemic had not a significant impact on the purchasing behavior of food products among local population. The resilience and adaptability of the rural population probably contributed to overcoming the difficulties imposed by the health emergency.

However, our survey present limitations that should be better explored in future studies such as exploring whether there are differences in behavior among various rural population groups (e.g., youth vs. adults, education level, and income classes). For this reason, for future studies it could be interesting to replicate the research in other rural areas in order to confirm our findings.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CB, RS, and GP: conceptualization, formal analysis, and writing—review and editing. CB and GP: methodology, writing—original draft preparation, and supervision. MP, CB, RS, and GP: validation. MP and GP: investigation. CB: project administration and funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Effects of dietary intake behavior, food supply, nutrition, and health during the COVID-19 outbreak

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The coronavirus disease 2019 (COVID-19) pandemic, which began in 2019, has far-reaching ramifications, including economic losses and health challenges that still affect various parts of the world. During our review, we learned that the entire world is working to stop the spread of the SARS-CoV-2 outbreak. We explore ways that may lower the danger of SARS-CoV-2 contamination and useful strategies to avoid the possibility of SARS-CoV-2 spreading through food. While hygienic protocols are required in the food supply sector, cleaning, disinfection, and the avoidance of cross-contamination across food categories and other related goods at different stages of the manufacturing process remain especially important because the virus can survive for long periods of time on inert materials such as food packaging. Furthermore, personal hygiene (regular washing and disinfection), wearing gloves and using masks, garments, and footwear dedicated to maintaining hygiene provide on-site safety for food sector personnel, supply chain intermediaries, and consumers. Restrictions imposed in response to the pandemic (e.g., closure of physical workplaces, canteens, cafes, restaurants, schools, and childcare institutions), changes in household grocery shopping frequency, individuals' perceived risk of COVID-19, income losses due to the pandemic, and sociodemographic factors are among the factors. The conclusions drawn from this study consider the implications of healthy diets, food system resilience, behavior change, and nutritional imbalance for policymakers and food supply chain participants, as well as the antimicrobial effects of vitamins and nutrients. During a public health crisis, people should eat less, necessitating preventive policies and nutritional advice to deal with this.

KEYWORDS

COVID-19, food supply, dietary patterns, nutrition, health

Introduction

The World Health Organization (WHO) confirmed the coronavirus disease 2019 (COVID-19), which began in China (Wuhan Province) and quickly spread throughout the country and subsequently to other countries worldwide; it was confirmed by the World Health Organization (WHO) as pandemic on March 11, 2020, despite widespread

global attention (WHO, 2019; Clemente-Suarez et al., 2021). Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was named by the International Committee on Virus Taxonomy (ICTV) (Hui et al., 2020). Even though COVID-19 has a lower fatality rate than SARS, it has a higher transmission rate due to mutation and increased recombination of genes in the SARS-CoV-2 receptor-binding domain S protein (Shereen et al., 2020).

In this study, over 633 million cases have been confirmed in over 230 countries, resulting in over 6.5 million deaths (CoronaBoard, 2019; Wu et al., 2020; Galvan et al., 2021). Despite this, unpaid particular antiviral medicines continue to spread new infections daily (outbreak worldwide presented in Figure 1). Furthermore, SARS-CoV-2 infection has a negative effect on each country's economy and causes marketing issues throughout the food supply chain. The precise source of COVID-19 is currently unknown. Phylogenetic comparisons show that SARS-CoV-2 is 96% similar to SARS-CoV, implying that bats are its natural hosts (Zhou et al., 2020; Han et al., 2021). However, no intermediate host has yet been identified to assist this virus in crossing the species barrier and infecting humans. This virus is known to be easily transmitted by respiratory droplets in human-to-human contact, and food surfaces are viral transporters (Mullis et al., 2012). The World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC) have stated that there is no evidence of SARS-CoV-2 transmission or direct contamination of food or water (CDC, 2021). The virus, conversely, can be disseminated by consuming food prepared and packaged on dirty surfaces or through transmission by an infected person during food handling or sharing (Galanakis, 2020; Han et al., 2021). In January 2020, at a conference, researchers infected a few people with COVID-19 *via* physical contact and shared meals (Pung et al., 2020), implying that food could be a possible SARS-CoV-2 infection channel. Using scientific information to find new ways to stop the virus from spreading quickly and to update international standards, it is important to find out how the virus spreads, including whether it can be spread through food.

Despite being a viral disease, the new coronavirus disease (COVID-19) is often treated with several antimicrobials (Wu et al., 2020; Ng et al., 2021). Healthcare professionals (HCP) use an empirical approach to treat COVID-19 patients regardless of the laboratory parameters due to the ambiguity of a successful treatment strategy (Fathi et al., 2021). The choice to begin antibiotics is typically made in response to clinical manifestations that resemble bacterial pneumonia (Lau et al., 2011; Bertuzzi and DiRita, 2020). The HCP is considering antibiotics as a treatment option due to concerns about community-acquired pneumonia, nosocomial bacterial superinfection in longer hospitalized patients, and high mortality due to COVID-19 among risk groups, including those over 60 and those with underlying medical problems (Li et al., 2005; Fathi et al., 2021). Worldwide, up to 72% of COVID-19 patients were treated with antibiotics (Lau et al., 2011; Bertuzzi and DiRita, 2020), but only 1–16% of these patients also had a bacterial co-infection (Lau et al., 2011). Broad-spectrum antibiotics were frequently used to treat various microorganisms (Lau et al., 2011; WHO, 2020; Fathi et al., 2021).

Additionally, COVID-19 was treated with antivirals (Li et al., 2005; Czarniecka-Skubina et al., 2021; Memon et al., 2021), antimalarials like hydroxychloroquine (Kassir, 2020), and antiparasitic medications like ivermectin (Kassir, 2020; Celorio-Sardà et al., 2021). Antibiotic use has increased and been sustained as a result of COVID-19 treatment. Antimicrobial resistance (AMR) is silently and gradually increasing due to empiric antibiotic use, becoming a major global threat (Assiri et al., 2013; Cockrell et al., 2016; Backer et al., 2020; Chan et al., 2020; Wu et al., 2020). As a result, there will probably be more cases of sickness and mortality both during and after the pandemic. The World Health Organization (WHO) has voiced concern that the COVID-19 pandemic will worsen the AMR situation, which is already a pressing problem (Mahase, 2020; Filip et al., 2021).

The actual pandemic directly affected people's daily lives worldwide, with limited policies such as lockdowns, the use of face masks, and restrictions on individual movement (Clemente-Suarez et al., 2021; Tornero-Aguilera and Clemente-Suarez, 2021). Fever, sore throat, headache, dry cough, weariness, dyspnea, and infrequent intestinal indications are prevalent clinical symptoms, asymptomatic to acute respiratory distress syndrome and multi-organ dysfunction (Singhal, 2020; Zhao et al., 2021). The common indications include fever, headaches, sore throats, dry coughs, lethargy, myalgia, shortness of breath, and gastrointestinal symptoms (Zhao Q. W. et al., 2020). The contagion can devolve into respiratory failure, pneumonia, and mortality by the end of the first week (Singhal, 2020). In addition, the eosinophilic cell blood count appears to have a significant role in COVID-19 analysis and prediction (Clemente-Suarez et al., 2020). COVID-19 has been studied in relation to many characteristics such as socioeconomic position, age, sex, nutrition, and race (Dastoli et al., 2020; Fuentes-Garcia et al., 2020; Golestaneh et al., 2020). Nutrition plays a crucial role in immunological conditions and sickness. The nutritional intervention has demonstrated various approaches with varying outcomes. The COVID-19 pandemic caused changes in food hygiene, lifestyle, and diet in various parts of the world. However, with the current development of SARS-CoV-2, changes are still occurring, and much more information is being acquired. Ultimately, determining the wider health effects of COVID-19 depends on how the pandemic influences the world's population's mental, social, and physical health compared to pre-pandemic conditions. This review aimed to offer current nutritional attention to the current COVID-19 situation. This review scenario aims to gather issues about dietary patterns, nutrition, nutritional deficiencies, vitamin involvement, physical activity, and the antimicrobial activity of nutritional elements (Han et al., 2021).

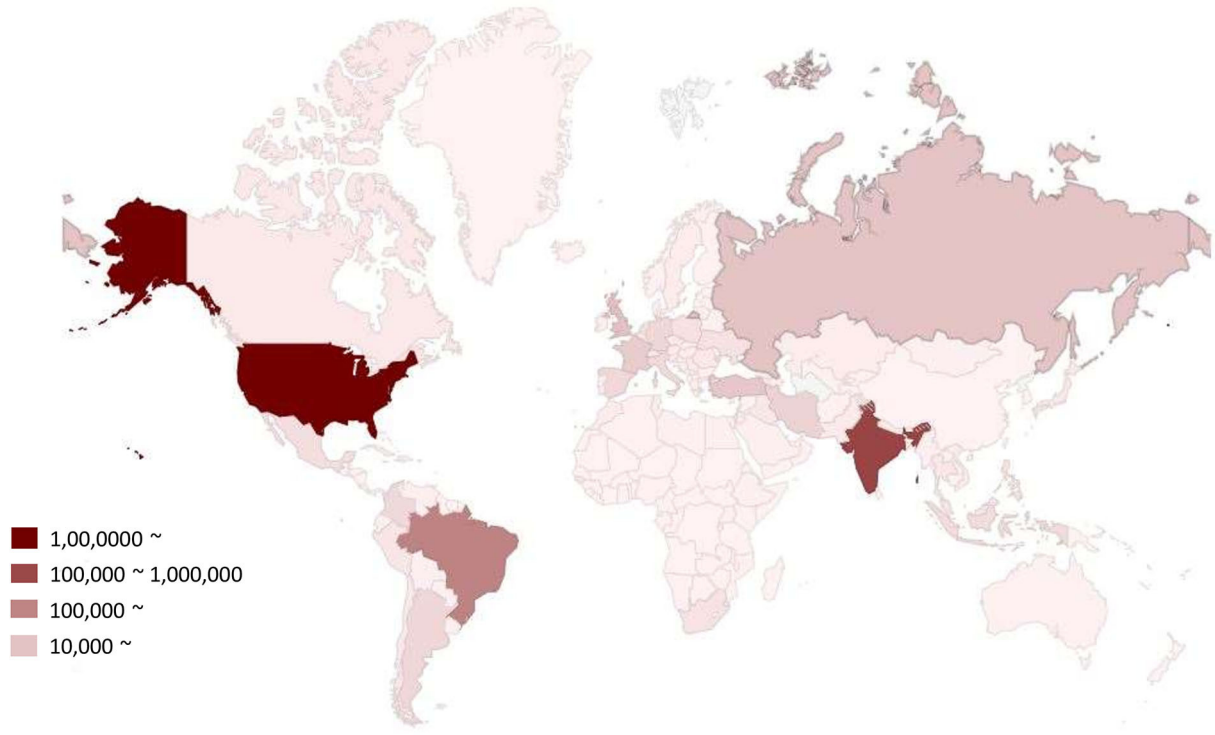

FIGURE 1
COVID-19 outbreak all over the world. Different color indicated number of infected populations.

Methodology and data collection approaches

This review study is based on evidence from reputable journals on Google Scholar, LISTA (EBSCO), the Web of Science Core Collection, and PubMed. Key phrases such as SARS-CoV-2, COVID-19, food supply, dietary patterns, nutrition, health, and publication date were also evaluated when searching for papers on the web. Most works published in 2020 and during COVID-19 (2019–present) were considered. A few studies published before 2020 and websites updating situation reporting are also acknowledged as documenting earlier viral outbreaks. This review study provided a broad and brief overview of the COVID-19 pandemic research landscape, which could be helpful for getting a general understanding of the subject.

Food supply during the COVID-19 pandemic

The food system is broad, multifaceted, interdependent, and capable of handling food security, safety, nourishment, quality, and industrial distribution (Clancy, 2017; Han et al., 2021). Food items frequently need components for multi-element preparations that are not readily available in the region; the absence of such substances can pose a substantial problem for food manufacturers, ranging from manufacturing to local, state, national, and worldwide points (Bhunnoo, 2019). However, it is essential to manage food worldwide to manage the crisis (Lima et al., 2018). According to the Food and Agriculture Organization (FAO), COVID-19 has a two-pronged impact on agriculture: supply and demand are directly tied to food safety (FAO, 2020). The food supply chain connects farm operations to customer tables through production, packing, supply, and stowing (Chen et al., 2020). All segments of the food supply chain—fruit, bakery items, fresh vegetables, and food products—were severely harmed (Ivanov and Dolgui, 2020). The main pillar of four pillars (production, packing, supply, and stowing) of the food safety scheme has been significantly harmed by COVID-19 (Galanakis, 2020). Table 1 illustrates the suggested food safety processes for food subdivisions from farmhouses to users. Workers are classified according to their treatment circumstances, individual cleanliness, apparent cleansing, work environment hygiene, food preparation and distribution, and communal separation (Galanakis, 2020). Despite all the safety regulations across the food supply chain, consumption necessitates the most thorough

TABLE 1 Food safety guidelines of the food chain during COVID-19 pandemic.

Conditions	Target					
	Agricultural products	**Handling during post-harvesting**	**Processing and packaging**	**Storage and marketing**	**Distribution and retail**	**Consumption**
1. Medical condition	Yes	Yes	Yes	Yes	Yes	Yes
- Stay home if felling unwell or sick						
- Check for symptoms like fever, cough, shortness of breath, difficulty breathing, fatigue						
2. Personal hygiene	Yes	Yes	Yes	Yes	Yes	Yes
- Proper hand hygiene – washing with soap and water for at least 20 s						
- Use of alcohol-based hand sanitizers on a regular basis						
- Unwashed hands should not be used to touch the eyes, nose, or mouth						
3. Disinfection of surfaces		Yes	Yes	Yes	Yes	Yes
- Disinfected high tough surfaces with proper products (70% ethanol)						
- Frequent use of sanitizers according to label instruction						
- Follow the protective measure						
4. Working on food-processing environments			Yes	Yes		Yes
- Provide PPE						
- Proper disinfection of toilet areas						
- Develop open plan workspaces						
- Apply the windows ventilation						
5. Preparations of food						Yes
- Properly wash the fresh fruits and vegetables before consumption						
- Cooking the food at suitable temperature (above 70°C)						
- Separate raw food from cooked products						
6. Delivery of food				Yes	Yes	Yes
- "No touch deliveries" is good						
- Controls and maintain the time and temperature						
- Assure that transport containers are cleaned and sanitized						
7. Social distancing					Yes	Yes
- Maintain social distance at least 2 m from other people						
- Do not gather in groups						
- Avoid crowded places and mass gathering						

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TABLE 2 Rates of food insecurity for specific population groups before and during COVID-19.

Group (population)	Rate of food insecurity	
	During COVID-19 (%)	Before COVID-19 (%)
1. All US households	23	11
2. Households with children (<18 years)	35	15
3. Non-Hispanic Black households	38	21
4. Mothers with children 12 years and under	41	15

Food insecurity during COVID-19 is caused by the following factors: structural injustices involving class and ethnicity, job loss, keeping a low-paying job (s), limited savings/credit availability.

safety considerations at the consumer level. Many food supply chains stopped selling rare steak and beef during the crisis to avoid contamination (Euractiv, 2021; Obayelu et al., 2021; Pravst et al., 2022). Furthermore, certain industries (meat processing) in the United States were completely shut down during the COVID-19 outbreak (Reiley, 2020). Therefore, food insecurity factors were involved during the COVID-19 pandemic (Table 2) (Leone et al., 2020).

Food demand refers to interest in and willingness to pay for food during a particular time period (Mankiw, 2014). Due to uncertainty and dwindling consumer power, food demand has declined marginally. Furthermore, these conditions may worsen due to a lack of money and employment losses (FAO, 2020). Because of the COVID-19 pandemic, there is an increasing demand for food and beverages from virtual sources. Food shortages are unavoidable under such stringent lockdown circumstances, during which the maximum logistical supply has ceased. Due to the risk of getting sick, one cannot order food from online food delivery services such as Tomato and Twiggy (Narayanan et al., 2020).

Food poverty is increasing because of the financial crisis due to COVID-19, and the number of individuals facing global food uncertainty may quadruple by the end of 2020 (WFP, 2022). Owing to heightened food uncertainty during the COVID-19 pandemic, developing and developed countries are in a similar scenario, with helpless and low-income populations suffering the most (Fitzpatrick et al., 2020). Authorities must play a crucial role. Everyone must have unfettered access to food that satisfies their basic needs for food security to encourage access to wholesome foods. An impending food crisis that disproportionately impacts the most vulnerable communities is signaled by a failure to act swiftly (Rosales and Mercado, 2020). FAO (2021) reported ∼820 million people are the most helpless group, being affected by long-lasting hunger and not consuming sufficient nutrients to live a decent lifespan. Due to their lack of resources and access to food, the effects of the virus spreading farther across nations could be disastrous. Small farmers are a second vulnerable group who might be prohibited from working on their property or traveling to markets to sell their harvests or buy seeds and other necessary goods. Last but not least, low-income families' children are largely fed through communal programs; program interruptions due to the pandemic risk their food safety and nutrition, decreasing their ability to cope with illnesses. Therefore, to stop the spread of viruses, each country needs to keep up with programs that help people work together to take the necessary precautions.

Dietary patterns during the COVID-19 pandemic

The COVID-19 pandemic has affected people's eating habits and nutrition patterns. Therefore, there have been differences in the category and period of family internment, the traditional and communal trends of the nations, the age of the trial investigated, and existing obesity, which have resulted in disparate assumptions. In Spain, it was found that the food consumed during the pandemic had higher energy consumption and lower nutritional quality than pre-COVID-19 consumption patterns (Batlle-Bayer et al., 2020). Furthermore, a 6% increase in daily intake was observed during the COVID-19 home confinement compared to 2019 (Batlle-Bayer et al., 2020). Similarly, a study in Poland revealed that people consumed snacks more throughout the lockdown, with this behavior being more common in bulky and obese people (Sidor and Rzymski, 2020). One possible explanation for this was that staying at home directly affected day-to-day food practices, resulting in increased energy consumption and demand for comfort food (Muscogiuri et al., 2020; Rodriguez-Perez et al., 2020; Zhao A. et al., 2020). Governments must assess how dietary changes that affect food quality (such as an increased intake of high-calorie meals) and a decrease in the consumption of wholesome foods (such as vegetables and fruits) may increase the prevalence of chronic diseases (Rundle et al., 2020). COVID-19 alters the rate of consumption of some foods as well as the amount consumed by others in terms of dietary composition (Rundle et al., 2020; Rodriguez-Besteiro et al., 2021). These results confirmed that staying at home and communal isolation had an adverse effect on adherence to vigorous eating practices (Rundle et al., 2020). In particular, a prior study found that Spanish people consumed fewer beverages, somewhat more eggs, and red meat and consumed much more plant-based foods, such as almonds, pasta, processed vegetables, or rice, than in 2019 (Rodriguez-Besteiro et al., 2021). Despite these modifications, red meat consumption remains higher than the suggested dietary requirements, whereas plant-based foods

remain within the required choices (Rodriguez-Besteiro et al., 2021). Conversely, during COVID-19, the dietary patterns of the Chinese shifted, with a fall in the consumption of garden-fresh vegetables and fruit, poultry, rice, pork, and soybean foods (Jia et al., 2021).

Interestingly, another report (Ruiz-Roso et al., 2020) found that COVID-19 confinement resulted in a healthy dietary adjustment in a teenage population from Chile, Brazil, Colombia, Italy, and Spain, increasing the incidence of vegetable, fruit, and legume consumption during the lockdown. Thus, the proportion of adolescents consuming the suggested weekly portions of fruits and legumes during the lockdown increased by 8 and 7.7%, respectively, compared to before the lockdown. Numerous factors could support these pattern alterations. First, sales of fruits and legumes have surged since incarceration started, and second, people have more time to prepare meals at home (Ruiz-Roso et al., 2020). Several studies, for example, examined populations with innate eating tendencies. Furthermore, authorities in each country imposed distinct levels of lockdown, varying degrees of severity, and population limits. These reasons may be the root of the inconsistencies observed in previous studies (Opichka et al., 2019; Ruiz-Roso et al., 2020).

Surprisingly, in all the categories affected by the COVID-19 pandemic, bulky and obese individuals had the worst dietary patterns and behaviors. These populations exhibit more troublesome eating patterns, such as food intake without feeling hungry and frequent overeating (Opichka et al., 2019). Because of a longer stay at home and typically limitless food access, bulky and obese people started eating and snacking more throughout their home confinement (Blaszczyk-Bebenek et al., 2020). Furthermore, participants with a higher body mass index consumed fewer vegetables, fruits, and legumes throughout the lockdown and consumed more meat, dairy, and fast foods throughout the lockdown (Blaszczyk-Bebenek et al., 2020). Furthermore, the lockdown altered the nutrition patterns of overweight children and teenagers, considerably boosting their use of sugary drinks, red meat, and potato chips compared with 2019 (Pietrobelli et al., 2020). These lifestyle modifications have the potential to increase fat mass (Larsen and Heitmann, 2019).

The long-term consequences of the negative dietary changes reported during the lockdown may include the development of unhealthy eating habits (Poobalan et al., 2014; Serra-Majem et al., 2020). During the lockdown, negative emotions such as boredom and worry increased the development of poor eating habits (Moynihan et al., 2015; Araiza and Lobel, 2018). Owing to the immunomodulatory effects of several macro-, micro-, and phytonutrients (Bhaskaram, 2002; Fernandez et al., 2021), a nutritious and balanced diet is a vital aspect of the personal hazard management plan during the COVID-19 pandemic (Gasmi et al., 2020). Furthermore, dietary deficits have been associated with increased host vulnerability to virus-related contagion and a more severe clinical course of sickness (Bhaskaram, 2002; Fernandez et al., 2021). As a result, while a healthy diet cannot entirely prevent illness, it can play a significant role in the host's response to an infectious agent (Blaszczyk-Bebenek et al., 2020). Surprisingly, other unhealthy habits followed the same pattern as food patterns. Thus, an increase in alcohol intake (15%) among alcohol addicts and an increase in smoking (Blaszczyk-Bebenek et al., 2020). Therefore, more investigation is needed to determine how food patterns changed during the COVID-19 pandemic and provide the necessary guidelines to endorse good behavior throughout probable future pandemics.

Effects of vitamin ingredients as antimicrobial agents during the COVID-19 pandemic

The COVID-19 pandemic has been related to other documented epidemics in the last 20 years, such as SARS and MERS (lower respiratory diseases), with comparable clinical symptoms in the early infection stages (fever and cough), resulting in significant fatalities among susceptible people (Das, 2020; Han et al., 2021). Consuming vitamins and functional foods can boost the immune system and aid in virus suppression (Gibson et al., 2012). Vitamin C boosts the immune system and is required for body tissue growth and repair due to its antimicrobial and anti-inflammatory properties (Li et al., 2020). Furthermore, vitamin A is a fat-soluble molecule that plays an important role in immune function and lowers infection susceptibility (Huang et al., 2018; Shirvani et al., 2019). Isotretinoin is a cellular protein that regulates the downregulation of angiotensin-converting enzyme 2 (ACE2), which is essential for SARS-CoV-2 entry (Sinha et al., 2020).

Furthermore, vitamins D and E can boost resistance to SARS-CoV-2 (Im et al., 2016). Bioactive lipids (arachidonic acid and other unsaturated fatty acids) can also boost resistance. Natural polyphenols such as hesperidin and rutin are effective against COVID-19 primary protease inhibitors and are key targets for therapeutic medicines (Adem et al., 2020). Herbal and Chinese medicines have been used to treat viral diseases. Ginseng root, for example, can be used to treat respiratory virus infections (Im et al., 2016). *Astragalus membranaceus* is widely used to treat colds and upper respiratory infections (Luo et al., 2020), but *Pelargonium sidoides* is an efficient herbal treatment (Kolodziej, 2011). Chinese herbal formulae are used as an alternative route to COVID-19 treatment and prevention (Pietrobelli et al., 2020). Some bioactive foods (quercetin) suppress the enzymatic activity of SARS 3-chymotrypsin-like protease (3CLpro). This is required for SARS-CoV-2 replication and can be used to treat COVID-19 patients (Yang et al., 2020). Dietary supplements (vitamins, botanicals, bioactive lipids, and flavonoids) may help the human immune system.

Nonetheless, there is no evidence that such bioactive compounds can sufficiently increase immune function to

TABLE 3 Antimicrobial activities of foods bioactive compounds.

Food source	Compounds	Antimicrobial activities
Kale	Kaempferol	Anti-inflammatory
Avocado, pistachio, almond	B-sitosterol	Anti-inflammatory
Red grape	Resveratrol	Anti-inflammatory
Turmeric	Curcumin	Anti-inflammatory
Onion	Quercetin, thiosulfinates, and anthocyanins	Antioxidant
Citrus fruits	Hesperidin	Antioxidant, anti-inflammatory, antiviral
Garlic	Diallyl disulphide, alliin, polyphenols, proteins	Antioxidant, antiviral
Honey	p-coumaric acid, ellagic acid	Antimicrobial, antiviral
Tea Plant	Gallic acid, theaflavin-3,3′-digallate, quercetin, catechins	Antioxidant, antiviral, immunomodulatory
Mango	Flavonoids, xanthones, phenolic acids, triterpenes	Antioxidant, antiviral
Plum	Anthocyanins, protocatechuic acid	Antioxidant
Soybean	Flavonoids, Isoflavones, phytosterols, saponins and organic acid	Antioxidant
Grapes, berries	Quercetin	Antioxidant, anti-inflammatory
Barberry	Berbamine, berberine	Anticancer
Long pepper, black pepper	Piperine	Anticancer
Banana	Bananin	Antiviral
Nuts, seeds	Stigmasterol	Antiviral
Cranberry	Myricetin	Antiviral

prevent or cure COVID-19 (Han et al., 2021). Furthermore, in the novel era of the COVID-19 pandemic, researchers are looking for suitable medications to enhance the immune system in the future. Nutritional deficiencies in macro- and micronutrients can have an effect on immune function and infection resistance (Filip et al., 2021). Several functional foods, including pepper, garlic, turmeric, and onion, may have immunomodulatory and antiviral effects (Table 3).

Health conditions

This section studied the associations between body compositions. The following issues are addressed: (a) body composition variations, (b) the correlation between body composition and changes (e.g., physical activity and nutrition), and (c) body composition as a risk factor.

Physical activity was marked by a sharp decrease at the pandemic's beginning (Ding et al., 2021). Those with a higher body fat percentage had less physical activity due to a lower fat proportion (Poobalan et al., 2014). Body composition was assessed by measures of fatness (Neovius et al., 2005), bioimpedance analysis (Ding et al., 2021), or BMI to investigate alterations between underweight, overweight, and normal-weight people (Gwynn et al., 2011; Bell et al., 2018). Obesity people are at an increased risk for COVID-19 (Freuer et al., 2021). For example, obesity class II increased the hazard of COVID-19 in individuals over 65 years; however, BMI has a linear relationship with the virus in adults aged 65 (Christensen et al., 2021).

Furthermore, visceral fat was found in patients with COVID-19 who required critical care (Favre et al., 2021). In COVID-19, body composition was assessed using the waist circumference/paravertebral muscle circumference ratio. It was proposed as a predictor of a poor clinical outcome on low-dose computed tomography of the chest (Kottlors et al., 2020). Additionally, abdominal obesity in COVID-19 patients with respiratory symptoms was found to be an independent risk factor for respiratory distress as determined by the waist-to-hip ratio (van Zelst et al., 2020). Obesity may also have an impact on immune responses to viruses, inflammatory reactions, and metabolic and respiratory issues (Coelho-Ravagnani et al., 2021; Sinska et al., 2021). It could be explained by its effect on immunity, which alters the etiology of ARF (acute renal failure) and pneumonia (Rebello et al., 2020). In COVID-19, obesity and morbid obesity were identified as major risk factors for ICU admission (Foldi et al., 2020). Obese patients with a higher BMI should be constantly monitored and may require medication assistance sooner to treat colds and upper respiratory infections (Zhao X. et al., 2020). Obesity or BMI should be considered key indicators, and obese COVID-19 patients should be considered a high-risk group (Tamara and Tahapary, 2020; Yang et al., 2021). Regarding energy balance, the negative changes in body composition during a pandemic should be endorsed to match changes in physical activity and diet, indicating a decrease in energy expenditure and an increase in caloric absorption (Huber et al., 2021). Furthermore, obesity reduces vaccine efficacy in people suffering from rabies, hepatitis B, tetanus, and influenza; thus, immunization conditions and constraints on the efficiency of COVID-19 inoculation should be considered (Liu et al., 2017).

TABLE 4 Multilevel framework to promote nutrition and food security during the COVID-19 pandemic.

Multilevel framework	Action to support
Individual	(a) Food usage
	(b) Alterations in eating habits
	(c) Insufficient physical activity
Community	(a) Food accessibility
	(b) Social services
	(c) Food availability
	(d) Vulnerable groups equality
	(e) Advertisement
Nationwide	(a) Agriculture and food policies
	(b) Public relations and food marketing
	(c) Food security
	(d) Food assistant programs
	(e) Nutritious food baskets
Worldwide	(a) Food safety laws and regulations
	(b) Food distribution and transportation
	(c) Agreement on food trade
	(d) Capacity development and research
	(e) Inventory pricing

Nutrition at multilevel and health conditions

Previous pandemics have shown that as a pandemic progresses, it is critical to expanding community health efforts through clinical supervision to include basic supervision concepts and optimize resource usage. Since the COVID-19 pandemic, personal and social resilience have emerged as valuable resources and continue to be the first line of defense in crisis response. Indeed, mental and behavioral countermeasures at both the personal and communal levels are critical factors in accomplishing public health ingenuities in the face of a pandemic with the magnitude of COVID-19 (Reissman et al., 2006). Individual nutritional status has long been considered a prognosticator of flexibility and instability (Cobb, 2011). The ecology of difficulty and flexibility indicates that significant stresses, such as deprivation of nourishment, can have long-term repercussions on health (Yousafzai et al., 2013). Deprived nutrition eminence is related to both corporeal and psychological health problems (Hislop et al., 2006). Optimal nutrition and dietary consumption are resources that extend beyond the personal and communal to have a worldwide impact (Ma and Lee, 2012). In response to the COVID-19 pandemic, this article suggests a plan of action (Table 4) for maintaining good nutrition on a personal, community, national, and international level.

The common denominator that drives most nutrition and dietary advice to treat viral infections, including COVID-19, is the relationship between food and immunity. Existing research indicates that nutrition significantly impacts the immune system and illness susceptibility. Specific food or nutritive element combinations influence the immune system via cell activation, signaling molecule synthesis changes, and gene expression (Valdes-Ramos et al., 2010). Furthermore, nutritional elements are important factors in gut infectious arrangements and, as a result, can determine the nature of the body's immunological responses (Wypych et al., 2017). Low immune function and increased sensitivity to infection have been linked to protein, energy, and micronutrient shortages. Maintaining immune function requires a diet rich in iron, zinc, and vitamins A, E, B6, and B12 (Nieman, 2020). So, the best way to keep an immune system that works is to avoid dietary deficiencies needed for immune cells to activate, interact, differentiate, or show how they work.

Pandemics cause consumer demand to be unclear and volatile, making it especially difficult to manage food supplies in a just-in-time economy (Vo and Thiel, 2006). A study of the effect of an outbreak on behavior found that stockpiling supplies, food, and water was the most common response (Kohn et al., 2012). Therefore, it is critical to raise community awareness of panic buying. Furthermore, during the COVID-19 pandemic, older people and patients with chronic illnesses were especially vulnerable to nutritional imbalances. Existing data indicates that people aged 60 years and older and patients with pre-existing medical disorders, particularly heart disease, lung illness, diabetes, or cancer, are more likely to suffer severe or even fatal coronavirus infections. Second, given their sensitivity, the instructions to stay at home and practice social distancing explicitly targeted these populations. Third, due to their weakened health and reduced purchasing power, the elderly and patients with chronic conditions may already be vulnerable to malnutrition. So, at the community level, it is very important to find these vulnerable groups and help them get food by setting up a structured and reliable support system.

While boundary safety is essential to protect the health of individuals, it can cause major disturbances in trade, travel, and tourism and infringe on civil liberties (Gostin, 2006). Therefore, ensuring the smooth flow of global trade and fully using international markets as a crucial weapon for guaranteeing global food supplies and eliminating food insecurity is critical. The worldwide nature of COVID-19, in which no country is immune to its spread and devastation, illustrates a fundamental lesson: a global threat necessitates global action. Each country's preventative measures should be complemented by global collaboration and coordination to ensure that humanity survives this epidemic with as few losses as possible. In summary, while there is still much to learn about COVID-19, its effect on nutrition and food consumption has already gone well beyond the individual and communal levels, reaching national and global levels. This outbreak underlined the interconnectedness of these numerous levels, as an individual's health directly

TABLE 5 Recommendations to reduce COVID-19's impact on nutrition and food security.

Multilevel framework	Recommendations for nutrition
Individual	(a) Avoid spreading myths about nutrition and nutritional consumption, as well as the COVID-19
	(b) Eat well-balanced meals to avoid irregular snacking.
	(c) Citrus fruits, dark green leafy vegetables, almonds, and dairy products, for example, are high in vitamins A, C, E, B6, B12, zinc, and iron
	(d) Uphold a healthy lifestyle that includes exercise (at home), adequate rest, and meditation
	(e) Smoking, drinking, and narcotics should all be avoided
Community	(a) Raise awareness about the dangers of hoarding and panic-buying
	(b) Identify and assist those in the community who are at risk of malnutrition, particularly the elderly and those with chronic illnesses
	(c) Generate a systematic and dependable support system to ensure that all people of the community have access to, and can afford, necessary food commodities
Nationwide	(a) Uphold a high level of transparency to foster trust, cooperation, and compliance
	(b) Define, finance, and distribute a low-cost food basket that fulfills the population's health needs, ensures the utilization of local agricultural produce, and reduces dependency on food imports
	(c) Raise funds to cover the cost of food and supplies
	(d) Exempt stable foods and goods from taxation
	(e) Agriculture and food processing sectors should be supported
	(f) Keep an eye on food prices and markets
	(g) Connect with the private sector, international organizations, and local communities to form networks
Worldwide	(a) Assuring the uninterrupted flow of global trade and preventing any trade restrictions would be useful to keep food and feed supplies, as well as agricultural input supplies, from worsening local conditions already strained by COVID-19 response actions
	(b) Import taxes and other food-related restrictions should be reduced

resulted from his understanding and choices, community togetherness, government readiness, and, eventually, global action in response to this threat. From this perspective, a framework for action and recommendations are offered at each of these levels. Table 5 summarizes these recommendations.

Conclusions

This study shows that the COVID-19 pandemic has a deleterious impact on people's diets and physical and mental health. During the COVID-19 pandemic, people's eating habits were, on average, less healthy, especially during a lockdown, which was linked to weight gain. According to this study, there was a significant prevalence of food and nutrition-related worries throughout the COVID-19 pandemic lockdown period. These worries were linked to a higher likelihood of reporting changes in dietary behaviors, such as food preparation and consumption. The capacity of the current dietary recommendations to manage dietary issues during a public health emergency is limited, and it is possible that they do not have the precision to offer dietary advice to various people. Age, weight, and income are among the sociodemographic factors linked to higher levels of food, nutrition, and health concerns, indicating the need for appropriate programs and policies to support disadvantaged people and lifestyle recommendations to encourage healthy eating. This study also sheds insight on probable explanations for this shift, such as depression, decreased shopping frequency, which is linked to lower fresh food consumption, and increasing fast food marketing. We also encourage scientists to anticipate future pandemic food and nutrition priorities as well as to build a more resilient food system that better integrates critical factors such as the food supply chain, nutritional security, healthy food accessibility, health, and food safety and preparation communication in the event of long quarantines. Developing long-term "exit strategies" and goals to prepare for future pandemics is vital. As a result, as also stated, a global food, nutrition, and associated science advisory council is needed to prepare for future pandemics and provide advice. The advising scientific body's recommendations must be shared and embraced by decision-makers to ensure successful and long-term program execution. It is important to practice food hygiene and eat a balanced diet rich in fresh fruits and vegetables to maintain a healthy lifestyle and an effective immune system that can fight off infection and disease. Although there is no proof that the coronavirus may spread directly through food, packages may be contaminated with SARS-CoV-2 and could do so. Packaging may be required to contain bioactive substances that neutralize infectious contaminants to lower the risk of transmission. We essentially want to prevent more outbreaks that tax the healthcare

system, given the possibility that SARS-CoV-19 will continue to spread throughout the population. Further research should be conducted on the psychological and physiological impacts of prolonged lockdowns, the probable persistence of altered behaviors, and their effects on personal and societal health in the post-lockdown and post-pandemic eras.

Author contributions

Conceptualization, software, validation, formal analysis, investigation, resources, writing—original draft preparation, and visualization: PR. Methodology and data curation: PR and MS. Writing—review and editing: PR, MS, EJ, and SK. Supervision, project administration, and funding acquisition: SP. All authors have carefully read, reviewed, edited, and agreed to publish the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Matching ecological transition and food security in the cereal sector: The role of farmers' preferences on production contracts

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Introduction: Under an increasing demand from citizen and public institutions, agri-food supply chains are requested to comply with stringent environmental requirements. Moreover, new sources of uncertainty related to pandemic and geo-political turbulences put further pressures on economic agents, calling for proper and resilient governance mechanisms. Under the lens of the Neo Institutional Economics, we focus on production contracts and their clauses which, in turn, perform different functions and contribute to allocate property and decision rights, in the attempt to conciliate sustainability and food security.

Methods: In this framework, contract design assumes a key importance. Thus, we analyze farmers' preferences for different contractual clauses in the cereal sector. A choice experiment is carried out among durum wheat producers in Italy and mixed logit estimations assuming heterogeneous preferences are performed.

Results and discussion: Findings provide interesting indications, revealing a strong farmers' willingness to adhere production contracts in exchange for price stability and knowledge transfer offered by technical assistance services. However, producers are not available to limit their decisional autonomy in unilateral agreement with buyers and they reveal a certain indifference to costly production techniques aimed to improve environmental sustainability.

KEYWORDS

contracts, sustainability, food security, NIE, transaction costs, uncertainty, choice experiment, Italy

1. Introduction

In the last decades, greenhouse gas emissions from agri-food systems have increased of around 20%, accounting for about 30% of all emissions related to human activities in 2019 (FAO, 2022). Moreover, it is estimated that 85% of projected losses in biodiversity will be caused by agriculture and forestry (Vazquez-Brust et al., 2020). It follows that not only the agri-food sector negatively impacts on the environment but it also increasingly suffers from the main consequences of climate change, that could irremediably affect biodiversity, soil fertility, and last but not least, food security (Chandio et al., 2020). In order to push the transition toward global sustainable food systems and models, United Nations Member States approved the 2030 Agenda for Sustainable Development, revolving around the 17 Sustainable Development Goals (SDGs). Lately, the European Commission promoted the ecologic (or green) transition thanks to the European Green Deal and the Farm to Fork and Biodiversity strategies, all aimed to make agri-food system more sustainable (Dupraz, 2020; Schebesta and Candel, 2020). Such a transition mainly entails full decarbonisation and reduction of all GHG emissions down to a very low level (Prieve, 2022). As the general level of society's environmental consciousness increases, both consumers and downstream supply chain partners need to select eco-friendly products (Chu et al., 2017). Concerned with improving sustainability to enhance operational, economic, and social

responsibility performance, many companies have begun therefore to incorporate cleaner technologies, and new organizational and logistical practices in the attempt to realize circular supply chains (González-Sánchez et al., 2020). For instance, food producers increasingly endorse and implement standards that establish criteria for sustainable production and sustainable management practices strongly relying on narrower collaboration with suppliers and customers for their implementation, with a growing interest for alternative food initiatives (Aggestam et al., 2017).

More recently, both the COVID-19 outbreak and the Russo-Ukrainian war had impacts on food security (Béné, 2020; Laborde et al., 2020; Mardones et al., 2020; Coopmans et al., 2021; Hassen and El Bilali, 2022; Hellegers, 2022). In this framework, there is an increasing need of progressively reconciling productivist and environmental standpoints, while addressing increasing technological, geopolitical, behavioral, and many other sources of uncertainty at stake. Such a situation calls into question coordinated, resilient, and responsive governance mechanisms regulating transactions in local and global agri-food supply chains. In more detail, both design and negotiation of contracts gain a key role (Li and Zhu, 2020). Companies requiring a consistent amount of agricultural raw materials have widely adopted contract farming (CF) to coordinate their supply chains (Abebe et al., 2013; Mugwagwa et al., 2020). According to Pinstrup-Andersen and Cheng (2009, p. 37), CF entails "agricultural production carried out according to a pre-planting agreement in which the farmer commits to producing a given product in a given manner and the buyer commits to purchasing it." In this paper, we focus on production contracts, that is, a type of agreement between a buyer and its suppliers (either farmers or storage organizations) that frame the production and the transaction of a commodity (Bogetoft and Olesen, 2002). Compared to CF, production contracts refer more explicitly to the type of agreement in itself and its organizational dimension and not to the more global phenomenon of agricultural production under contract. Unlike traditional marketing contracts, which only specify basic clauses related to delivery modality, quantity and price, crop production contracts also contain also input and output specifications (Ricome et al., 2016). According to Cholez et al. (2020), therefore their main aim is to coordinate production, exchange and knowledge development among stakeholders. In doing so, they may play a relevant role in the field crop sector, because of their effect on reducing transaction costs.

Against this backdrop, the present paper aims to explore and analyze the role played by production contracts and their clauses (or terms) in matching farmers' preferences in the durum wheat sector. This is a strategic sector (particularly relevant in Italy, where the study was conducted) at the center of geopolitical turmoil for food security reasons, since the Russia-Ukraine conflict has started. The innovative contribution of this paper to the literature in the field of production contracts is two-fold. First, it proposes and test an original classification of contractual clauses and their function according to the NIE framework. Then, accordingly, using a discrete choice experiment and a mixed logit analysis, it analyzes the potential attractiveness of contractual clauses, including those related to the diffusion of sustainable production patterns in an uncertain context. To this purpose, in the following sections we first conceptualize the role of production contracts and their content, then, we elaborate research hypotheses looking at different functions and areas of intervention of contractual terms and at their likely acceptance from farmers. Methodology adopted is then described in detail, focusing on the characteristics of a discrete choice experiment conducted among Italian wheat producers and analyzed by means of mixed logit estimations. Lastly, results are described and discussed in the light of the existing literature in this field, before final remarks and recommendations are provided.

2. Conceptual framework

2.1. The NIE approach to contracts

A relevant strand of the agribusiness literature has been mainly centered on CF solutions as a tool (or "treatment") for rural poverty alleviation, evaluating their impacts on smallholder farmers' welfare (in terms of employment, credits, farm incomes) in the least developed countries and across many crops (see Bellemare and Bloem, 2018 for an exhaustive review). Not without exceptions due to unfair practices and lack of transparency (Ruml and Qaim, 2020), CF clauses provide access to knowledge, better technologies (e.g., highly productive varieties), and credit, stimulating skill transfer and promotion of quality standards (Da Silva and Ranking, 2013; Mishra et al., 2018). However, under the concept of CF, there is a diversity of governance mechanisms that widely range from basic to more articulated contracts providing inputs and technical assistance.

The term "governance mechanism" is rooted in the Neo Institutional Economics (NIE) (Coase, 1988; Williamson, 1991, 1996). According to Williamson (1985), it is necessary to choose the mechanisms that minimize transaction costs, i.e., the ex-ante and ex-post costs of planning, adapting, and monitoring task completion of an agreement intrinsically related to different sources of asset specificity and uncertainty. Under the NIE view, contracts gain momentum as interesting governance solutions in response to coordination, safeguard and adaptations needs, so as to lower transaction burdens (Ménard, 2013; Martino and Polinori, 2019; Vazquez-Brust et al., 2020; Vicol et al., 2021).

In this paper, we adopt the Ménard (2022) representation (Figure 1) in order to conceptualize the role of contractual mechanisms which are able to provide monetary and non-monetary incentives aimed to stimulate a process of joined centralization/decentralization of both property rights (that is, control over strategic investments) and decision rights (that, is governance). In turn, such a combination of incentives (to centralize/decentralize decision rights and/or the control over strategic investments) established by contractual clauses is able to shape organizational solutions aimed to minimize both production and transaction costs due to asset specificity and uncertainty.

Going into details, the curve from A to B (or external frontier) in Figure 1, that is concave to the origin, defines the optimal alternatives that could be reached with respect to the degree of control and coordination required. The curve from C to D (or internal frontier), that is convex to the origin, designates more formal agreements, with no room for relational adjustment. The intersection between these two curves delimitates the area under which misalignments between decision and property rights tend to make the organization of transaction costs hardly feasible, with the only exceptions of "spot markets" (segment from A to C) and

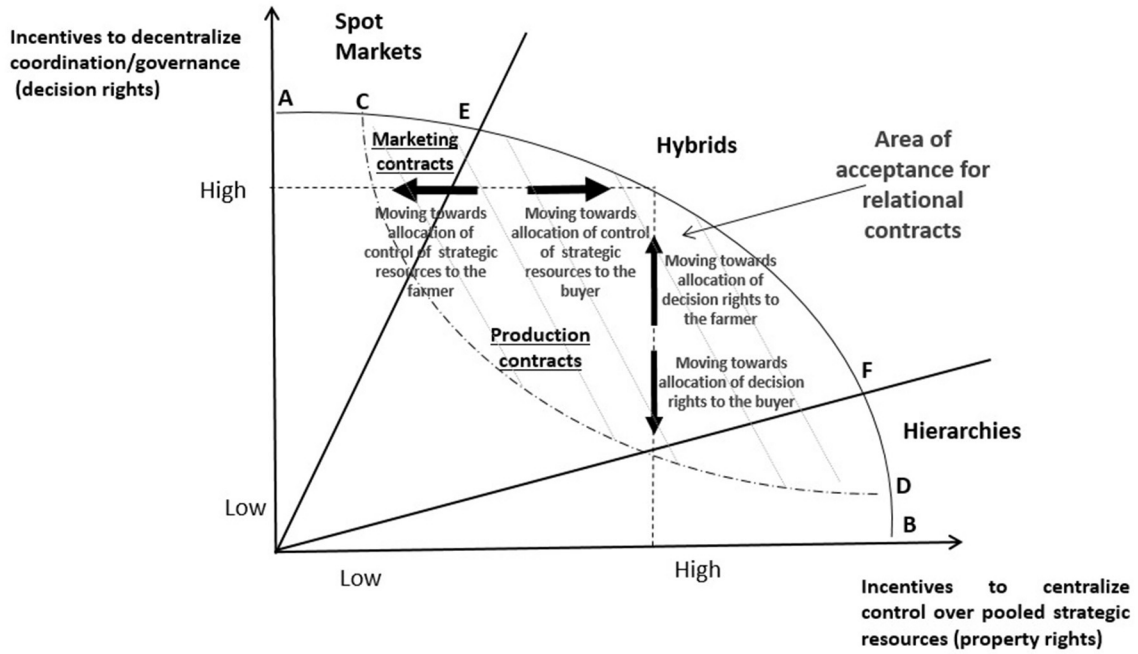

FIGURE 1
Setting the research problem under the NIE lens: linking property and decision rights, transactional attributes, and organizational arrangements. Source: Our elaboration based on Ménard (2017, 2018, 2022).

"command firm" (segment from B to D). All other arrangements involve relational contracting with varying degree of efficiency and are located in the lens-shaped area covering markets (segment C-E), hierarchies (segment F-D) and, mainly, hybrids (segment E-F). This latter is the zone where commonly production contracts flourish, develop, and operate offering incentives for pooling strategic resources and governance decisions among the parties. Moreover, the figure reveals that, within the area of acceptance of relational contracts, the more partners expect to gain from pooling strategic assets, the more motivated they are to sacrifice their autonomous control over property rights. Symmetrically, the more they expect to gain from coordination over co-specialized investments, the more motivation they have to endorse centralized decision-making (Ménard, 2022).

Focusing on the topic under analysis, in response to the increasing interest of consumers and public authority for environment protection, agri-food production contracts engage multiple area of farming activities, spanning from technology definition and implementation, to quality strategies, and environmental resources. Multiple sources of uncertainty then affect the decision making process of farmers and processors, facing the necessity of combining private good provisioning and environmental services and protection. This fact has two implications, since economic agents seek to combine the contractual arrangements economizing on both transaction and production costs (Martino and Polinori, 2019). First, production contracts tend to become more complex requiring the specification and the alignment of multiple contractual terms. Second, because of the uncertainty surrounding transactions parties may face the need to adapt the contractual arrangement during its life and design further mechanisms to cope with the issues raised by non-contractible elements emerging after that the contract has been signed by the parties.

2.2. The role of contractual clauses

Following Martino and Polinori (2019) and Oliveira et al. (2021), a production contract is seen as the combination of specific clauses/terms (henceforth also named "attributes") that encompass both governance and production costs. As a consequence, the profit of the farmer i (i = 1, 2, 3 . . . N) for each contract c (c = 1, 2, 3. . .) is:

$$\pi_{ic} = V_{ic} - (C_{ic} + T_{ic}) \quad (1)$$

where π_{ic} is the profit, V_{ic} is the value of the final product obtained from the contract under the form of revenue, C_{ic} represents production costs and T_{ic} represents the transaction costs (that are function of the type of rights at stake and their negotiation).

In line with Williamson (1985) and Ménard (2017, 2018, 2022), we adopt a comparative approach that considers the alternative combinations (of property and decision) rights that are derived from different contractual attributes, entailing different values and costs. For instance, all other things being equal, insertion/removal of a contractual clause affects both value and (production and transaction) costs involved, as follows.

$$\sum_{j}^{J} \beta R_{ijk} = V_{ijk} - (C_{ijk} + T_{ijk}) \quad (2)$$

where R_{ijk} represents an index for the alternative j from a choice situation k of contractual attribute which are included in a contract by the i_{th} farmer, and β represents the unit monetary value of each term.

In our case, each contractual term brings its own value (that we assume constant for simplicity) as well as production and transaction costs. In practical terms, because we assume that the value V is given and therefore independent of the contract chosen, the farmer

maximizes profit π by choosing, among alternatives, a contract c including combinations of contractual attributes j that minimize the expected variations of both production and transaction costs.

Hereafter, further elaborating on Williamson (1979), Mellewigt et al. (2012), and Ménard (2022), we conjecture connections among transactional attributes and functions of contractual clauses in allocating decision and property rights, which are able to affect preferences under scrutiny. Moreover, based on previous empirical evidences in the agri-food sector, we assume that widely adopted contractual clauses operate in some of the following areas of intervention: production, exchange and knowledge transfer. Accordingly, we develop research hypotheses on farmers' preferences, separately looking at contractual clauses based on their main areas of intervention and their functions.

2.2.1. Exchange clauses

Irrespective of the degree of centralization of decision and property rights, one of the fundamental elements of (more or less elaborated) contracts is represented by exchange clauses. This category encompasses a group of contractual clauses that parties adopt to regulate prices, methods and time of payment, and modality of delivery.

Price is probably the most common attribute in empirical studies dealing with contracts (Tuyen et al., 2022). Scholars report several different solutions, spanning from "open" price following market volatility to fixed price, under the form of minimum guaranteed price, passing through mixed alternatives where market price is used as a reference point for complex design of contract price (Bogetoft and Olesen, 2002).

Other exchange clauses refer to the schedule, modalities, location, and methods of payment and delivery (Ochieng et al., 2017). Solutions mainly encompass immediate, anticipated or postponed payment, taken the delivery as reference point. Under the NIE lens, the rationale of these categories of contractual clauses is to offer monetary incentives and coordinate decisions about exchange and payment with the aim to both safeguard parties against opportunistic behavior and offer a protection against uncertainty in output market. As a consequence, a first set of research hypotheses that explicitly refer to exchange clauses is elaborated.

Hypothesis 1a. Contractual clauses centralizing coordination of decision rights on price significantly affect farmers' preferences, protecting them from market uncertainty.

Hypothesis 1b. Contractual clauses centralizing coordination of decision rights on the modality of payment significantly affect farmers' preferences, protecting them from behavioral uncertainty.

2.2.2. Production clauses

This category encompasses a wide variety of contractual clauses providing incentives to concentrate decisions rights over production, so as to enhance coordination among parties. In more details, these clauses intervene to regulate production techniques and, increasingly in the last decades, quality and sustainability requirements.

2.2.2.1. Technique and production rules

This type of contractual clauses refers to production decisions and rules for the use of specific technical inputs that are sometimes also provided by the buyer with specific arrangements (Lemeilleur et al., 2020). Clauses may also include the way the final product must be delivered to the buyers, with or without storage, additional treatments or first processing (Blandon et al., 2010). To sum up, contractual clauses allocate among the parties involved in the contract the right to decide the rules of production. In doing so, they incentivize coordination and offer safeguard to specific investments, against potential negative consequences of opportunistic behaviors related to the wrong use of technology in the production process. Thus, the following research hypothesis comes out as a consequence.

Hypothesis 2a. Contractual clauses centralizing both coordination of decisional rights on production techniques and control over pooled strategic resources significantly affect farmers' preferences, offering safeguard for specific investments and protection from technological uncertainty.

2.2.2.2. Quality

Increasing importance of credence attributes leads to a growing need for coordination along the agro-food supply chain, so as to avoid deleterious consequences in terms of legal liability, reputational damage and consumer confidence (Ménard and Valceschini, 2005; Martino and Perugini, 2006). Contractual clauses introducing quality requirements provide incentives to centralize decision over the use of technology, since this can have direct consequences on the use of input and dedicated investments to achieve certain quality threshold (Frascarelli et al., 2021). As a consequence, a new research hypothesis is elaborated, as follows.

Hypothesis 2b. Contractual clauses centralizing both the coordination of decision rights on quality requirements and control over pooled strategic resources significantly affect farmers 'preferences, since they safeguard dedicated investments and protect them from technological and behavioral uncertainty.

2.2.2.3. Sustainability practices

The concept of jointness of production is a key characteristic of so-called nature-related transactions costs that have been often overlooked in literature, even if with some important exceptions in the NIE field (Hagedorn et al., 2002; Vatn, 2002; Hagedorn, 2008). Following Hagedorn (2008), for example, buying and applying fertilizers and pesticides on a crop might result in higher yields with farm income increases as a consequence. While such a transaction is intended and expected, a fraction of the applied chemical inputs might end up in the groundwater or in a nearby river imposing additional costs on actors using this water for drinking purposes. According to the seminal work of Coase on social costs (Coase, 1960), in the real world the attempt to allocate property rights in order to establish who is in charge of compensating whom for some environmental damage is not costless, because of the existence of transaction costs.

This fact explains why when formal laws or environmental standards are absent or not well-enforced and implemented, sources of technological, and behavioral uncertainty around the outcomes of nature-related transactions increase: to cope with them, economic agents react developing governance mechanisms and organizational structures (Ménard, 2017). Such a situation paves the road for the increasing diffusion of contractual clauses that refer to environmental sustainability. Even if these contractual terms are intrinsically related (and somehow similar) to production rules and quality specifications,

they have gained importance because of the increasing collective demand for developing and adopting sustainable innovations techniques from both consumers and public authorities (Stanco et al., 2020). Accordingly, we formulate another research hypothesis.

Hypothesis 2c. Contractual clauses centralizing both coordination of decision rights on sustainable cultivation techniques and control over pooled strategic resources significantly affect farmers' preferences, since they safeguard dedicated investments and protect them from technological and behavioral uncertainty.

2.3. Knowledge transfer clauses

Another area where production contracts increasingly intervene is related to knowledge and innovation (Martino and Polinori, 2019). Under a NIE perspective, economic rationale of knowledge transmission thanks to clauses referred to the provision of technical assistance is at least three-fold (Ciliberti et al., 2019). First, these contractual ensure terms a continuous monitoring of production processes and coordination of decisions, possibly reducing risks of opportunistic behavior and information misalignment. Second, in doing so they indirectly allow to safeguard specific investments in key inputs, monitoring and controlling their use so as to enhance quality of productions. Last but not least, to a certain extent, it introduces a flexible and dynamic mechanism to adapt the use of key inputs, techniques and production to exogenous and incontrollable factors that in turn represent sources of technological uncertainty. As a consequence, we are able to formulate the following research hypotheses.

Hypothesis 3. Contractual clauses centralizing both coordination of decision rights and control over strategic resources by means of a technical assistance services significantly affect farmers' preferences, since they safeguard key investments as well as coordinate and adapt production choices in presence of behavioral and technological uncertainty.

3. Material and methods

3.1. Experimental design and contract attributes

Choice experiments are a standard tool to evaluate the preferences of respondents with respect to hypothetical goods or services and are widely used in consumer research and environmental economics (Hensher et al., 2005; Louviere et al., 2010). Recently, choice experiments have also gained popularity in the agricultural economics field. The choice model on which this study is based deepen its roots in random utility approach (Louviere et al., 2010).

The starting point in designing a choice experiment is selecting relevant attributes and their corresponding levels (Hensher et al., 2005). Attributes (i.e., contractual clauses in our case) and levels were based on previous analyses and direct observations of the most representative contracts used in the durum wheat supply chain in Italy. Moreover, attributes and their levels were selected and tested with key stakeholders directly involved in designing and negotiating contracts, to validate the experimental design and enhance its robustness and reliability. Table 1 reports the list of attributes and levels considered for this work, building a bridge between the conceptual framework and the analytical framework.

Once we decided on the final attributes and levels specification, we designed the choice sets that would be presented to respondents. In more detail, combining the six attributes according to their three levels, a full factorial design would consist of $3^6 = 729$. However, such a number of contracts is too complex to manage for a respondent. Therefore, we reduced the design to a D-efficient DCE where attributes and their levels were randomly distributed into 18 choice sets, each one with three possible contracts. As a result, 54 different contracts were involved in the end, representative of 729 possible contracts.

Moreover, choice sets were arranged into six blocks (each one with three choice sets) and each farmer was submitted to one of these blocks. Then, for each choice set, three choice situations came out in which the farmer was allowed to specify his preference toward one out of three contracts; as an alternative, he could also decide to select the opt-out (no-choice), opting for "none of the previous contract." As a result, different contracts were proposed to farmers, characterized by six attributes (each one with three levels), reflecting different types of transactional attributes, contractual functions, and incentives to centralize property and decision rights.

In order to test the research hypotheses a purposive sampling strategy was adopted to get insights from our study population, consisting of Italian farmers producing durum wheat. This crop covers 40% of the Italian cereal production, with around 150,000 farms cultivating an area of 1.3 million hectares, for an average production of around 4 million tons and a total value of 2 billion euro (Council for Agricultural Research Economics, 2021). Face-to-face interviews were conducted by trained and experienced interviewers, based on their own judgment when choosing potential respondents attending technical workshops and seminars all around Italy, between late 2019 and early 2020. As a consequence, inclusion in the sample mainly depended on farmers' participation to these workshops, their willing and interest to participate in the survey and their ability of correctly answering. To gather information, we used a structured questionnaire including a choice experiment to investigate farmers' preferences over contractual terms, details of which are provided later on. Characteristics of the sample, made of 163 farmers, are displayed in Table 2.

3.2. Econometric analysis

From a statistical point of view, the standard choice model, the multinomial logit (McFadden, 1974), assumes that substitution patterns are defined by the Independence of Irrelevant Alternatives (IIA) restriction. It implies that relative probabilities of two alternatives are unaffected by other alternatives, so that preferences for attributes of different alternatives are assumed to be homogeneous across individuals (Kanninen, 2007). Over the past years alternative modeling approaches have been developed that relax the IIA restriction, such as the mixed logit model also known as a mixed multinomial logit model or random-parameter logit model, which uses random coefficients to model the correlation of choices across alternatives. Mixed logit or random parameter logit is used in many empirical applications to capture more realistic substitution patterns than traditional conditional logit. The random parameters are usually

TABLE 1 Contract design: Concepts, areas of interventions, functions, and attributes.

Area of intervention	Transactional attribute(s) involved	Contractual attributes under analysis	Levels of attributes	Main contractual function(s)	Research hypothesis
Exchange	Market uncertainty	Price	• Guaranteed minimum price • 100% open price based on the average of the commodity exchange • Mixed (50% open−50% fixed) price based on production costs	Coordination	H1a
	Behavioral uncertainty	Modality of payment (time)	• 100% in September • 50% in September, 50% in March • Monthly payments	Coordination	H1b
Production	• Technology and behavioral uncertainty • Asset specificity	Technique and production rules	• Free process (freely decided by the producers) • Agreed with industry • Imposed by industry	• Coordination • Safeguard	H2a
	• Technology and behavioral uncertainty • Asset specificity (brand and dedicated investments)	Quality threshold	• Proteins content > 12.5% • Proteins content > 13.5% • Proteins content > 14.5%	• Coordination • Safeguard	H2b
	• Technology and behavioral uncertainty • Asset specificity (brand)	Sustainability of production	• Optimized nitrogen application methods (ONAM) • Conservation agriculture (CA) • Both (ONAM + CA)	• Coordination • Safeguard	H2c
Knowledge transfer	• Technology and behavioral uncertainty	Technical assistance	• Yes • Yes, through a decision support system • No	• Coordination • Adaptation	H3

TABLE 2 Characteristics of the sampled durum wheat producers and their farms ($n = 163$).

Variable code	Variable meaning	Mean	SD	Min	Max
Age	No. of years	48.66	12.82	19	87
Exp	No. of years of experience as farmers	28.09	13.44	3	60
High_edu	Owner of high school diploma, degree or Ph.D. (y/n)	0.82	0.38	0	1
UAA	No. of hectares of utilized agricultural areas	144.87	291.27	2.6	2,204
UAA_dw	No. of hectares of durum wheat (y/n)	68.75	145.49	0	1,000
COOP/POs_m	Members of cooperatives/producers organizations	0.53	0.50	0	1
Contr_COOP/POs	Contracts with cooperatives and POs	0.16	0.37	0	1
Contr_proc	Contract with processors	0.62	0.49	0	1

assumed to follow a normal distribution, and the resulting model is fit through simulated maximum likelihood.

In doing so, it accounts for preference heterogeneity among respondents and repeated choices (McFadden and Train, 2000; Train, 2009). To account for such a heterogeneity, the random utility approach describes the utility U_{ijk} consisting of a systematic (observable) component and an error (unobservable) component ε_{ijk}. In more detail the latter component is represented by a vector of random coefficients of the attributes X of individual i for choosing alternative j and choice situation k can be included in equation.

$$U_{ijk} = X_{ijk}\beta_i + \varepsilon_{ijk} = X_{ijk}\beta + \text{ÆŠ}(\beta)X_{ijk} + \varepsilon_{ijk} \quad (3)$$

The utility coefficients β vary according to individual (hence β_i) with density function of the random parameters $f(\beta)$. This density can be a function of any set of parameters, and represents in this case the mean and covariance of β in the sample population.

The mixed logit choice probability of choosing alternative j in a choice situation k is therefore given by

$$P(Y_{ijk} = 1) = \int \frac{\exp\left(x_{ijk}\beta\right)}{\sum_{j=1}^{J}\exp(x_{ijk}\beta)} f(\beta)d\beta \quad (4)$$

where Y_{ijk} is the choice variable of individual i for alternative j in choice situation k.

For this paper, we ran four mixed logit estimates. In model 1 the price coefficient is fixed, since we assume homogenous preferences of farmers for high prices, following a common approach in similar studies (Schipmann and Qaim, 2011; Ochieng et al., 2017). Then, being in presence of modalities of pricing options rather than price

levels, we also considered price as random in model 2, allowing for heterogeneous preferences among farmers. Both models include an alternative specific constant (ASC) to account for the fact that the choice sets include a *status quo* ("none of the proposed contract") option. Lastly, since contract preferences may be correlated with socioeconomic characteristics, we run two additional models (models 3 and 4) with the same specification of model 1 and 2 and interaction terms between ASC and control variables (related to farmers and farm characteristics) already described in Table 2.

Econometric analyses are run using the software Stata 14.2 and, in particular, packages based on Train (2003) and Hole (2007) for mixed logit with usual optimization methods for maximum likelihood estimation.

4. Results

Results are obtained on a final sample of 163 completed questionnaires, filled in by durum wheat producers. Since each producer faced three choice situations, 489 choice set were available. However, 105 times (equivalent to 21.3% of the choice set), respondents opted for the "no-choice" alternative. Table 3 shows the raw choice frequency (%) for each attribute level, excluding the case where the "no-choice" option is selected. What emerges is that choices were almost equally spread over the three levels of each attribute, with some interesting exceptions for the price, technique and technical assistances attributes. Going into details, the "guaranteed minimum price" and the "100% open price" were selected in 44.7 and 21.0% of the choices, respectively. Moreover, only in <1 choice out of four, farmers opted for contracts were production techniques were imposed by the industry. Lastly, producers showed a larger acceptance for technical assistance (77% of the choices), combined or not with decision support systems.

TABLE 3 Percentage of "yes" for each attribute ($n = 384$*).

Attribute	Level	%
Price	Guaranteed minimum price	44.7
	100% open price	21.0
	Mixed (50% open−50% fixed) price	34.3
Time of payment	100% in september	35.1
	50% in september, 50% in March	35.3
	Monthly payments	29.6
Technique	Free process	39.0
	Agreed with industry	37.1
	Imposed by industry	23.9
Quality threshold	Proteins content > 12.5%	37.6
	Proteins content > 13.5%	35.1
	Proteins content > 14.5%	27.3
Sustainable cultivation practice	Optimized nitrogen application methods (ONAM)	33.5
	Conservation agriculture (CA)	31.2
	ONAM + CA	35.3
Technical assistance	No	23.1
	Yes	38.2
	Yes, through a decision support system (DSS)	38.7

*Excluding the "no-choice" option, frequencies within each attribute sum up to 100%.

Overall, the sample resulted quite heterogeneous with respect to respondent characteristics. On average, farmers are 48 years old (sd = 12.82), with 28 years of experience in the field (sd = 13.43). About one-fifth of the respondents own a degree, while about 18% has low or no education at all; the remaining 60 % took a high-school diploma. Farmers manage on average 144.87 hectares (sd = 291.27), of which on average 68.75 hectares (sd = 145.5) are cultivated with durum wheat. While 12.7% of respondents are associated with producers' organizations (POs) and 40.5% with cooperatives, the remaining respondents (46.8%) are not. Contracts with POs are used by 16.1% of respondents, while those with processors in 62.1% of the cases. Moreover, almost 42% of those contracting with POs also use contract with processors. However, almost one-third of the respondents do not use any type of contracts at all.

As far as the mixed models estimation are concerned, Tables 4, 5 report the marginal effects of the estimated models to facilitate the interpretation of the results.

Results reveal that some preferences toward attributes are significant and relevant.

First of all, the "no-choice" option has a negative and significant coefficient (m.e. are −3.406 in model 1 and −3.500 in model 2), indicating that farmers strongly prefer the contracting alternative over maintaining the status quo. This result is remarkable, given that not all the sampled farmers used to adopt contracts, suggesting a potential relevant interest for such a governance tool.

As for the price, in both mixed models farmers significantly prefer a guaranteed minimum price solution (the reference clause) in spite of open price solutions (m.e. are −0.878 in model 1 and −1.588 in model 2) or mixed price alternatives (m.e. are −0.410 in model 1 and −0.922 in model 2).

With regard to technique, results highlight a significant farmers' reluctance to rules unilaterally imposed by the processing industry purchasing durum wheat (m.e. are −0.533 in model 1 and −1.024 in model 2) compared to the possibility for a free production process (the reference clause).

Very interestingly, producers do not show significant preferences toward contractual attributes referred to the adoption of sustainable practices. At the same time, durum wheat producers are strongly and significantly attracted by the opportunity to benefit from technical assistance and decision support systems provided by buyers (m.e. are +0.488 in model 1 and +0.711 in model 2 for traditional support only, and +0.526 in model 1 and +0.679 in model 2 for modern technical assistance by means of decision support systems).

As far as the quality threshold and related duties are concerned, empirical evidences highlight clear and significant farmers' preferences toward lower level of commitment (and related production costs), that is a protein content of 12.5% rather 14.5% (m.e. are −0.546 and −0.815, respectively, in models 1 and 2).

Time of payment do not significantly affect farmers' preferences, with the only exceptions of mixed model 2 where estimates reveal a slight opposition to monthly payments compared to full payment after harvesting (m.e. = −0.430).

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TABLE 4 Parameter estimates for the mixed logit models 1 and 2: marginal effects (m.e.).

Attribute	Level	Mean (1)			SD (1)			Mean (2)			SD (2)		
		m.e.	$P>\|z\|$	Std. err.	m.e.	$P>\|z\|$	Std. err.	m.e.	$P>\|z\|$	Std. err.	m.e.	$P>\|z\|$	Std. err.
Price	100% open price	−0.878	***	0.194	:	:	:	−1.588	**	0.456	−1.748	**	0.567
	Mixed price	−0.410	**	0.163	:	:	:	−0.922	**	0.318	1.919	***	0.458
Time of payment	50% in September 50% in March	0.137		0.165	0.438		0.294	0.152		0.228	−0.478	**	0.314
	Monthly payments	−0.219		0.181	−0.226		0.317	−0.430	*	0.251	0.658	***	0.302
Technique	Agreed with industry	0.064		0.146	0.146		0.460	0.486		0.216	1.030	**	0.378
	Imposed by industry	−0.553	**	0.184	−0.309	**	0.471	−1.024	**	0.347	1.679	**	0.591
Quality threshold	Proteins content > 13.5%	−0.255		0.174	0.857	**	0.274	−0.386		0.252	0.926	**	0.354
	Proteins content > 14.5%	−0.546	**	0.189	−0.856	**	0.310	−0.815	**	0.288	0.330		0.597
Sustainable cultivation practice	CA	−0.151		0.160	−0.106		0.401	−0.099		0.231	−0.197		0.454
	ONAM + CA	−0.109		0.181	−0.646	**	0.318	−0.050		0.244	1.043	**	0.387
Technical assistance	Yes	0.488	**	0.185	0.730	**	0.294	0.711	**	0.271	−1.153	**	0.436
	Yes, through DSS	0.526	**	0.176	−0.025		0.293	0.679	**	0.240	0.357		0.349
No choice	Yes	−3.406	***	0.876	4.475	***	0.865	−3.506	***	0.845	4.340		0.771
No. of observations	1,956						1,956						
No. of respondents	163						163						
Log likelihood	−570.894						−560.281						
LR chi^2 (11)	139.51	***					160.74	***					

Significance levels: ***1%, **5%, *10%. ":" means "not estimated".

Lastly, models 3 and 4, introducing interaction terms between the "no-choice" option and control variables, substantially confirm previous results revealing also a significant role played by high education in fostering farmers participation to contracts. Interestingly, previous contracting experiences with cooperatives, producers' organizations and processors significantly decrease farmers' willingness to join production contracts.

5. Discussion

Empirical results allow to confirm the majority of the hypotheses under analysis, even if with some relevant exceptions. Henceforth, findings are therefore properly discussed in the lights of the existing literature in the field, following the order of presentation of the hypotheses in the conceptual framework.

The first group of hypotheses refers to clauses that affect exchanges.

As for the hypothesis 1a, results reveal that farmers prefer clauses able to ensure a higher level of coordination leading to a centralization of decision rights on price in order to address market uncertainty. In our case farmers perceive a minimum guaranteed price as explicitly abler to play a stabilization role even better than a mixed price, that is however costlier to enforce and somehow exposed to price volatility. This result is in line with Minten et al. (2009), Miyata et al. (2009), and Blandon et al. (2010), confirming that fixed price options provide farmers insurance against downside price risks. However, evidences contrast with Wang et al. (2011) and Abebe et al. (2013) who reported smallholders' preference for a floating price, when the ex post spot market price is expected to exceed the price proposed in the contract.

TABLE 5 Parameter estimates for the mixed logit models 3 and 4: marginal effects (m.e.).

Attribute	Level	Mean (3)			SD (3)			Mean (4)			SD (4)		
		m.e.	$P>\|z\|$	Std. err.	m.e.	$P>\|z\|$	Std. err.	m.e.	$P>\|z\|$	Std. err.	m.e.	$P>\|z\|$	Std. err.
Price	100% open price	−1.043	***	0.233	:	:	:	−1.328	**	0.401	0.924		0.652
	Mixed price	−0.439	**	0.179	:	:	:	−0.848	**	0.306	1.801	***	0.499
Time of payment	50% in September 50% in March	0.236		0.186	0.248		0.275	0.124		0.225	0.145		0.361
	Monthly payments	−0.139		0.204	0.326		0.348	−0.331		0.258	0.533		0.439
Technique	Agreed with industry	0.094		0.164	−0.027		0.411	0.168		0.198	0.422		0.406
	Imposed by industry	−0.660	**	0.250	0.741		0.461	−1.034	**	0.354	0.977	**	0.470
Quality threshold	Proteins content > 13.5%	−0.262		0.201	0.582		0.377	−0.445	*	0.267	0.835	**	0.383
	Proteins content > 14.5%	−0.529	**	0.217	0.654	*	0.386	−0.784	**	0.275	−0.398		0.467
Sustainable cultivation practice	CA	−0.128		0.185	0.061		0.346	−0.067		0.233	−0.316		0.517
	ONAM + CA	−0.102		0.188	0.030		0.452	−0.160		0.240	0.503		0.405
Technical assistance	Yes	0.386	*	0.216	1.157	**	0.342	0.552	**	0.258	1.179	**	0.495
	Yes, through DSS	0.328	*	0.188	0.228		0.379	0.388	*	0.226	−0.067		0.495
No choice (nc)	Yes	−2.846		2.200	2.987	***	0.673	−4.770	*	2.544	4.174	***	1.00
nc*Age		−0.065		0..068	:	:	:	−0.097		0.078	:	:	:
nc*Exp		0.092		0.057	:	:	:	0.182	**	0.079	:	:	:
nc*High_edu		3.434	**	1.105	:	:	:	4.416	**	1.317	:	:	:
nc*UAA		0.000		0.001	:	:	:	0.001		0.001	:	:	:
nc*UAA_dw		0.003		0.004	:	:	:	0.001		0.004	:	:	:
nc*COOP/POs_m		−0.694		1.051	:	:	:	0.250		0.844	:	:	:
nc*Contr_COOP/POs		−2.075		1.458	:	:	:	−3.791	**	1.301	:	:	:
nc*Contr_proc		−2.118	**	0.917	:	:	:	−3.809	**	1.228	:	:	:
No. of observations	1,512						1,512						
No. of respondents	163						163						
Log likelihood	−430.098						−420.760						
LR chi^2 (11)	69.10	***					87.77	***					

Significance levels: ***1%, **5%, *10%. ":" means "not estimated".

For what concerns the other clause intervening on the exchange area, findings do not allow to confirm hypothesis 1b related to the modality of payment. Farmers do not see such a contractual attribute as a remedy able to offer coordination and mitigate potential behavioral uncertainty. This result contradicts other studies (Schipmann and Qaim, 2011; Gelaw et al., 2016; Anh et al.,

2019), where delivery and payment mechanisms are of paramount importance for farmers. However, while Widadie et al. (2020) noticed a group of interviewed farmers neglecting this type of clauses, Oliveira et al. (2021) also found a similar pattern in a previous study in the durum wheat sector, where producers were not significantly interested to contractual terms establishing the modality of payment in advance.

The second group of hypotheses is referred to clauses regulating production and its features.

In this area of intervention, what emerges is that farmers prefer a higher degree of decentralization of decision rights on the production process rather than a quasi-hierarchical centralization imposed by the industry without negation. Interestingly, against the expectation that farmers rely on clauses that ensure coordination of decisions to both safeguard their specific investments and protect them from technology and behavioral uncertainty (as in Oliveira et al., 2021 and in Al Ruqishi et al., 2020), here what prevails is the decisional autonomy for a production cycle characterized by a low level of dedicated investments. However, this evidence is in line with Abebe et al. (2013) and Vaissiere et al. (2018), which showed that the probability of accepting a contract decreases with increasing levels of restrictions on management practices, since farmers place more value on the freedom to make autonomous decisions. All that said and considered, we must reject hypothesis 2a.

With regard to quality of durum wheat production, the hypothesis 2b is confirmed. In line with Goodhue (2011), farmers reveal a preference toward a contractual clause introducing a certain degree of coordination aimed to centralize decision rights on quality requirement, reducing technology and behavioral uncertainty and introducing safeguard for dedicated investments. In this regard, literature is plenty of examples of contractual clauses regulating stringent food safety and product quality standards or imposing quality specifications (Raynaud et al., 2005, 2009; Arouna et al., 2017). All these clauses refer to quality requirements, which have a large impact on farmers' acceptance because they not only define minimum quality levels but also payment of premium prices. In our case, the reluctance to accept costly obligations, such as an excessive quality threshold (e.g., 14% or even 13% of protein content for durum wheat), can be attributed to possible quality measurement problems in line with Abebe et al. (2013) and Oliveira et al. (2021).

Very interestingly, despite the potential of contractual arrangements in promoting environmental sustainability in the agri-food sector (Ren et al., 2021), empirical evidences do not allow to confirm hypothesis 2c, in line with Van den Broeck et al. (2017). Results highlight that farmers tend to not accept a clause centralizing decision rights on sustainable cultivation techniques, which could contribute to guarantee safeguard for dedicated investments and protection from technological and behavioral uncertainty. Possible explanations are at least two-fold. First, such a clause can be used to transfer liability of the environmental pollution from agribusiness firms to farmers (Huong et al., 2020). Second, producers are not particularly committed to more sustainable practices *per se*, so that they do not accept specific obligations, if not in exchange for incentives promoted by leading actors in the agri-food supply chains (Shi et al., 2020; Ciliberti et al., 2022). Looking outside, a decisive role certainly can be played on the one hand by the institutional environment, unable to provide sufficient incentives or disincentives (in terms of rewards and penalties) and on the other hand, by consumers and clients unwilling to pay more to compensate producers from extra costs due to the adoption of environmental-friendly practices.

The last hypothesis concerns clauses intervening on knowledge transfer.

In this case, results show that farmers see favorably a contractual term centralizing both coordination of decision rights and control over strategic resources by means of whatever form of technical assistance. What emerges is that durum wheat producers rely on this category of services, in order to better coordinate and adapt their production choices, reducing behavioral and technological uncertainty and benefitting from some form of safeguard for their key investments as well. In line with Anh et al. (2019) and Ihli et al. (2022), these evidences allow to confirm research hypothesis 3 revealing that extension and advisory services are largely accepted from farms, since they can help improving both their productivity and performance. Moreover, technical assistance may contribute to guiding farms in transitioning toward more sustainable and resilient practices (Labarthe and Laurent, 2013; Šumane et al., 2018).

6. Conclusions

In a scenario where continuing societal and institutional pressure for an ecological transition are imposing a shift toward eco-friendlier production process, the COVID-19 crisis and the Russian-Ukrainian conflict increasingly questioned the ability of the agricultural sector to ensure both food security and environmental sustainability. This fact calls for a necessary balance between two apparently contrasting goals, that in turn interrogates coordination mechanisms along the agri-food supply chain as an opportunity for reconciling food production and environmental protection.

Adopting a NIE perspective, our paper shed lights on production contracts as an interesting solution to govern transactions among economic agents, regulating not only modality of production but also exchange and knowledge transfer and directly impacting on both property and decision rights allocation. Looking at production contracts under this lens, we focused on contract design, that is a fundamental step where actors' preferences toward specific terms reflect the role played by transactional attributes, such as uncertainty and asset specificity, and the consequent need for safeguard, coordination or adaptation solutions.

In doing so, this paper contributed to unravel the complex interactions among contractual areas of interventions, contractual functions, and transactional attributes in the cereal sector, highly impacted by recent geo-political turmoil. Even if based on a small and not representative sample of Italian farmers that hinder whatever generalization of results, empirical evidences revealed a widespread interest for production contracts and offered other valuable indications.

What emerged was that farmers' preferences on contractual clauses were composite and not necessarily in line with previous evidences. Farmers did not accept unilateral and extremely stringent rules imposed by the industry, showing a certain degree of managerial autonomy which must be taken into account when negotiating contracts. In this regard, fixed prices and the provision of technical assistance were key terms in leading producers' choice to join a contract. These clauses have a role in safeguarding investments and protecting against uncertainty, while making the relationships more adaptive to unexpected events and new techniques. Likewise, quality

thresholds also played an important function in coordinating and guiding production choice and protecting investments, but only if the request from industry was not extremely burdensome for farmers.

However, neither the condition of payments nor, more interestingly, the adoption of sustainable practices without specific rewards were of any interests for producers. Such a latter finding raised important questions on what could be useful monetary or non-monetary incentives able to stimulate sustainable commitments in the cereal sector.

In conclusion, matching production and sustainability targets in contractual arrangements brings implications that, in turn, call for both managerial and policy actions in a scenario of international crisis with direct and negative consequences on international trade and prices for fertilizers and energy.

Governing the ecological transition cannot ignore farmers needs for containing increasing input costs and adapting to potential sources of uncertainty, related to increasing market and geopolitical instability as well as to new technological pressure in emerging digital business ecosystems. Along this pathway, due to their organizational nature, contractual solutions should not be approached as one size fits all solutions, since they are not able to automatically ensure the achievement of whatsoever targets, even more when they are apparently conflicting such as sustainability and food security. Rather, recognizing different contractual functions, areas of intervention and effects on property and decision rights, managers and policymakers should invest in supporting more inclusive process of production contract design, based on fair and collaborative negotiation of contractual terms, so as to enhance their diffusion.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

SC: conceptualization, methodology, formal analysis, software, and writing—original draft preparation. AF: investigation. SC and GM: writing—review and editing. GM and AF: validation and supervision. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Interstate war and food security: Implications from Russia's invasion of Ukraine

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In this article, we review and shed light on the interlinkages between interstate war and food insecurity and discuss global policy actions needed to address the challenges of food insecurity due to interstate war. We conceptualize the interlinkages between these two issues with a focus on: (i) the most critical and direct cause of interstate war, namely geo (territorial) political conflict, and (ii) the mechanisms through which interstate war affects four different food security pillars, namely food availability, food access, food utilization, and food stability. We position that, if unsuccessfully addressed, geo (territorial) political conflicts will create a vicious cycle of violence and hunger. This position is illustrated by analyzing recent Russia's invasion of Ukraine. Herein a summary of the root and nature of the invasion and how it has affected global food security is presented, with a discussion on the potential considerations and solutions to avoid the cycle of violence and hunger.

KEYWORDS

food security, geopolitical conflict, interstate war, cycle of violence and hunger, international security system

1. Introduction

The right to food is considered a human right. Whilst under international law, states are obliged to respect, protect and fulfill the right to food of their populations, the practical difficulties in achieving this human right are demonstrated by prevalent food insecurity across the world (Margulis, 2013). According to the Food and Agriculture Organization (FAO), the number of hungry people worldwide has increased from about 630 million in 2014 to 690 million in 2019, and to between 720 and 811 million in 2020 (FAO, 2021). This means in 2020, around 1 in 10 of the world population faced hunger, and roughly 70 to 161 million more people faced hunger in 2020 than in 2019 (FAO, 2021). In addition, around 2 billion people (25.9% of the global population) did not have regular access to nutritious and sufficient food in 2019. The increase in the number of hungry and undernourished people is mainly attributed to the growing number of conflicts, climate-related shocks, or economic slowdowns due to the COVID-19 pandemic (FAO, 2021). These figures indicate that we are not on track to ending hunger by 2030 and that further actions are required to achieve the Sustainable Development Goal (SDG) of zero hunger.

One of the reasons and also consequences of food insecurity is geopolitical conflict, generally referred to as conflicts with geographic and political natures and roots. Although geopolitics might also indicate relations between sub-national geopolitical entities, the term usually refers to countries and their relations. Geopolitical conflict heightens tensions between countries, and interstate armed conflict or war might happen if the conflict is not

successfully solved (Sempa, 2002). The association between domestic (or within-country) armed conflict and different dimensions of food security has been well documented in the literature (see Messer and Cohen, 2007; Brück et al., 2016). However, much less is known about the interrelations of geopolitical conflict between countries and global food security. The end of the Cold War seemed to awaken the old hope of a new and democratic world freer from violence than in previous ages, and instead, the "new world order" further increased armed conflicts (Reuber, 2000). The most visible impact of armed conflicts on food security is that they destroy farmland, irrigation schemes, and infrastructure. Moreover, armed conflicts also disrupt food supply chain and distribution, creating food crises in food-importing regions. Food insecurity, in its turn, can prolong or intensify armed conflicts, creating a vicious circle of violence and hunger (Martin-Shields and Stojetz, 2019).

The Russia's invasion of Ukraine is a typical example of an armed conflict rooted in geopolitical considerations (Saâdaoui et al., 2022). The direct effects of the war are already evident. Thousands of people, mainly Russian and Ukrainian, including children and women, have died, and millions have been displaced (UNHCR, 2022). Food, fuel, and fertilizer prices have spiked. As it is widely known, war-induced food insecurity problems are very likely to trigger armed conflicts in already poor regions (Bellemare, 2015). Russia's invasion of Ukraine has led to food crises in many countries, with several of them being very poor such as Cameroon, Kenya, and Nigeria (Human Rights Watch, 2022). The current food crises due to the war in Ukraine indicate the weaknesses of the international community in governing food (in)security in conflict settings (Kemmerling et al., 2022). Since the beginning of the invasion on February 24, 2022, there have been a number of publications either on the causes or the effects on food security (Behnassi and Haiba, 2022; Harvey, 2022). However, these efforts have not linked the two issues systematically and have, therefore, been unable to provide sufficiently useful information for international policy responses.

Against this background, in this article, we review and shed light on the interlinkages between interstate war and food insecurity to better understand the global policy actions needed to address the food insecurity challenges resulting from interstate war. Our aim is not to undertake a comprehensive and systematic literature review on either interstate wars or food security, as this has been done and is available in the literature. Instead, we synthesize the literature to conceptualize the circle of violence and hunger based on the two-way relationship between interstate war and food (in)security. We use Russia's invasion of Ukraine as an example which is rooted in the geopolitical conflicts between these two countries and has profound effects on global food security. The food crises induced by this invasion are likely to trigger conflicts in other parts of the world. We use the data from secondary but reliable sources such as articles published in peer review journals or from international organizations such as FAO and the World Bank to establish our arguments supported by reliable media sources such as Reuters or Bloomberg. Our paper is structured as follows. Section Geopolitical conflict, interstate war, food security, and the circle of violence and hunger conceptualizes the interlinkages between interstate war and food security. We start this section with one of the most important causes of interstate war, i.e., geopolitical conflict. We then review the mechanisms through which an interstate war impacts different pillars of food security. We position that geopolitical conflict, if unsuccessfully addressed, will create a vicious cycle of violence and hunger, not only in the current conflicting region but also in other regions that are experiencing food crises due to the conflict. Section 3 illustrates our position regarding the current invasion of Russia to Ukraine. Herein, we briefly summarize the root and nature of the invasion and how it affects global food security. Section 4 discusses potential considerations and solutions to avoid the vicious cycle of violence and hunger.

2. Geopolitical conflict, interstate war, food security, and the circle of violence and hunger

2.1. Geopolitical conflict and interstate war

Conflict is defined as a serious disagreement or argument, typically a protracted one, between countries, human groups, and individuals (Bearce and Fisher, 2002). There are several forms of conflict, but armed conflict or war between or among countries (interstate war) is the most severe, destroying human society through loss of infrastructure and human lives. There are several causes of interstate war, such as (i) trade or commerce (Lake, 1992; Lake and Rothchild, 1996; Henderson, 1997; Henderson and Tucker, 2001; Rosato, 2003), (ii) identity or ideology (Sambanis, 2000; Sanín and Wood, 2014), (iii) geo (territorial) political issues (Flint, 2006; Valigholizadeh and Karimi, 2016), and (iv) external events or processes, such as climate change (Burke et al., 2015). Interstate war can happen due to only one or several causes. For example, the last cold war period between the capitalist and the communist blocs witnessed many geopolitical conflicts and interstate wars between or among countries in the two blocs (Sempa, 2002). The cold war also reflects the ideological differences between socialism/communism and capitalism; the Vietnam War from 1955 to 1975 is a typical example of a war on both ideology and identity. Even though it was between the North and South of Vietnam, the war was essentially between the two states: one in the North that the communist bloc supported, and the other in the South that was supported by the United States (US) and several Western countries (Miller and Wainstock, 2013). In fact, during the last several decades, armed conflicts within or between some countries have arisen as different armed groups have tried to prove their identity or impose their ideology (Ugarriza and Craig, 2013; Pettersson et al., 2021).

Among these causes, geopolitical conflict seems more complicated and challenging to address. Geopolitical conflict refers to the struggle over controlling geographical entities with an international and global dimension and using such entities for political advantage (Flint, 2006, p. 16). Thus, geopolitics involves thinking and acting geographically and explains how countries, human groups, or individuals try to reach their political goals by controlling geographic entities such as the places, regions, territories, scales, and networks that make up the world.

TABLE 1 Milestones of global food security policy.

Year	Issues	Authority
1946	Rights of labor	UN declaration of Philadelphia
1947	Exclusion of agriculture from trade rules	General Agreement on Tariffs and Trade (GATT)
1948	Freedom from want	Universal declaration of human rights
1966	Right to food	International covenant on economic, social, and cultural rights
1974	Freedom from hunger and malnutrition as the inalienable right	World food conference universal. declaration of hunger and malnutrition
1974	Agriculture included in trade rules	Uruguay round of multilateral trade negotiation
1992	Food security and sustainability	UN earth summit
1992	Rights extended to nature	Convention on biological diversity
1996	Right to sufficient, safe, and nutritious Food	World food summit
2000	Food security and eradication of poverty	UN millennium summit: millennium development goals
2009	Food security as a systemic challenge	UN committee on world food security
2010	Ramifications for the global food system	North–South summit: international meeting on cooperation and development
2013	Food insecurity experience scale (FIES)	FAO
2015	Sustainable development Goal 2 aims to achieve "zero hunger"	UN general assembly: sustainable development goals
2016	Food and humanitarian aid	UN world humanitarian summit
2018	Protection of civilians in armed conflict	UN security council resolution 2417
2022	The Food Shock Window (FSW)	International monetary fund
2022	Global alliance for food security	G7
Source:	Adopted from wilkinson, 2015, IMF, UN.	

If a geopolitical conflict cannot be resolved through peaceful methods, it could lead to war (Valigholizadeh and Karimi, 2016). Geopolitical conflict, thus, is considered one of the most potent causes of interstate war, threatening the entity and sovereignty of nation-states.

Two critical features characterize geopolitical conflict. First, it is persistent and not easy to be resolved because the causes of conflict are geographic values that are among the national and collective interests. Therefore, it is not negligible and challenging for the parties involved to compromise on it (Hafeznia, 2006, p. 126–128). Second, resolving geopolitical conflict requires goodwill, cooperative behavior, friendly relations, and trust between states involved in the conflict (Mojtahedzadeh, 2000, p. 176) and full respect and compliance with international principles and laws on the sovereignty of other states. This is even more difficult if one party of geopolitical conflict is a "super" power in international relations such as the USA or Russia, who are among the five permanent members of the United Nations Security Council with the right to veto any resolutions that go against their own national interests.

2.2. Food security

The right to food was first established in 1948 in the globally recognized Universal Declaration of Human Rights. As defined by the Committee on Economic, Social and Cultural Rights (CESCR), the right to adequate food is realized when every man, woman, and child, alone or in a community with others, has physical and economic access at all times to adequate food or means for its procurement (CESCR, 1999). In 1974, the United Nations (UN) announced the Universal Declaration on the Eradication of Hunger and Malnutrition in the wake of the food price shocks during the 1970s and major food calamities, such as famine in Bangladesh (Wilkinson, 2015) and in 2015, Zero Hunger was created as one of the Sustainable Development Goals (SDGs) by the UN General Assembly and is intended to be achieved by 2030.

Food security is the measure of food and individuals' ability to access it. The UN Committee on World Food Security defines food security as "when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life." According to the World Food Summit (1996), food security has four pillars: availability, access, stability, and utilization. Food availability refers to the availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports (including food aid). Food access means the access by individuals to adequate resources (entitlements) for acquiring appropriate food for a nutritious diet (e.g., through money). Food utilization refers to the quality and diversity of diets. Food stability means that food can be accessed at all times (Grote et al., 2021).

From a historical perspective, there have been milestones in understanding the food security concept (see Table 1). First, the "Right of Labor" was established in 1946 by the UN in the declaration of Philadelphia. Next, agriculture was excluded from

trade rules in 1947. Access to food became a human right with the Universal Declaration of Human Rights in 1948. The right to food was included in the International Covenant on Economic, Social, and Cultural Rights in 1966. Overall, the post-war period consolidated individual rights and progress toward food security with a new geopolitical framework to exclude food from being commodification. In 1974, the UN announced the Universal Declaration on the Eradication of Hunger and Malnutrition, under which agriculture was excluded from the General Agreement on Tariff and Trade (GATT).

However, with the reformulation of the World Trade Organization (WTO), agriculture began to be progressively treated as other economic commodities. Food security has transformed structurally with historical changes in international trade and agreements and is bound by geopolitical perspectives. The US and European Union (EU) initially pushed for agricultural trade liberalization to promote a competitive agricultural economy by negotiating with the GATT and WTO. Since the 1980s, simultaneous advances in the agriculture and global food markets have impasse at multilateral level pressures for liberalizing agricultural markets with free trade agreements (Wilkinson, 2015). In 2000, the eight Millennium Development Goals were adopted at the UN Millennium Summit, in which the first goal was to eradicate extreme poverty and hunger by 2015. In 2015, the 17 Sustainable Development Goals were adopted by the UN General Assembly as part of the Post-2015 Development Agenda, including no poverty (Goal 1), zero hunger (Goal 2), and peace, justice, and strong institutions (Goal 16). Various efforts have been made to assist in the achievement of these SDGs. For example, the Committee on World Food Security (CFS) was established in 1974 and reformed in 2009 as the foremost inclusive international and intergovernmental platform for all stakeholders to work together to ensure food security and nutrition for all. FAO developed the Food Insecurity Experience Scale (FIES) to create a shortened, standardized experience-based measure for use across sociocultural contexts (Ballard et al., 2013).

In response to conflict-induced crises, including food crises, the UN World Humanitarian Summit was organized in 2016 to fundamentally reform the humanitarian aid industry to react more effectively to crises. The UN Security Council Resolution 2417 of 2018 stresses the importance of belligerent compliance with international law and condemns the denial of humanitarian access to affected civilians. The resolution also stipulates that obstructing humanitarian access in conflict settings can result in targeted sanctions (Kemmerling et al., 2022). In 2022, the International Monetary Fund (IMF) Executive Board approved a new Food Shock Window to provide a new channel for emergency fund financing to member countries that have an urgent balance of payment needs due to acute food insecurity, a sharp increase in their food import bill, or a shock to their cereal exports. Also, in 2022, the Global Alliance for Food Security was established by the G7 countries to support immediate aid measures relating to food security and facilitate the long-term transformation of global agri-food systems toward more resilience and sustainability. Despite all these efforts, ensuring food security is still a challenge, especially in the context of increasing geopolitical and armed conflicts worldwide.

2.3. Interlinkages between interstate war, food security, and the circle of violence and hunger

Interstate war, primarily due to geopolitical conflict, and food security are characterized by high complexity and contextualization. On the one hand, geopolitical conflict negatively affects the level of food security and, thus, is considered a cause of food insecurity as it reduces food availability, access, utilization, and stability. On the other hand, food insecurity can cause or trigger conflict (Messer and Cohen, 2007). Interstate war affects food security in conflict regions directly and in other regions indirectly. There are at least five channels through which an interstate war affects food security (Figure 1): physical destruction, human displacement, food control, hunger as a weapon of war, and disruptions in trade and value chains. The first four channels can be easily observed in a conflict region as war destroys agricultural land, irrigation schemes, and infrastructure; displaces humans; and creates starvation, and threatens the food security of the affected population (Kemmerling et al., 2022). In interstate wars, belligerent states aim to harm, defeat, or even eliminate their enemies, and consequently, this results in massive physical destruction, which affects people's vulnerabilities.

The destruction of agricultural land and related infrastructure due to armed conflicts and the expansion of war zones lead to mass displacement. The impacts on food security are direct and severe in both the short- and long-term. War-induced displacement leads to the collapse of agricultural production and the decay of infrastructure at the origin; disrupts or interrupts local, regional, or even international supply chains; and increases food prices. At the same time, the displaced are exposed to food insecurity. The government or armed forces undertake food control because the food supply is of strategic economic importance to any armed group.

During conflict or crisis, food security concerns might force food-exporting countries to halt or stop their food exports, thereby reducing food supply in international markets, which leads to food price spikes and results in severer food insecurity in food-importing countries. In addition, when conflicts are directed at certain human groups, food insecurity can become a "weapon of war" (Messer and Cohen, 2015), either as an intended strategy or a by-product. The goal is either to deprive a particular warring party or to eliminate entire population groups by starvation (e.g., ethnic cleansing or genocide) (Kemmerling et al., 2022), even though the 1996 World Summit on Food Security declares that food should not be used as an instrument for political and economic pressure. Lastly, interstate wars disrupt the import and export of agricultural inputs and food imports and exports and increase food prices, and this results in food crises in other parts of the world that depend on food imports.

Food insecurity, in turn, can spark, intensify, or perpetuate violent conflict (Buhaug et al., 2015; Martin-Shields and Stojetz, 2019). While food insecurity alone might not be able to cause violent conflict, it can become a decisive factor in increasing social grievances, combined with threats to livelihood, socioeconomic inequalities, and political marginalization (Kemmerling et al., 2022). These factors ignite a vicious circle of violence and hunger and vice versa. A well-known example in history is the French

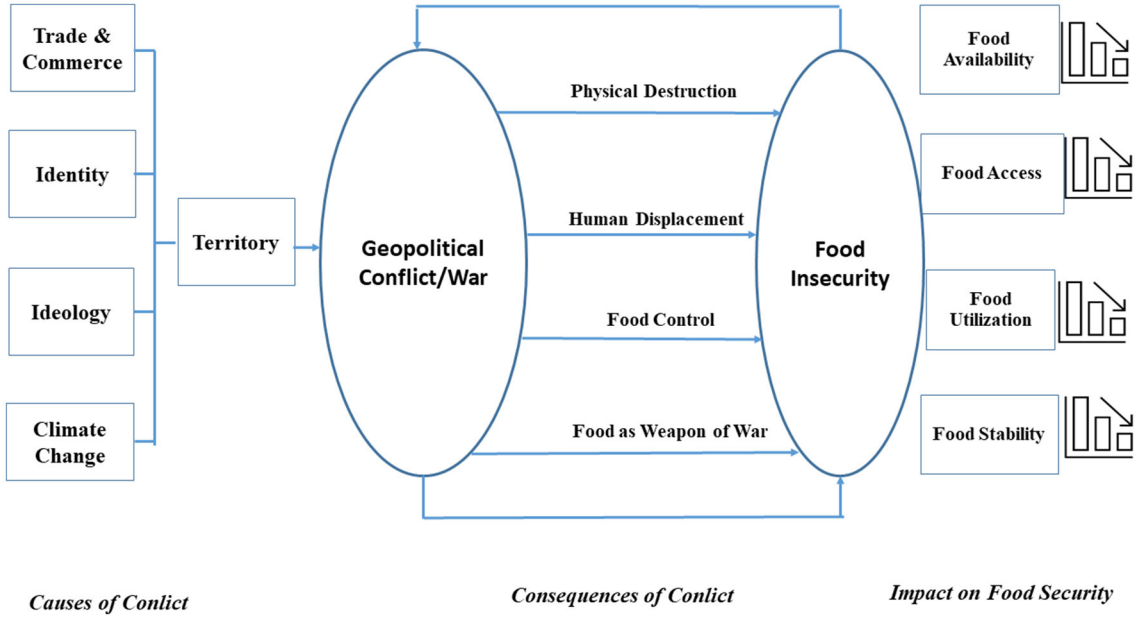

FIGURE 1
Interrelations between interstate war, food security, and the circle of violence and hunger.

Revolution of 1789, primarily fuelled by poor grain harvests that led to sharp increases in the price of essential food commodities, such as bread (Miguel et al., 2004; Bruck and Schindler, 2009). The Arab Spring uprisings of 2011 brought historically high food prices in North Africa and the Middle East. Several other contemporary internal wars indicate the nuances of hunger problems, such as in South Sudan in 2013, Syria in 2011, and Yemen in 2018 (Miguel et al., 2004; Pettersson et al., 2021; Bjornlund et al., 2022). Bellemare (2015) argues that rising food prices causes social unrest and lead to food riots. Food insecurity may trigger, fuel, and sustain conflicts that channel broader grievances, such as poverty, unemployment, low incomes, unpaid salaries, and political marginalization (Brinkman and Hendrix, 2011; Maystadt and Ecker, 2014). Overall, in this way, food insecurity forces more people to be involved in the conflict. Consequently, the vicious cycle of violence and hunger continues to affect people worldwide. As stated by Houngbo (2022), conflict and hunger are closely intertwined; when one of them escalates, the other follows; and it is the poorest and most vulnerable who are hardest hit, and in our globalized world, the impact of the conflict will reverberate across continents.

3. Russia's invasion of Ukraine and global food security

3.1. Root and nature of Russia's invasion of Ukraine

Ukraine is located in Eastern Europe and borders Russia to the east and northeast, Belarus to the north, Poland, Slovakia, and Hungary to the west, and Romania and Moldova to the southwest. The country has a coastline along the Black Sea and the Sea of Azov. Essentially, it is at the crossroads of Russia and Europe. Ukraine used to be a member of the Soviet Union but became a sovereign state after the collapse of the Soviet Union in 1991.

Although most of the population in Ukraine is ethnically Ukrainian, there is a significant ethnic Russian minority, particularly in the eastern region. While the official language in Ukraine is Ukrainian, most people can speak both Ukrainian and Russian (Gessen, 2022). Ukraine was the second most populous and powerful of the 15 Soviet republics. The country is, therefore, significant to Russia geopolitically, historically, and culturally. According to Masters (2002), in its three decades of independence, Ukraine sought to forge its path as a sovereign state while aligning more closely with Western institutions, including the EU and the North Atlantic Treaty Organization (NATO). However, Kyiv has struggled to balance its foreign relations and bridge deep internal divisions. A more nationalist, Ukrainian-speaking population in western parts generally supported greater integration with Europe, while a primarily Russian-speaking community in the east favored closer ties with Russia (Masters, 2002).

On the Russian side, after the Soviet collapse, many Russian politicians, including long-time president Putin, viewed the divorce from Ukraine as a mistake of history and a security threat to Russia (Masters, 2002). President Putin has undertaken a policy based on the assumption that the national identity of Ukraine is artificial and, therefore, fragile. This helps explain the root of the current conflict. It also suggests that Moscow's ambitions extend beyond preventing Ukrainian NATO membership and encompass a more thorough aspiration to dominate Ukraine politically, militarily, and economically (Mankoff, 2022).

The geopolitical issues from both the Russian and Ukrainian sides are reflected in what has been happening in these regions. In

2014, Russia launched an attack on Ukraine, citing that the invasion was just a defense of ethnic Russians who live in the eastern Donbas region (Reals and Sundby, 2022). Russia also used the invasion to annex the Crimean Peninsula unilaterally and has since continued to occupy it even though the international community does not recognize the annexation (Nguyen and Do, 2021). Since 2014, an armed conflict between the Russian-backed separatists and the Ukrainian government has been intensifying in the eastern Donbas region.

A peace deal in 2015 put an end to major battles, but the armed conflict has continued. Russia has now unilaterally recognized the independence of two regions in Donbas (Donetsk and Luhansk) held by the Russian-backed separatists, breaking the peace deal. With the justification that Russia could not feel "safe, develop and exist" due to a serious threat caused by Western-leaning Ukraine, Russia, on February 24 2022, authorized airstrikes across Ukraine and ordered armed forces to advance into the country (Osborn and Nikolskaya, 2022; Reals and Sundby, 2022). In response to Russia's invasion of Ukraine, the USA, EU, and several other countries and entities have been imposing a range of economic sanctions against Russia, targeting the allies of its top leaders, Russia's banking system, and its access to crucial technology. In response to the economic sanctions, Russia has also retaliated by imposing an export ban for more than 200 products, including agricultural and some forestry products, which could directly affect developing nations relying on agricultural imports from Russia (Bloomberg, 2022).

3.2. Role of Russia and Ukraine in global food markets

Ukraine and Russia are major producers and exporters of many food commodities, such as wheat, barley, maize, and vegetable oils. Each country contributes about 6% of global market shares in food calories (Emediegwu, 2022). Ukraine is the world's largest producer of sunflower oil and the fourth, fifth, and sixth largest producer of maize, barley, and wheat, respectively. Together, Ukraine and Russia provide more than half of the world's exports of sunflower oil and approximately about 22, 20, and 14% of global exports of wheat, barley, and maize, respectively (Table 2). They rank first as the world's largest producers of essential staple foods such as wheat, meslin, and barley. In addition, the two countries also come in fourth place as the world's largest producers of maize. Since low-income countries depend more on staple foods in their diets compared to higher-income nations (FAO et al., 2020). Ukraine and Russia, thus, play an important role in feeding the world population, especially the poor and vulnerable. The disruption in the supply of these important staple foods to their trading partners has increased their prices globally, hurting the poor and vulnerable whose diets consist mainly of staple foods (FAO et al., 2020).

Ukraine and Russia also export their food commodities and important agricultural inputs such as fertilizer and fuel to developed and developing countries. As the world's largest exporter of wheat, meslin, barley, and sunflower oil, Ukraine and Russia's agricultural imports reach a wide range of nations, from the world's most populous country (China) to one of the world's

TABLE 2 Export value, share of total world exports, and world ranking of major exported food commodities and agricultural inputs from Ukraine and Russia in 2020.

	Ukraine			Russia			Ukraine and Russia	
	Export value ($ billion)	Share of world export (%)	World Rank	Export value ($ billion)	Share of world export (%)	World Rank	Export value ($ billion)	Share of world export (%)	World Rank
Food commodities:									
Wheat and meslin	3.59	6.80	5	7.92	14.97	1	11.51	21.77	1
Maize (corn)	4.89	12.92	4	0.40	1.05	11	5.29	13.97	4
Barley	0.88	9.95	5	0.90	10.19	4	1.78	20.14	1
Sunflower seed, safflower, or cotton-seed oil	5.3	37.87	1	2.47	17.60	2	7.77	55.47	1
Agricultural inputs:									
Fertilizers	0.38	0.70	23	6.99	12.90	1	7.37	13.6	1
Fuels	0.56	0.04	68	141.92	10.99	3	142.48	11.03	3

Source: Compiled from World Bank data (www.wits.worldbank.org).

poorest countries (Somalia). According to the world trade data in 2020, the top importers of Ukrainian and Russian sunflower oil are India, China, Turkey, and some European countries, while the Middle East and South and Southeast Asia are the leading importers of important grains such as wheat, maize, and barley from the two countries (Figure 2). Similarly, China, Brazil, India, and some Southeast Asian countries are among the top ten largest importers of crucial agricultural inputs such as fertilizers and fuels. Although the majority of the top importers of staple foods and agricultural inputs from Ukraine and Russia have a relatively large economy, a large share of their population still suffers from poverty, nutrition, and food insecurity (i.e., India, China, Brazil, and Southeast Asian countries). In addition, ∼40% of wheat and maize from Ukraine is supplied to the Middle East and Africa, where hunger issues are pressing (IFAD, 2022). Up to 25 African countries, many of which are least developed countries, import over one-third of their wheat supply from Ukraine and Russia (UNCTAD, 2022). The countries include, for example, Eritrea, Somalia, Egypt, Madagascar, Tanzania, Libya, Congo, Namibia, Djibouti, Senegal, Cameroon, Mauritania, Togo, Tunisia, Ethiopia, Sudan, and Kenya. Moreover, humanitarian organizations also buy their grain supply from the region. For instance, the World Food Program (WFP) purchases half of its grain supply from Ukraine (Bearak, 2022). Therefore, the supply of staple foods and agricultural input products from Ukraine and Russia is crucial in achieving the world's food security and nutrition.

The food supply disruption from Ukraine and Russia could jeopardize the food security of many low-income countries worldwide. Figure 3 projects that wheat imports in many African and Middle East countries are highly concentrated toward supplies from Ukraine and Russia. The figure also shows that there are 33 countries whose wheat imports from Ukraine and Russia account for more than 30 percent of their total wheat imports. African nations, including Eritrea, Somalia, and Egypt, are among the top 10 net wheat importers from Ukraine and Russia. Six countries, including Somalia, Georgia, Azerbaijan, Mongolia, Armenia, and Eritrea, have a wheat import dependency level of more than 90%, an overly concentrated level. In case of disruption of wheat supply from Ukraine and Russia, the food security of these countries would fall into a crisis.

3.3. Impact of the war on food security

The ongoing war has affected food security through several channels, as described in Figure 1, including physical destruction, human displacement, food control, food as a weapon of war, and disruptions to the trade and value chains of many food and energy commodities. Farmland, irrigation systems, agricultural machinery, and other facilities have been destroyed within Ukraine, and Ukrainian farmers joined military forces, died, or were displaced. By June 2022, at least 45 million square meters of housing, 256 enterprises, 656 medical institutions, and 1,177 educational institutions in Ukraine had been damaged, destroyed, or seized. The Kyiv School of Economics estimated that the damage done so far to building and infrastructure was nearly $104 billion, and the Ukrainian economy had already suffered losses of up to $600 billion (Deutsche Welle, 2022). Since February 24, 2022, tens of thousands of people have died in this ongoing war (Reals and Sundby, 2022; UN News, 2022). More than 5 million Ukrainians have fled their homes to bordering countries (Russia, Poland, Romania, Moldova, Slovakia, Hungary, and Belarus) to seek safety, and approximately 8 million people are displaced inside Ukraine (BBC, 2022a). Despite various efforts by the EU, UN, and individual nations, such as Germany, Poland, and Turkey, food exports from Ukraine have been very limited due to shuttered ports and mined maritime routes in the Black Sea. Commercial operations in Ukraine's ports have been suspended, making food exports from the country for several months impossible.

Both Russia and Ukraine have undertaken food control, and Russia has been trying to use food as a weapon. The former Russian president and senior security official Dmitry Medvedev called food exports a "quiet weapon" in the fight against Western sanctions: "*Many countries depend on our supplies for their food security,*" Medvedev wrote on his Telegram channel on April 1, 2022, and "*it turns out that our food is our quiet weapon*" he wrote. The invasion and its associated sanctions imposed by and on Russia have also disrupted the export of food and agricultural inputs such as fertilizer and energy. In addition, several other countries have already ban or announced their intention to ban exports of food and essential agricultural inputs, such as India, Egypt, Argentina, Indonesia, Serbia, Turkey, and Hungary (EU, 2022; Nicas, 2022). These all have caused food shortages and price hikes that have pushed millions of vulnerable people into poverty.

3.3.1. On food availability

The invasion affects global food availability directly through a reduction in food production. According to FAO, the invasion causes major concerns on food production due to disruptions to harvesting and planting; agricultural labor shortages; access to and availability of farm inputs such as fertilizer and fuels; disruption of logistics and food supply chains; abandonment of and reduced access to agricultural land; damage to crops due to military activities; and destructions of food system assets and infrastructure (FAO, 2022).

Since the onset of the war, Ukraine's most productive agricultural regions have fallen under Russian control (Bearak, 2022). As farms are either shut down or occupied by Russian soldiers, future agricultural output in Ukraine will likely decline sharply (Emediegwu, 2022). Former Ukrainian agriculture minister Roman Leshchenko estimated that the country's spring crop sowing area in 2022 may be less than half of the previous year, about 15 million hectares (Polityuk, 2022). As of April 2022, it is reported that only 210 square kilometers had been cultivated in the Chernihiv oblast, compared to about 10,000 square kilometers last year (Mercy Corps, 2022).

Besides the reduction of available farm area, the availability of agricultural labor also declines due to war-induced displacement. Many farmers are among the 8 million displaced inside Ukraine, and 5 million who fled their homes to neighboring countries to seek safety. For remaining farmers in the country, their time working in the fields is also limited due to imposed curfews and security reasons (Emediegwu, 2022). Since workers are at risk when

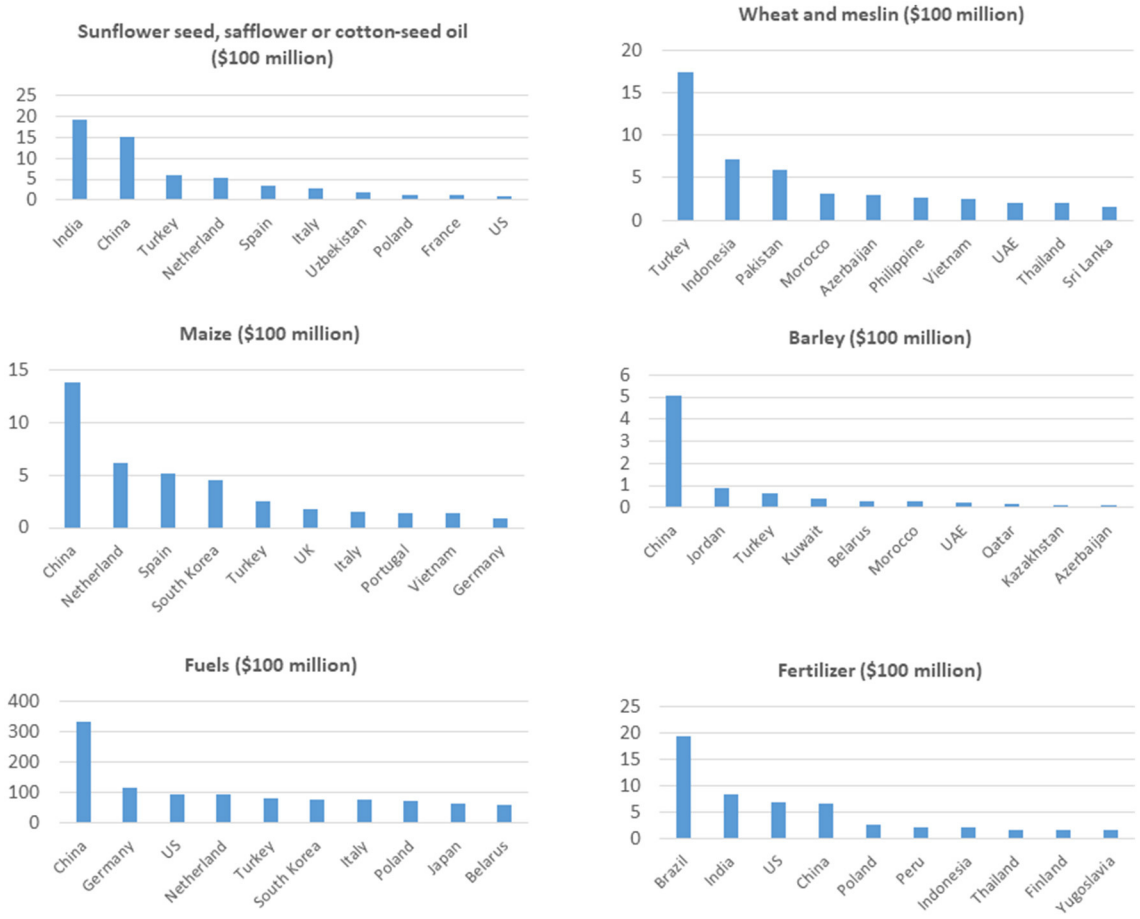

FIGURE 2
Top 10 countries importing major food commodities, fertilizer, and fuels from Ukraine and Russia [Source: Data from the World Integrated Trade Solution of the World Bank (https://wits.worldbank.org/)].

working on farms during the war, several major agribusinesses have stated that a number of plantings would not be possible this year (Durisin and Choursina, 2022). The oilseed crushing operations in the country are also suspended (FAO, 2022b).

Another major negative effect of the war on food production is the destruction of food system assets and infrastructure. The damage to farms, storage facilities, agricultural equipment, roads, and railways all contributes to a decline in food production. For instance, shelling caused a warehouse fire in Ukraine's largest frozen-food store, damaging about $8.5 million worth of frozen chickens (Durisin and Choursina, 2022). Many more warehouses of other food commodities are also at risk since damaged roads and railways limit access to facilities (Durisin and Choursina, 2022). According to a study by the Kyiv School of Economics (2022), at least 195 factories and enterprises, 295 bridges and bridge crossings, and 151 warehousing infrastructures have been damaged, destroyed, or seized. The study estimated that total damages to Ukrainian business assets amounted to almost $10 billion.

The reduction of food production in Ukraine has led to lower food exports. With port closures and export licensing restrictions for major crops and food commodities, the exports of Ukraine's giant industrial agriculture sector may decline sharply or even completely halt. In response to the severe economic sanctions (The New York Times, 2022), Russia has also retaliated by imposing an export ban for more than 200 products, including agricultural products and some forestry products (Bloomberg, 2022). Without export income, farmers may go bankrupt, and the global grain supply will become increasingly limited even after the end of the war (Bearak, 2022). The conflict reduces food supply not only in the conflict zones due to a decline in food production but also in the rest of the world due to a fall in the export of major staple food commodities and agricultural inputs such as fertilizers and fuels (Emediegwu, 2022). The EU estimated that an additional amount of 25 million tons of wheat is needed to meet worldwide food needs in the current and the following season (EU, 2022). All these factors caused by the invasion have contributed to the reduction in global food availability.

3.3.2. On food access

Food access reflects the number of food choices that individuals or households can consume, given the prevailing prices, income, and safety net arrangements through which food can be accessed (Barrett, 2010). The invasion affects global food access mainly

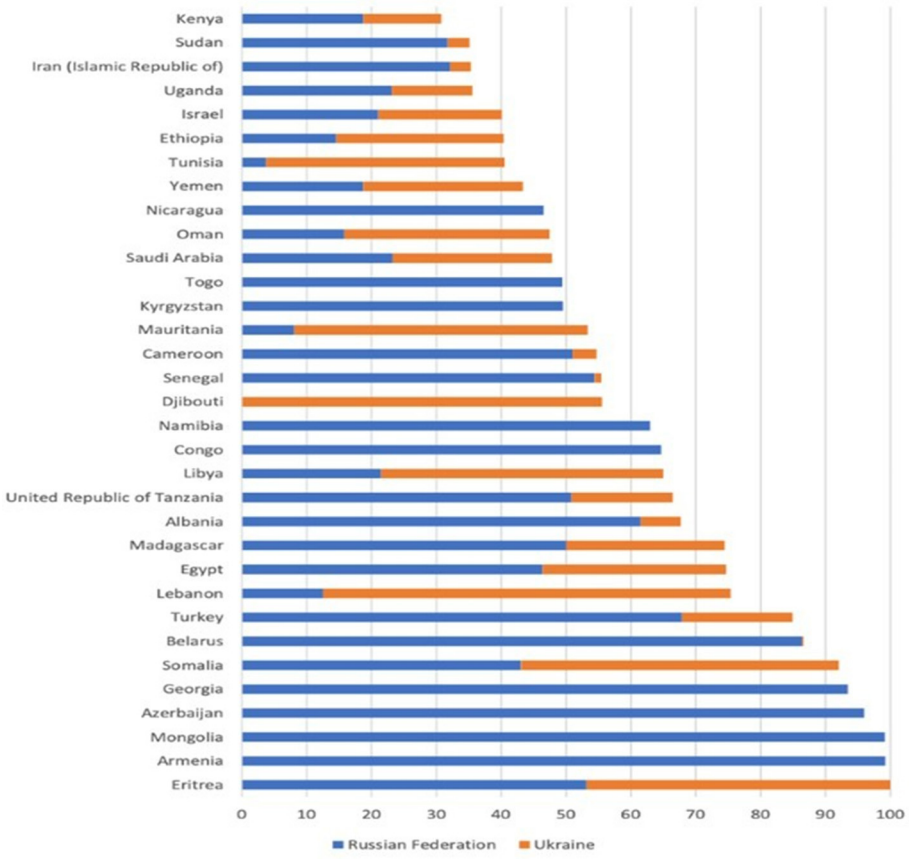

FIGURE 3
Wheat import dependency (%) of net wheat importers from Ukraine and Russia, 2021 (Source: FAO et al., 2020).

through increases in prices of food, fuel, and fertilizer, as well as in the level of economic uncertainty, which reduces consumption and investment, with depressive effects on economic growth and employment. As discussed above, the availability of major food commodities declined while food demand remained high, increasing food prices in both local and global markets. The increase in food prices means lower access to food and thus rising food insecurity, not only in the conflict zones but also in the rest of the world. Besides the effect on the global grain market–which directly affects global food security–the conflict also indirectly threatens global food security through an increase in energy and fertilizer prices. As fuels and fertilizers are important inputs for agricultural production, a rise in their prices increases agricultural production costs and thus further increases food prices.

Due to the COVID-19 pandemic, food prices have been rising since mid-2020. The war between two of the top producers of food commodities, and the intention to control food export by some other countries, for example, India, has pushed prices into the realms of the 2008 and 2011 food price crises (Husain et al., 2022). The FAO Food Price Index, an indicator showing the monthly change in international prices of a pre-determined basket of food commodities, reached a new all-time high in February 2022 (FAO, 2022a; Rice et al., 2022). Figure 4 shows that, after one month into the war, the FAO Food Price Index reached 156 points in March 2022, an increase of 17% from January 2022 and 31% higher than its level in 2021. This war-induced food price hike reached an even higher level than during the food price crises in 2008 and 2011. The vegetable oils price index saw the sharpest increase, and it rose to an average of 246 points in March 2022, a sharp increase of 35% in the two months. The cereal prices index also rose sharply after the onset of the war, a rise of 20% from January to March 2022.

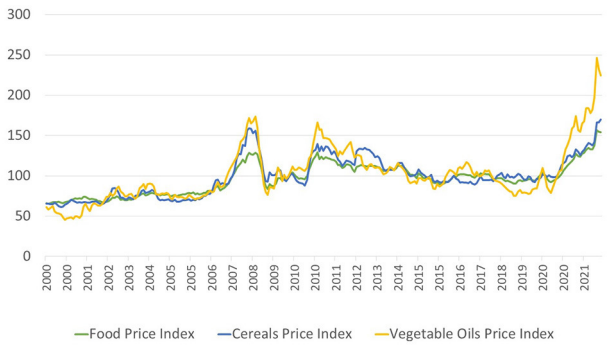

FIGURE 4
Price indices of food, cereals, and vegetable oils, 2000–2022 (Source: FAO, 2022).

Russia is the world's third-largest exporter of mineral fuels and oils, after USA and Saudi Arabia (Table 2). Russia is also the largest producer and exporter of fertilizer. Various sanctions imposed on Russia, including the ban on Russian oil and gas imports, have resulted in a sharp rise in fuel prices in the international market (BBC, 2022b). With the ban on oil supply from Russia and other top oil producers being unable or unwilling to raise their output in the near future, the price of Brent crude oil (the global benchmark) reached $128 per barrel in early March 2022, up almost 65% since early January and the highest since 2015 (Lynch, 2022) (Figure 5). It should be noted that Figure 5 also illustrates a sharp fall in oil price in early 2020, mainly due to a decrease in demand resulting from business closure and travel restrictions during the onset of the COVID-19 pandemic. Oil price began to increase in May 2022 following an agreement between oil-producing countries to reduce oil production. Since then, oil price have seen an increasing trend until it rose sharply after the onset of the war in Ukraine in February 2022.

The fertilizer market is subject to supply disruptions as nitrogen-based fertilizers are produced mainly from natural gas, and the price of natural gas has soared since 2021, pushing some fertilizer prices to their highest levels since 2010. In early March 2022, Russia's Industry Ministry announced that it would temporarily suspend fertilizer exports, and the announcement followed an earlier ban on ammonium nitrate to guarantee supplies to domestic farmers. China has also suspended urea and phosphate exports through June 2022 to ensure adequate supplies for domestic food production. As Russia and China are the world's two largest suppliers of fertilizers, fertilizer prices have thus been on the rise (Figure 6). For instance, the price of urea reached a level higher than 900 US$/mt in early 2022, compared to less than 400 US$/mt in early 2021.

These all lead to increases in commodity prices worldwide. In the Organization for Economic Co-operation and Development (OECD) countries, food price has continued to increase, reaching 12.6% in May 2022 compared with 11.5% in April. The energy price jumped to 35.4% year-on-year in May 2022, up from 32.9% in April (OECD, 2022). Excluding food and energy, year-on-year inflation increased to 6.4% in May 2022, compared with 6.2% in April 2022. The G7 area saw an increase in year-on-year inflation in May, reaching 7.5%, compared with 7.1% in April. It increased in all G7 countries except Japan, which was stable (at 2.5%), with the most substantial rises between April and May 2022 recorded in Canada and Italy (OECD, 2022). These price hikes have lowered purchasing power and reduced access to food. This is especially significant for poorer net food purchasers, whose food expenses comprise a high proportion of their total income.

Besides the increase in food prices and production costs, Ukrainian households also face a fall in their income due to the deaths of household laborers, job losses following damage to infrastructure and businesses, and reduced economic activities (Emediegwu, 2022). Loss of income coupled with the rise in food prices makes it even more challenging for Ukrainians to access food. In the rest of the world, especially in poor countries, higher food price reduces household's real incomes, pushing vulnerable households into the food poverty trap. This effect on household's real incomes is more serious for developing nations since a higher share of a household's disposable income is spent on food. According to UNCTAD (2022), on average, more than 5% of the poorest nation's import baskets are commodities, of which prices are expected to increase following the onset of the war; the share is <1% for richer nations.

In addition, the invasion has increased the level of economic uncertainty, which reduces consumption and investment, with depressive effects on economic growth and employment. High inflation forces central banks worldwide to increase interest rates and causes companies to reduce production, delay investment, and decrease employment.

3.3.3. On food utilization and stability

Food utilization refers to the food safety and diversity of diets that individuals or households choose to consume based on their affordability (Barrett, 2010), while food stability refers to a condition in which food can be accessed at all times (Grote et al., 2021). According to Koren and Bagozzi (2016), food utilization and utility are less likely to be directly affected by conflict than food availability and access. Nevertheless, since food utilization and stability depend largely on access to food, which, in turn, depends largely on food availability, the ongoing invasion–which intensely hurts availability and access to food–also indirectly jeopardizes food utilization and stability as well.

When access to food is being disturbed due to the war, as discussed above, households, especially the poor and vulnerable ones, are prone to hunger. Thus, food safety and diversity aspects may seem less relevant to their needs. For the less vulnerable households who may not be pushed into hunger due to the war, their access to food is still lowered due to higher food prices, reduced real income, and damaged infrastructure. Therefore, their ability and concern about food safety and diversity would be reduced, thereby decreasing their food utilization. Currently, there is no sign that the invasion will end soon, which means that food availability and access will be further affected. In addition, it will take time, probably years, depending on post-war efforts, for agricultural infrastructure to be rebuilt to the pre-war level. According to Welsh and Dodd (2022) from the Center for Strategic and International Studies (CSIS), rebuilding Ukraine's agricultural sector also requires huge investments in establishing new transportation routes and increasing storage capacities. These all indicate that food utilization and stability remain affected.

4. Addressing the circle of violence and hunger

The invasion was not expected and was a surprise to many people who thought such an invasion would never come true in Europe. Of course, undertaking an unprovoked war against an independent country, killing tens of thousands of people, including women and children, and threatening the independence and sovereignty of other nations is another matter which is absolutely intolerant. The conflict has been protracted, and there is no sign that it will finish soon, which means that its impacts on global food

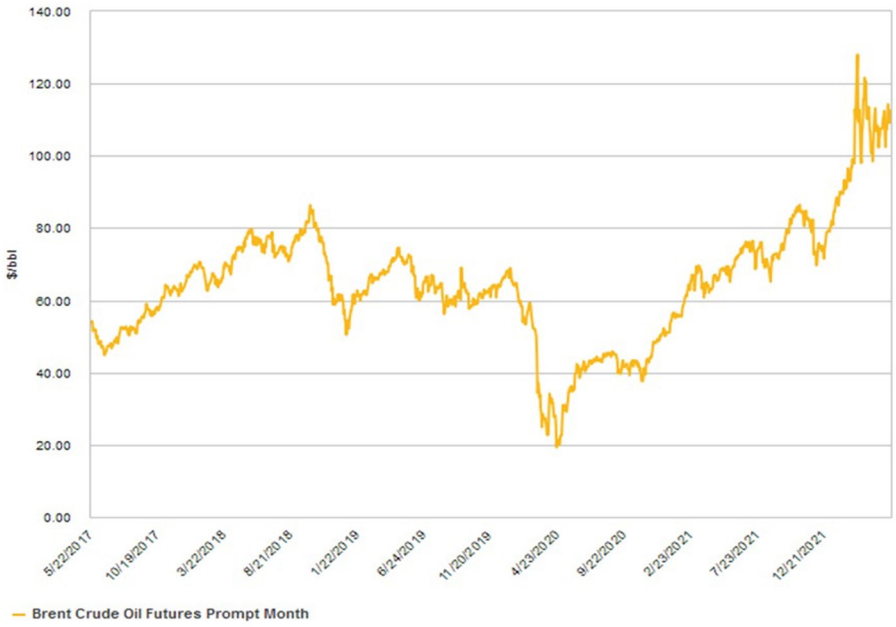

FIGURE 5
Brent crude oil price per barrel in US dollars, 2017–2022 [Source: S&P Global Market Intelligence. Market & financial data application (S and P Global Market Intelligence, 2022)].

security will remain and will likely trigger food insecurity-induced conflicts in other regions. Thus, in the following, we position some key challenges that should be addressed to avoid the vicious cycle of violence and hunger.

4.1. Mediating geopolitical conflict to avoid interstate war by facilitating democracy, dialogue, and trust building

Promoting democracy, dialogue, and trust building should also be considered key to avoiding armed conflict and food security. Gowa and Mansfield (1993) use data for an 80-year period beginning in 1905 and position two findings: (i) free trade is more likely within, rather than across, political-military alliances; and (ii) alliances are more likely to evolve into free-trade coalitions if they are embedded in bipolar systems than in multipolar systems. Similarly, Gartzke (2007) introduces the term "capitalist peace" as a result of economic development, free markets, and similar interstate interests that anticipate lessening militarized disputes or wars. Walter (2003) argues that governments are more concerned with the long-term reputational effects of their actions when they decide how to respond to a demand for greater self-determination that is heavily influenced by reputation and by the level of democracy and government military spending.

Simmons (2005) argues that governments are less likely to engage in territorial disputes as economic actors. Settled boundary agreements benefit economic agents on both sides of the border. Settled borders help to secure property rights, signal much greater jurisdictional and policy certainty, and involve significant economic opportunity costs in the form of foregone bilateral trade. Lake (1992) and Lake and Rothchild (1996) explain that democratic nations are more likely to prevail in a conflict with autocratic ones as autocracies are more expansionist and, in turn, conflict-prone. They further argue that democracies are constrained by societies from rent-seeking behaviors and devote greater resources to security, enjoy greater societal support for their policies, and tend to form overwhelming counter-coalitions against expansionist autocracies. Moreover, trust is a central requirement for the peaceful and effective management of all relationships, and thus, building and maintaining trust is critical in resolving conflicts in general and geopolitical conflicts in particular (Kelman, 2005). One of the claims that President Putin made with regard to the war is that the national security of Russia has been increasingly threatened by Ukraine and NATO. Hughes (2022) and Das (2022) claim that the trust between Russia and the West had been eroded, which led to the war. Under such circumstances as the loss of trust, the nation need to engage in policy dialogue to prevent armed conflict. Even nations should be able to raise such issues with United Nations.

4.2. Preventing interstate war by complying with international law and improving the UN Security Council

Addressing geopolitical conflict is difficult, but that cannot be the excuse for any invasion of sovereign nations. One of the principles set out in the UN Charter and signed by

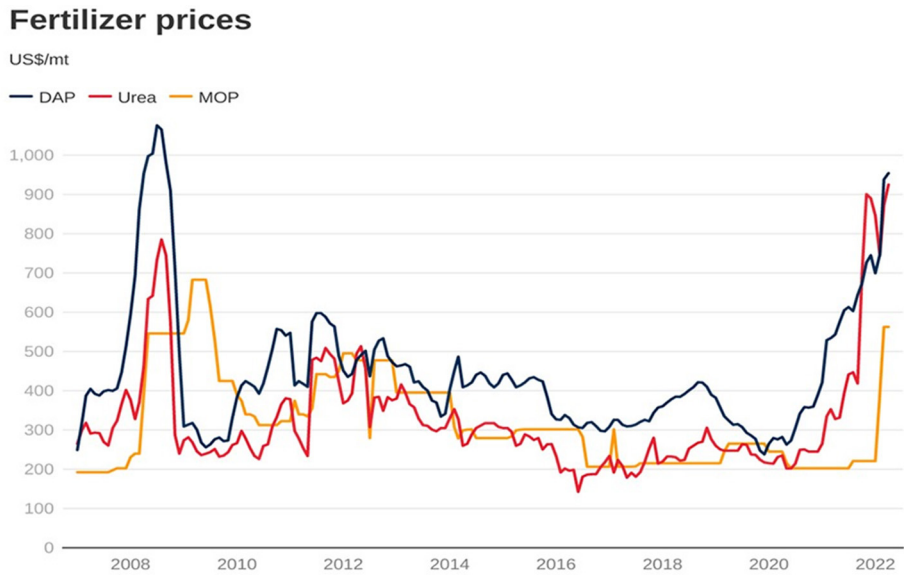

FIGURE 6
World Fertilizer Prices, 2008–2022.

all UN members is to respect the national sovereignty and territorial integrity of all nation-states. The Russia's invasion of Ukraine indicates the weakness of the global security system. Except for a few countries, the majority of the international community has condemned the invasion. However, this is far from being able to force Russia to end the invasion. Thus, the first issue for the UN system is to establish a mechanism to control for the compliance of this principle from all UN member states, and all violations must be accounted for and paid for.

The second issue is to restructure and improve the UN Security Council. Currently, all UN General Assembly resolutions are generally non-binding toward member states. The UN Security Council is primarily responsible for maintaining international peace and security, and all UN member states are obligated to comply with Council decisions. However, the Council has not been able to undertake any effective measures in preventing or terminating the invasion due to the veto right of Russia as one of the five permanent members. Therefore, the veto right of the permanent members must be terminated if one of these great powers ignores the principle of respecting the national sovereignty and territorial integrity of other nation-states and undertake an invasion. As demonstrated from the invasion of Russia, the security in general, and food security in particular, of many countries have been and will continue to be negatively affected by the invasion. This must not happen again.

The ineffective operation of the current international political system and non-binding resolutions of the United Nations and other global institutions place small nations (in terms of size, economy, and defense capabilities) in a disadvantageous situation. In addition, institutions like the International Court of Justice are not able to intervene. Therefore, a significant challenge facing humanity today is to create a system that will ensure compliance with international law and resolutions and respect for the sovereignty and territory of other nations/states and human rights.

4.3. Ensuring the right to food and food security for all

Global communities should address several challenges to ensure the right to food and food security for all. The first challenge is food access. Humanity has made significant progress in terms of food production. The gain in food production has been mainly through intensification rather than an increase in the land area, as there is little or no room for expansion of the land area for agriculture. With climate change, land degradation, and water stress, it is becoming increasingly difficult to feed the growing population. Despite tremendous progress, a large section of the population is hungry, and many cannot afford a healthy diet. Currently, the problem of food unavailability is not severe, but those of food access; thus, the food security policy should focus on improving the distribution system and reducing food waste and loss. Further, inclusive development to support the poor would help reduce food and nutritional insecurity.

The second challenge is the myopic behavior of some nation-states with regard to food security. Food security strategies should avoid myopic behavior and focus on national, regional, and international food security. For peace and a prosperous world, for food security, we have to work as one global community, not as individuals. Policy to support global nutrition and food security should prioritize local, national, regional, and international priorities. As food is crucial for the sustenance of life, the international community should prevent nations from using food

commodities and agricultural input as a weapon of war or coercing other governments.

The third challenge is on agricultural research and development. Global communities should support the development and dissemination of technology through research. Investment to produce and deploy agricultural technology combined with sound distribution systems and trade of food and agricultural products will ensure the food supply. Global communities should not allow escalation of aggression and interstate conflict as it is detrimental to global supply chain, economic growth, life, and food security. Countries dependent on imports should diversify the sources of imports, build a partnership with stable nations, and prepare a food security strategy for various uncertainties.

The next challenge is a lack of global good governance and respect for international treaties and sovereignty that generally triggers conflicts and uncertainties. Thus, the anarchical structure of the international political system should be changed to ensure equality, stability, and peace, thereby reducing uncertainties in the global value chain and food supply. Although food security has been of particular attention to the international community, and it is widely acknowledged that the problems of food insecurity are beyond the capacity of individual states to manage alone (Margulis, 2013), it is surprising that so far, there have been no global or international food security agreements or treaties. Therefore, improving the global governance of food security to address rising world hunger and improve the efficacy of existing food security interventions is a pressing need. The efforts of FAO, WFP, the International Fund for Agricultural Development (IFAD), and other international and regional institutions (e.g., the World Trade Organization) seem insufficient, especially during food crises such as the 2007-2008 World Food Price Crisis or the current food crisis due to the COVID-19 pandemic or the Russia's invasion of Ukraine. In this regard, a global or international food security treaty should be established with the participation of both rich and poor nation-states as well as non-state institutions.

Author contributions

TN conceptualized and wrote the paper. RT collected, analyzed the data, and contributed to drafting the paper. TS and DR conceptualized and edited the text. All authors contributed to the article and approved the submitted version.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Food values: How they relate to legality

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Introduction: A value is an implicit principle that arises from judgments about everything around people, whereas a value system is a set of values ordered according to personal preferences. In this context, values can be seen as the adherence to an implicit or explicit set of rules, many of which are related to legality. In this study, legality is understood as the willingness of citizens to abide by the existing set of formal laws. A value system can guide consumers' food choices and provide information on their preferences. In this way, the citizens' food value system can influence the decisions of producers and policymakers.

Methods: The present study investigates the food value system of a sample of young adults using the Best-Worst Scale method.

Results: Values such as environmental impact rank high in their value system, indicating that adherence to a set of implicit rules and regulations concerning the environment are very important values when choosing food.

Discussion: Although adherence to a legal system that protects a public good (the environment) is considered an essential value, legality *per se* is not. This might suggest, on the one hand, a lack of awareness of legality issues in the Italian food system and, on the other hand, a strong interest in issues perceived as more urgent.

KEYWORDS

best-worst scaling, values, food values, legality, maximum-difference scaling

1. Introduction

The line of analysis emphasized the circumstance that "[…] All humans have a value system that contains a finite number of universally important value types, but differ in terms of the relative importance they place on each of these value types (people's value priorities) […]" (Rohan, 2000, p. 262). A *value* is an implicit principle that arises from judgments about everything surrounding people, allowing for the best possible life (Rohan, 2000). It can also be considered that importance is given to an implicit or explicit set of rules. According to Lusk and Briggeman (2009), there may be a set of intermediate values related to people's food choices that are more stable than mere preferences related to food attributes or specific products (Lusk and Briggeman, 2009). A set of values, through the intermediate value explained by the middle-end chain theoretical framework (Gutman, 1982), is capable of being "an enduring organization of beliefs about preferred modes of conduct or end states of existence along a continuum of relative importance" (Rokeach, 1973). Therefore, identifying the value system that guides consumers' food choices can provide information about their preferences (Connors et al., 2001), turning them into a competitive advantage for entrepreneurs and a valuable guide for policymakers (Conner, 2004; Lindgreen and Wynstra, 2005).

Therefore, when thinking about food, it is natural to ask whether a set of values can guide food choices and, if so, in which direction. Indeed, a value system may guide people's choices toward elements that can positively affect the community. One example is the steady increase in the number of people moving toward a diet low in meat and meat products for

environmental reasons.[1] In addition, socially sensitive consumers who are turning to fair trade markets are growing (Konuk, 2019). Especially among young adults, there is a stronger push toward consuming environmentally and socially sustainable products (see text footnote 1) (Ma et al., 2012; Castellini and Samoggia, 2018). All this has meant that in recent years there has been a proliferation of private and public certifications and labels that talk about sustainability and corporate choices aimed at reducing environmental impact.

For this reason, the current paper aims to investigate the values underlying the purchasing choices of a sample of young adults and how these relate to the value of legality, understood as the willingness to abide by a formal system of laws. More specifically, we would like to investigate whether this group of consumers considers compliance with a legal system in their food purchasing choices. Furthermore, it will be analyzed how this relates to other food values. Indeed, one can also see values as an implicit or explicit set of rules, in some ways linked to legality. Legality can be seen as a baseline for other values, representing the framework in which food producers should organize their activity. Other studies considered legality to measure consumers' concern over food (Burnier et al., 2020) but not as a determinant of food purchase. Although there is a legal part in many other values (such as rules and norms for food safety or the requirements for certification), we decided to consider legality as a separate one to understand its weight in young adults' food value systems. The novelty of the current study lies in the decision to consider legality as a value on its own, connected with a value system, and a driver of individual behavior.

In order to do it, a survey was conducted among young university students, using the Best-Worst Scaling to order the values proposed in relation to their importance (Lusk and Briggeman, 2009) and thus identifying a value system. From the results, a focus on the environment emerges, whereas legality as a value and Fairness takes a back seat.

The paper is organized as follows: in the second section, the theoretical framework will be presented, where issues concerning values and the food value system, as well as the concept of legality, will be explored. The third section will present the material and methods, methodology and experimental design. The fourth section will present survey results, and the fifth will discuss them. Finally, the conclusions, summarizing the work done, will also provide an overview of the policy and managerial implications of the study.

2. Theoretical framework

2.1. Values and value system

Values can be seen as human needs and norms guiding human activities. Based on personal priorities, they can be ordered in a value system. It is an integrated structure which determines the relationships between priorities about each value (Rohan, 2000). They are thus organized according to personal inclinations, determined by preferences, experience, environment and social dimension (Rokeach, 1973). The theory states that values transcend particular actions and situations (distinct from norms) and are linked to desirable goals (Schwartz and Bilsky, 1987; Schwartz, 1992). Several authors have written about human values and their role in everyday life (Rokeach, 1973; Schwartz, 1992, 1996, 2012).

Regarding the food sector, several scholars have paid attention to values, i.e., food value (Lusk and Briggeman, 2009; Cembalo et al., 2015). *Food value* is a multifaceted concept encompassing different dimensions of food choice (Dagevos and van Ophem, 2013). The value of food is not only the "value of the product" as a physical good but also the value of "feeling good" by consuming the product because of its ethical and emotional implications (Barlow and Maul, 2000; Canetti et al., 2002). Food choices thus imply the involvement of a "personal system" consisting of value negotiations and behavioral strategies. Consumer food value systems can have profound implications, both personally and globally. For example, consumers' power of choice can affect the behavior of producers, determining the spread of specific practices or the cessation of others (Vitell and Muncy, 1992; Zollo et al., 2018). Thus, identifying the value system that guides consumers' food choices is crucial because it can give information on their preferences and valuable indications to policymakers (Conner, 2004; Lindgreen and Wynstra, 2005).

2.2. Food values

There is a link between the consumer's food value system and purchasing behavior. It can indicate the personal instances that guide food choice. In addition, it can allow consumers to be divided into different segments. In the current study, the consumer value system concerns the importance attached to a legally constrained system, be it the market, work ethic, safety or environmental regulations. The level of importance attached to a given value can also be seen as that attached to compliance with a set of implicit or explicit rules. Among the food values studied by Lusk and Briggeman, we chose Naturalness, Price, Safety, Nutrition, Fairness, Environmental Impact, and added Legality (we discuss this choice in the next paragraph). *Naturalness* value can be defined as the extent to which food is produced with the lowest possible level of technological sophistication (Lusk and Briggeman, 2009). It can be traced back to emotional instances (Lockie et al., 2004; Kooijmans and Flores-Palacios, 2014) that may influence food choice behavior (Hauser et al., 2011). Indeed, those interested in Naturalness often express concerns about quality, the (local) origin of products, and the impact of production methods on their health (Innes and Cranfield, 2009; Nielsen et al., 2009; Sidali et al., 2016). From a managerial perspective, strategies to promote sustainability should recognize the component of Naturalness (Sidali et al., 2016), especially in introducing new food technologies (Nielsen et al., 2009).

Price is a product-related attribute linked to personal value. The importance of price may vary with consumer culture (Bazzani et al., 2018) and the segment analyzed (Innes and Cranfield, 2009). Indeed, consumers primarily interested in price may belong to a segment defined as "self-centered." However, there may also be environmental or social conditions that determine this interest.

Safety can be defined as the extent to which the consumption of food will not cause illness (Lusk and Briggeman, 2009). It has come to play a crucial role in purchasing decisions (Loader

1 https://ourworldindata.org/vegetarian-vegan

and Hobbs, 1999; Henson and Northen, 2000) mainly due to the increasing focus on quality and Safety that pervades the food supply chain (Ménard and Klein, 2004; Hobbs et al., 2005; Loureiro and Umberger, 2007). *Nutrition* is a value related to the nutritional value of food (Lusk and Briggeman, 2009). Regarding nutritional value, there is a general interest in nutrition labeling, although it differs between products, consumer segments and countries (Grunert and Wills, 2007; Cavaliere et al., 2015; Marchini et al., 2021). When choosing food, health and nutrition beliefs are involved in a negotiation between values (Furst et al., 1996). This negotiation is mediated by nutritional knowledge, eating behavior, consumption habits and lifestyle (Wardle et al., 2000).

Fairness is linked to the ethical aspects of food (Lusk and Briggeman, 2009; Bazzani et al., 2018). Consumers are increasingly aware of the impact of current consumption patterns on the stock of social, human and economic capital. Often those who attach importance to this value are those belonging to a more "altruistic" segment of consumption and interested in ethical and human needs.

Environmental impact regards the effect of food production on the environment (Lusk and Briggeman, 2009). Just as with Fairness, pro-environmental preferences and behavior could be interpreted as a form of altruism that aims to improve the distribution of public goods (Stern, 2000; Young et al., 2010). However, awareness of environmental issues is only sometimes linked to reduced or sustainable consumption (Macdiarmid et al., 2016). Indeed, many manufacturers have exploited the growing environmental concern (Banterle and Cavaliere, 2014), making considerable efforts to communicate environmental sustainability characteristics through (more or less accurate) claims on packaging or labels (Cavaliere et al., 2014; Marchini and Riganelli, 2015). This information can be provided in good faith but can also constitute a form of so-called "greenwashing." However, environmental attributes can also become essential policy tools to ensure consumer safety and protection (Caswell and Mojduszka, 1996; Teisl and Roe, 1998; Nilsson et al., 2004).

2.3. A role for legality

Regarding L*egality*, scholars are increasingly paying attention to the food sector, i.e., to the legal state of food production and consumption. It concerns the implications of food law on production and consumption and the dimension of individual behavior linked to values. How producers and consumers comply with the law is a relevant aspect of food practices (Lei and Zhou, 2015) as well as of the role of civic organization (Counihan and Siniscalchi, 2013; Siniscalchi, 2013) or of emerging innovative practices (Hayden, 2014). Legality concerns Agri-food systems under different perspectives related to both the production and the consumption side. More precisely, legality in the food system can be intended both as compliance with regulations and laws and the absence of criminality (primarily organized crime) from the production system. Regarding the first aspect, a positive attitude toward legality can be recognized at the roots of compliance with the laws concerning food safety and Geographical Indications of production and supply. Under this view, adopting food standards raises the systems of practices that substantiate that attitude (Fritz et al., 2008; Martino, 2010). Likewise, compliance with agricultural labor market regulation is a fundamental divide among groups of farmers [Osservatorio Placido Rizzotto (a cura di), 2022]. As for a "negative" attitude toward legality, e.g., the adoption of illegal practices, much evidence is provided in the literature which underlines the existence of various behaviors (Manning et al., 2016). Burnier et al. (2020) considered legality an essential aspect of constructing a scale to measure consumers' concerns over the meat production process. In particular, they considered the indications provided to implement the Rainforest Alliance Sustainable Agriculture Standard (Rainforest Alliance, 2022). They involve several aspects of legality regarding water use, workers' conditions, ownership, use of chemicals, and waste management, making legality a crucial element for other food values (such as environmental impact, safety and equity).

On the other hand, legality in the food sector can also be related to the absence of organized crime from the supply chain. In Italy, organized crime ("mafia") is widely spread in the agri-food sector (Santos, 2004; Rizzuti, 2022). It is responsible for food fraud (Lord et al., 2017), labor exploitation, illegal investments and procurements in distribution and logistics (Rizzuti, 2022).

The current study assumes that legality is connected with value systems as a driving force of individual behavior. From a theoretical point of view, this hypothesis is justified because scholars have identified an expressive function of law as the driving force of behavior. Law and Economics scholars have primarily emphasized the imperative role of the law (Posner, 1983) and have progressively recognized the relationship between legal rules and social norms (Ellickson, 1998; Stout, 2006; Feldman, 2009). Sustein (1996) states, "Many laws have an expressive function. They make a statement about how much, and how, a good or bad should be valued. They are an effort to constitute and affect social meanings, norms, and roles. Most simply, they are designed to change existing norms and to influence behavior in that fashion." Namely, the expressive function of the law is mainly explained by its ability to (Cooter, 2000; Pearce, 2013):

1. Create focal points and facilitate coordination;
2. State morality;
3. Impose a social cost in order to prompt agents to implement the norms;
4. Reflect and existing consensus, especially in democratic societies.

In other words, they constitute and influence social meanings, norms and roles. Consequently, legality maintains a role in the constitution of social relations (Deakin et al., 2017). Above all, it is being studied to investigate its influence in shaping and channeling the behavior of economic agents. Several definitions of legality are adopted, which variously reflect the emphasis on law enforcement's role in shaping economic agents' activities. For the current study, *Legality* is operationally defined as the willingness of citizens to comply with the existing set of formal laws. This definition has nothing rigorous concerning the relationship between the rule of law and the principle of legality (Bobbio, 1959). However, this definition is closest to the common sense of legality and the widespread understanding of legality as the engine of the behavior of economic agents.

Legality is linked to values in various ways. For example, concern for a fair price implies that consumers and the food supplier rely on the market's legal functioning of the pricing process. Fairness also implies an interest in legality as an ethical dimension of food practices. Similarly, safety and environmental concerns have to do with the legal interest of consumers.

While most of the literature on legality and its influence focuses on how legality drives behavior, our study takes a different perspective. This study considers, in particular, the consumers' assessment of the legality pursued in the food supply system. More precisely, we investigate whether and how food consumers consider compliance with the legal system in producing and supplying food.

3. Material and methods

3.1. Method

We used best-worst scaling (BWS) to study the relevance of food values in consumer choices. The value system was developed by adapting that of Lusk and Briggeman (2009), who attempted to identify consumers' food value systems using the BWS. Legality was added to their set of values to investigate the relationship between this value, which is directly dependent on consumers' willingness to comply with a legal system, and other values, which may be more related to ethical and moral judgements as moral behavior. Legality is linked to the other values but involves a different evaluation process. People often do not have a thorough knowledge of the law; therefore, legal judgements are made under uncertainty (Tversky and Kahneman, 1974). Furthermore, there may be discrepancies between ethical judgements and the law (Pearce, 2013), although illegal conduct is often considered unethical. As previously mentioned, food values related to ethical aspects (such as Fairness, Safety and the environment) and legal values may be correlated (Vitell and Muncy, 1992; Vitell, 2003).

The best-worst (BW) choice experiment is a variant of the widely adopted binary choice experiment approach to measuring preferences based on Random Utility Theory (Thurstone, 1927; McFadden, 1973; Louviere et al., 2015). There are three types of BWS: (1) the object case (Case 1), (2) the profiling case (Case 2), and (3) the multi-profile case (Case 3) (Louviere et al., 2015). The object case typically allows obtaining measures for each person (respondent) on a differential scale with known properties (Marley and Louviere, 2005). Several sets are shown, each including options based on the experimental design. This case is suitable for our study because we are interested in measuring a set of objects (values). In addition, a model can be interpreted as a constrained sequence of repeated choices (i.e., best/worst choices). Finally, it is suitable for a web-based questionnaire because participants must choose in a particular order (Louviere et al., 2015).

3.2. Research design

The idea behind BWS is that people can choose the two items in three or more choices representing their extreme (lowest and highest) preferences. The respondents are shown a set of items and asked to indicate the best (or most important) and the worst (or least important). The statistical model under this method assumes that the relative choice probability of a given pair is proportional to the distance between the attribute levels on the latent utility-scale (Flynn et al., 2007). Respondents make several repeated choices, and each time they make a difference between the value that maximizes the utility and the value that minimizes it.

The widely used rating scales ensure that all individuals use the same numerical scale, but in practice, it is possible to find various idiosyncrasies in response style (Auger et al., 2007). These idiosyncrasies can arise from individuals' differences using rating scales (Lee et al., 2008). BWS is a way to avoid and overcome these limitations (Louviere et al., 2013) because it allows us to compare the relative impact of attributes. Therefore, BWS has several advantages compared to other measurement methods (such as the Likert scale). In fact, with these methods, the respondents are free to make trade-offs between the relative importance of the issues (Lusk and Briggeman, 2009). Indeed, all the issues become "important" for the respondents. To demonstrate it, Lee et al. (2007) have applied the best-worst approach to measuring people's life values. Their results suggested that this method better measures people's values than some frequently used rating approaches.

Table 1 presents the seven food values of interest. We built the choice set using a Balanced Incomplete Block Design (BIBD) to assign each of the J objects (values) to various subsets of a fixed size k (in our case, three) (Colbourn and Dinitz, 2007). Each subset is called a "block" and can be seen as a "comparison set," and the objects in a block are what is presented to the sample (Louviere et al., 2015). A block or comparison set is a "choice set." Our experimental design was obtained using the R software to assign each of the seven values to the choice sets. The resulting design consisted of seven choice sets of three values per set (Table 2). In our BIBD, there are seven objects (j), repeated three times (r), in seven blocks (b, i.e., the total number of subsets, or choice sets) of three observations (k, the size of the subset). The fifth parameter, lambda (λ), records the number of blocks where every pair of treatments occurs in the design (Louviere et al., 2015). In a nutshell, a BIBD table has a b subset of k items. Each item occurs r times and co-occurs with each other item l times. Thus, each respondent answers to seven choice sets containing three values. Each of the seven values appeared three times, and the respondents were asked to indicate the most essential and negligible values for each set. Figure 1 shows an example of one choice set. Respondents were also asked about socio-demographic characteristics: age (ranked from under 20 to over 28), studies, country of origin, and Italian area from which they came (Center, North-East, North-West, South, and Islands). Respondents were also asked about their purchase habits: where food is purchased (such as discount, market, or organized distribution) and the purchase frequency.

3.3. Econometric analysis

We used a conditional logistic regression for the quantitative analysis, performed using Stata 13 (Train, 2009). The choice is treated as a function of the alternatives' characteristics rather than the individuals' characteristics. Thus, we used a conditional logit model (Hoffman and Duncan, 1988). Conditional Logit is used

TABLE 1 Food values and descriptions.

Value	Description	References
Naturalness	Limits within which food is produced without the use of additives, chemicals, or modern technology (e.g., low-processed foods)	Small et al., 2005; Lusk and Briggeman, 2009;
Price	The price paid for food	Lusk and Briggeman, 2009; Andreyeva et al., 2010
Safety	Extent to which consumption of food is safe and it will not cause illness (e.g., reliability of producers, security of origin)	Lusk and Briggeman, 2009; Dowd and Burke, 2013
Nutrition	Nutritional characteristics of food: amount and type of fat, proteins, vitamins, etc.	Loureiro et al., 2006; Lusk and Briggeman, 2009
Fairness	Limits within which all participants in the value chain receive fair benefits for their work or business (e.g., working conditions, dignified wages)	Lusk and Briggeman, 2009; Dowd and Burke, 2013; O'Connor et al., 2017
Environmental impact	Effect of food production on the environment (environmental sustainability of the process)	Lusk and Briggeman, 2009; Dowd and Burke, 2013; Salazar-Ordóñez et al., 2018
Legality	The respect of the laws during the production and distribution (e.g., supply chain not controlled by organized crime, animal conditions according to the laws)	Croall, 2013; Burnier et al., 2020

Authors' elaboration based on Lusk and Briggeman (2009).

TABLE 2 Balanced incomplete block design.

	Options		
Set	1	2	3
1	Naturalness	Price	Equity
2	Safety	Nutrition	Equity
3	Naturalness	Safety	Environmental impact
4	Price	Safety	Legality
5	Price	Nutrition	Environmental impact
6	Naturalness	Nutrition	Legality
7	Equity	Environmental impact	Legality

Authors' elaboration.

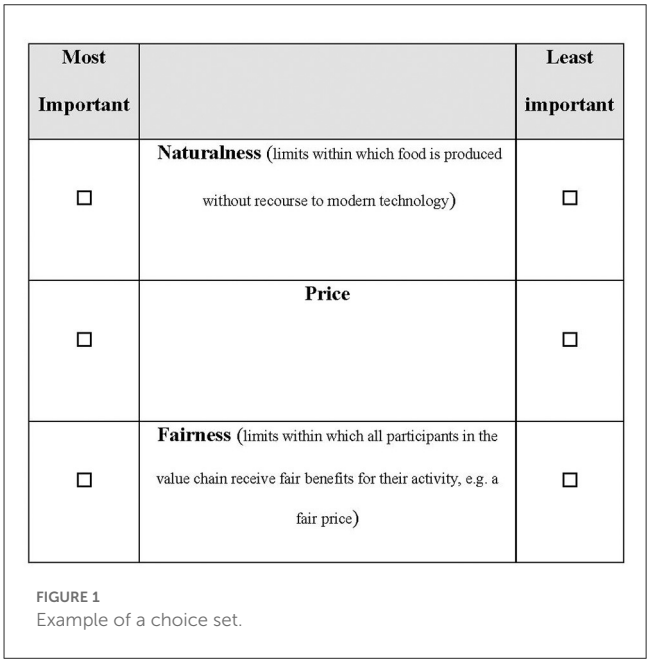

FIGURE 1
Example of a choice set.

to analyze an individual's choice between a set of alternatives J (Hoffman and Duncan, 1988), focusing on the set of alternatives for each individual. We made two estimates: one for the best choice and one for the worst choice, to establish the probability that each value is chosen as the most important and the least important (Louviere et al., 2015).

Considering N individuals and a set of J values, a person could choose J(J – 1) possible best-worst combinations across the seven choice sets. The pair of items chosen represents a choice out of all the J(J – 1) pairs that maximize the difference in importance. Let β_j represent the location of value j on the scale of importance (β is a vector of the value). The conditional logit McFadden-type choice model assumes that there is no correlation in unobserved attributes over the alternatives, and the utility (in our case, importance), for each alternative is only related to the attributes of that alternative (McFadden, 1973; Train, 2009). Each individual is denoted by *i*, and let the true or latent unobserved level of importance be given by:

$$I_{ij} = Z_j + \varepsilon_{ij} = \beta X_j + \varepsilon_{ij} \quad (1)$$

Where Z_j is the representative importance from alternative *j*, given that not all factors which affect the respondents are observable. The term X_j stands for observable factors of alternative *j*. The term ε_{ij} is a random error term. Thus, the probability that the respondents choose item *j* as the best (or worst) item, in choice set J is:

$$P_j = \frac{e^{\beta X_j}}{\sum_{j=1}^{J} e^{\beta X_j}} \quad (2)$$

Given the potential confusion with the scale, we calculated the "preference share" (Lusk and Briggeman, 2009) for each value ($Share_j$), i.e., the expected probability that each food value is chosen as more (or less) important:

$$Share_j = \frac{e^{\beta_j}}{\sum_{j=1}^{J} e^{\beta_j}} \quad (3)$$

These shares of preference must sum to one across the seven values. In fact, the Equation (3) reports the importance of the value *j* on a ratio scale, so the probability that a value is picked as more important than another.

3.4. Data

A convenience sample of young adults was interviewed for the analysis. A questionnaire was administered to them using Google Forms in Italian (the mother tongue of most of the respondents) in April 2018. The final sample consisted of 333 students. Table 3 summarizes the characteristics of the sample. The age of the respondents was mainly between 21 and 24 (56.2%), while 23.4% are aged 20 or under, 15% around 25-28 and only 5.4% over 28. Most currently only have a high school diploma (68.5%), 29.7% have a Bachelor's degree, and only 1.8% have a Master's degree. The geographical area of origin of these students is Central Italy (80.2%), followed by 12% from Southern Italy, and the rest from the North-East (2.7%), North-West (1.8%) and Islands (3.3%). Most of the interviewees usually go to the supermarket to buy (71.5%), 9% of the interviewees go to the neighborhood shop, 6.6% of the interviewees buy at the hypermarket (GDO), 6 % discount, 5.1% at the farmers' market and only 0.9% buy from Fairtrade buying groups or the local market. 44.1% of respondents shop 2/3 times a week or once a week (38.4%), 9.3% of respondents every day and 8.1% are not responsible for the purchase.

TABLE 3 Socio-demographic characteristics of the sample.

Variable			Total
Responsible for Food Shopping (frequency)			333
	Never	28	
	Once a week	129	
	Two or three times a week	146	
	Every day	30	
Age			333
	≤20	80	
	21–24	185	
	25–28	51	
	>28	17	
Origin			333
	Northern Italy	15	
	Center Italy	268	
	South Italy	39	
	Islands	11	
Customary place of purchase for food			333
	Convenience store	20	
	Fairtrade buying groups	3	
	Superstore	21	
	Farmer market	17	
	Local market	3	
	Corner shop	31	
	Grocery store	238	
Education			333
	High school	228	
	Bachelor degree	100	
	Master degree and over	5	

Authors' elaboration.

4. Results

4.1. Descriptive results

To perform the first descriptive analysis, we used a ranking based on the ratio score. To compare the importance of the attribute, we derive the ratio scores by taking the square root after dividing the best total score (B) by the worst total score (W) for each respondent (Table 4). The square root of B/W for all attributes [SQRT (B/W)] has been scaled by such a factor that the most important attribute with the highest SQRT (B/W) becomes 100, in our case Safety (Lusk and Briggeman, 2009). The result is interpreted as X per cent as it is likely to be chosen as the most important value. Table 4 shows that Safety, on average and according to Lusk and Briggeman, is the most important value, while Fairness is the least important. Generally, Safety is widely preferred; the second is Environmental Impact with 48%, and the third is Nutrition (44%). Legality and Naturalness have a 37% and 34% probability of being chosen as the best (i.e., the most important), and the last two values are Price and Fairness, with 30% and 27%. Therefore, Fairness is usually not considered an important value by the consumer and is less critical than legality and values related to food.

4.2. Quantitative results

Table 5 (for the best) and Table 6 (for the worst) report food values' relative importance. It was estimated with respect to the least important food value, "Fairness" (Lusk and Briggeman, 2009). Each of the 333 respondents chooses the "most important" and "least important" value from three choices, repeated in 7 sets of choices. The total number of alternatives was 21, so the number of choices analyzed was 6,993 (333 * 21) for the best and 6,489 for the worst, as 54 cases were dropped due to missingness. Assessing the importance of each value from the conditional logit results is difficult because there is no natural interpretation of the estimates themselves (Lusk and Briggeman, 2009). Therefore, we report the share of preferences to interpret the results using Equation (3) (Lusk and Briggeman, 2009). All values are statistically significant; therefore, the food values analyzed would influence the consumption behavior of the sample. According to the conditional estimation, about 25% of the sample would evaluate Environmental Impact as the most important food value. The second highest preference share is Naturalness, with 22%. These two values are closely linked to environmental sustainability. The 15% and 16% of the sample would rate Price and Safety as the most important. Only 10% of the sample chose legality as the most important, and 11% chose Nutrition. The results mostly agree with Lusk and Briggeman (2009), according to which natural and environmental values are more important than Convenience and Fairness.

TABLE 4 Descriptive statistics for the sample.

Attributes	Total counts/7 BWS tasks across respondents n^*		(B/W)	SQRT(B/W)	Ln(SQRT)	Scale by a factor such that the most important (safety) becomes 100
	Most important	Least important				
Safety	791	61	12.97	3.60	1.281	100
Environmental impact	603	204	2.96	1.72	0.542	48
Nutrition	575	225	2.56	1.60	0.469	44
Legality	495	273	1.81	1.35	0.298	37
Naturalness	509	346	1.47	1.21	0.193	34
Price	453	399	1.14	1.07	0.063	30
Fairness	401	435	0.92	0.96	−0.041	27

$^*n = 333$.
Authors' elaboration.

TABLE 5 Model estimation: beta coefficients and odds ratio for the most important (best) values.

Variables	Econometric estimates		Share of preference
	β	Odds ratio	
Environmental impact	1.18*** (0.14)	3.26*** (0.45)	25%
Naturalness	1.04*** (0.19)	2.82*** (0.53)	22%
Safety	0.74*** (0.19)	2.10*** (0.40)	16%
Price	0.65*** (0.18)	1.92*** (0.35)	15%
Nutrition	0.39* (0.21)	1.47* (0.30)	11%
Legality	0.25* (0.13)	1.28* (0.16)	10%

***$p < 0.01$, **$p < 0.05$, *$p < 0.10$. There are robust standard errors in brackets.
No. of cases = 333.
No. of observations = 6,993.
Log pseudolikelihood = −3101.6878.
Authors' elaboration.

TABLE 6 Model estimation: beta coefficients and odds ratio for the least important (worst) values.

Variables	Econometric estimates		Share of preference
	β	Odds ratio	
Nutrition	−0.69** (0.29)	0.50** (0.12)	23%
Price	−0,93*** (0.17)	0,39*** (0.08)	18%
Legality	−0.96* (0.28)	0.38* (0.06)	18%
Naturalness	−0,99*** (0.18)	0,37*** (0.07)	17%
Safety	−1.09*** (0.19)	0,34*** (0.05)	16%
Environmental impact	−1.76*** (0.20)	0.17*** (0.03)	8%

***$p < 0.01$, **$p < 0.05$, *$p < 0.10$. There are robust standard errors in brackets.
No. of cases = 309.
No. of observations = 6,489.
Log pseudolikelihood = −2,851.8364.
Authors' elaboration.

The parameter estimates can be interpreted as "low priority grade" regarding the worst values. Table 6 shows that Nutrition is the highest grade of low priority (23%), followed by Price and Legality (18%). 17% of the sample would choose Naturalness as the least important value, while 16% would choose Safety. Only 8% of the sample would rate the Environmental Impact as the least important food value. However, except for the latter, all values would be rated mainly with the same degree of low priority, which means that compliance with some regulation (written or not) is a reassurance sought by most consumers in the sample.

5. Discussion

In the present research, we analyzed a young sample's value system composed mainly of young adults. In particular, the paper attempts to evaluate the system of values of a young sample and how ethical/legal judgments are considered with respect to other food values. Focusing on individuals of given characteristics is relevant because people's value priorities would change in response to experiences and changes in their life (Braithwaite and Scott, 1991).

A food value system can identify peoples' food and consumption preferences (Lusk and Briggeman, 2009) and the relative importance of multiple values that guide action, attitudes, and behaviors (Schwartz, 1992, 2012). According to Schwartz's theory (Schwartz, 1992, 1996, 2012), values are followed by actions, which can conflict with some other values and agree with still others. Therefore, a specific value system may lead to particular choices.

Considering a value system as the relative importance given to an implicit or explicit set of rules, consumers' preference for individual values and how their food value system is composed can also tell us which rules/laws/regulations are crucial. People's different importance to different values, and therefore the value system, is mainly led by goals or motivations that values express (Schwartz, 2012).

Thus, the current study follows the research line of the previous studies about values and food values (Rokeach, 1973; Rohan, 2000; Lusk and Briggeman, 2009), and it tries to evaluate values relations and oppositions with respect to food consumption and food equity, considering a food value system as the relative importance that consumers give to the compliance with different sets of rules. However, unlike Lusk and Briggeman (2009), we also included "Legality" to evaluate the relation with other values. Considering the economic and political power of consumers' choices, especially young adults (increasingly aware of these issues), the results may be relevant.

The results show that the young adults in our sample built a particular awareness during their lives, mainly related to Environmental Impact and Naturalness. At the same time, in the study of Lusk and Briggeman (2009), the most important value was Safety. In our study, this value is the third in terms of importance. Environmental sustainability, Naturalness and Safety are often related, probably due to companies' marketing strategies (Caswell and Mojduszka, 1996; Teisl and Roe, 1998; Nilsson et al., 2004). On the other hand, Price and Nutrition, which are values that are given importance in relation to the country and cultural background (Grunert and Wills, 2007; Bazzani et al., 2018), are not the first interests of the sample. Finally, Fairness and Legality are not considered as important as the other values, in accordance with Lusk and Briggeman (2009).

Based on our definition of value and Schwartz's theory, the value system emerging from the data analysis presents specific features. Environmental Impact and Naturalness are two values that prioritize compliance with both an implicit and explicit set of rules. The first concerns consumers' natural and sustainable consumption, and the second concerns national and international regulations about production sustainability and related incentives. However, the ethical component of food consumption and production (Fairness) and Legality are less important than protecting the environment and Naturalness. This result can be due to two factors: first, Fairness and the Legality of food are usually taken for granted. There are international certifications (standards) for occupational health and safety management systems (like OHSAS 18001) and trade unions to guarantee Fairness and the authority to enforce laws. Therefore, consumers may not feel they must encourage compliance with these legal systems through their consumption choices. However, it should not be taken for granted. Slavery and un-ethic work are still present, especially in the food system. In Italy, particularly in the agro-industrial sector, the spread of organized crime follows a profit logic based on illegality. Within this framework, there is a range of criminal behaviors, from fraud to the exploitation of immigrant labor.

Furthermore, work ethic is not only about fair-trade productions and slavery. As the facts of Kellogg's have shown, Fairness in food production is not always ensured, even with specific laws to protect workers and trade unions. Talking about these themes implies sharing some views about work ethic, and for the companies may be dangerous to expose themselves to these issues. The instability of the labor market and the weakness of the trade unions can lead workers to fear exposing themselves to the problems they encounter in the workplace. Legality is as tricky as Fairness to talk about, especially in countries (such as Italy) where organized crime is still widespread (Perone, 2018; Acemoglu et al., 2020). On the other side, the media pay much attention to environmental sustainability and the Naturalness of food. Companies may also drive engagement in these aspects because, on the one hand, they are easier to implement and promote through marketing strategies. On the other hand, these aspects engage consumers.

The current study aimed to shed light on what value system guides young adults' consumer choices and, in particular, how Legality is positioned within that system. By isolating Legality as a value, we could observe how it relates to other values which embed a legal part, both in terms of norms/laws and requirements. However, although compliance with a legal system which protects a public good (the environment) is considered an essential value, legality *per se* is not. It indicates that the legal part is not what concerns consumers, as it is taken for granted. This finding might suggest, on the one hand, a lack of knowledge of the issues surrounding legality in the Italian agri-food system and, on the other, a strong interest in issues perceived as more urgent by the sample in question.

6. Conclusions

This paper has tried to evaluate a system of food values by valuing the importance consumers give to compliance with different sets of formal and informal rules. It was also observed how ethical/legal judgments are considered with respect to other food values.

We used best-worst scaling (BWS) to study the relevance of food values in consumer choices and a conditional logit to evaluate preference share. The resulting food value system puts values relating to the environment and nature first, followed by Safety and Price. Legality and Fairness are the least significant values. However, in the last few years, the awareness of labor exploitation and poor working conditions has increased, especially among the youngest consumers. For example, in December 2021 in Italy, a scandal arose around a Parmigiano Reggiano commercial, which seemed to praise unsustainable working conditions. Moreover, Kellogg's faced a social media backlash and a boycott important and that consumers' choices may lead to fundamental organizational and political changes.

The current study has some limitations. Firstly, the sample considered consists mainly of young adults from central Italy, not allowing comparisons between subgroups. It might be interesting, for further research, to conduct the analysis on a larger sample that would allow this type of assessment. Second, it was conducted before COVID-19, which has disrupted the job market, supply chains and lifestyle. Finally, another significant limitation lies in the research design. It would be interesting to include preliminary qualitative research (interviews or focus groups) to select the values worth having in the questionnaire. We selected values included in previous studies, but future researchers should consider them.

In this regard, it can be interesting to repeat this study in different countries, maybe comparing the results. As the theory states, several values depend on the country and the cultural background (such as price and Nutrition). Furthermore, comparing the results across different ages could be interesting to assess how social media and generations affect personal value systems.

From a managerial point of view, companies may start to pay attention to legal and ethical aspects other than the environment. However, as the growing attention to the environment has led to the need to favor ethical practices from the view of sustainability, so can the increasing awareness of ethical and legal issues.

It seems that legality is not perceived as an essential element, taken for granted from a political standpoint until a scandal involving the food world occurs. Organized crime, especially in Northern and Center Italy, is perceived as something distant from everyday life, not concerning the food production process. However, as previously illustrated, organized crime is often involved in several food supply chains (Perone, 2018; Rizzuti, 2022), posing a threat to safety and equity in the sector. Over the years, excellent communication has been done on the need to make food production more environmentally sustainable, both by private entities and institutions, putting food sustainability as one of the priorities on the European agenda (Di Marzio, 2015). Similarly, efforts should be made to improve communication on aspects related to the legality of food. In this way, interest in this aspect could be increased, thus leading to a push toward consuming "legal" and "fair" food.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AM contributed to the conceptual framework, writing, and revising. BP performed the statistical analysis, wrote result interpretation, and contributed to the writing. GC collected the data. EM organized and prepared the dataset. GM designed the questionnaire and contributed to manuscript writing and revision. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Diversifying agrifood systems to ensure global food security following the Russia–Ukraine crisis

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The recent Russia–Ukraine conflict has raised significant concerns about global food security, leaving many countries with restricted access to imported staple food crops, particularly wheat and sunflower oil, sending food prices soaring with other adverse consequences in the food supply chain. This detrimental effect is particularly prominent for low-income countries relying on grain imports, with record-high food prices and inflation affecting their livelihoods. This review discusses the role of Russia and Ukraine in the global food system and the impact of the Russia–Ukraine conflict on food security. It also highlights how diversifying four areas of agrifood systems—markets, production, crops, and technology can contribute to achieving food supply chain resilience for future food security and sustainability.

KEYWORDS

Russia–Ukraine conflict, food security, agrifood systems, diversification, sustainable intensification

1. Introduction

In the past 2 years, global issues such as climate change, the COVID-19 pandemic, and the Russia–Ukraine conflict have taken the spotlight, with reports and discussions around these events flooding the media. This has led to intense pressure on socioeconomics, healthcare, and food systems in a short time. Confronting us are direct consequences of these global crises on the agrifood systems, particularly from the Russia–Ukraine conflict, throwing food security issues into the limelight. Ukraine and Russia are in the top three global exporters of various staple foods, including wheat, barley, maize, rapeseed, and sunflower (FAO, 2022a). Disruptions to their exports are having strong ripple effects on the global food market and concerns for food security (Behnassi and El Haiba, 2022).

The Russia–Ukraine conflict directly impacts global agrifood systems through trade, production, and prices (FAO et al., 2022). The FAO estimates that the shortfall in grain and sunflower seeds exports from Ukraine and Russia will increase international wheat prices by between 8.75% (moderate case) and 21.5% (severe case) in 2022/23. Countries hardest

hit by the reduction in Ukraine and Russia's food exports in terms of physical supply are those relying heavily on wheat and wheat products imports—the Middle East and North Africa, developing countries in Europe, and sub-Saharan Africa (World Bank Group, 2022), therefore impeding the efforts to eradicate malnutrition and hunger by 2030 which is the focus in the second goal of the United Nation's 17 Sustainable Development Goals (SDG Target 2, Zero Hunger). This will be pronounced in net food-importing developing countries (Figure 1), i.e., the world's poorest countries (UNCTAD, 2022), concentrated in sub-Saharan African nations that imported 85% of national food requirements in 2016–2018. The Russia–Ukraine conflict has caused a shortfall of at least 30 million tons of food in sub-Saharan African nations (African Development Bank Group, 2022), as well as other regions (South Asia, the Middle East, North Africa, Latin America and the Caribbean, and East Asia) that were already facing food security problems (UNCTAD, 2021).

This food crisis at a global scale was not unexpected. Global food crises have occurred in the past, incurred by: (1) high oil prices in 2007–2008, (2) increased food demand in emerging economies (Mittal, 2009; Headey and Fan, 2010), (3) extreme weather incidents such as drought, floods and storms in 2010–2011 in many grain-producing countries (e.g., China, Australia, Argentina, Russia, and Ukraine) (Johnstone and Mazo, 2011; Werrell et al., 2013), and more recently, (4) the COVID-19 pandemic causing global disruptions in the food supply chains (Hart et al., 2022; Pauw and Thurlow, 2022). If past global food crises have taught us anything, agrifood systems need to be restructured to make them more resilient and strategies put in place to manage such crises (Pellegrini and Fernández, 2018).

To this end, this review highlights the impact of the current international crisis on agrifood systems. We first discuss the role of Russia and Ukraine as the main exporters of cereal grains and oilseed crops, followed by a discussion of the impact of the conflict on global agrifood systems. We then highlight the over-reliance on a few countries for a large portion of our major food staples and its potential consequences for global food security. Lastly, we offer suggestions on several aspects of diversification within the agrifood systems to enhance global food security and nutrition in this challenging time.

2. Agrifood systems

Agrifood systems comprise all players and components in producing agricultural food products, such as crops, livestock, fisheries, forestry, and aquaculture, and non-agricultural food products, such as synthetic meat. The production, storage, processing, distribution, consumption, and disposal of these products support human food consumption and sustain life (FAO, 2021; United Nations 2021 Food Systems Summit, 2021). Agrifood systems also encompass non-food products that are agriculturally based, such as textiles, biofuels, fiberglass, and cosmetics, but these are outside the context of our current discussion. The 2020 FAO statistics record shows that the total gross value of agricultural production (crop and livestock) worldwide equated to USD 4.79 trillion (FAOSTAT, 2022). The main players in the global agrifood systems are those that influence international food prices and demand through various agrifood sectors. These include major exporters of food commodities, agriculture companies involved in agrochemicals, commercial seed suppliers, farm equipment suppliers, food processors, retailers, and others (ETC Group, 2022). We discuss how we should not over-rely on major food exporters and propose diversification as a sustainable way to achieve agrifood system resilience.

3. Role of the Russian federation and Ukraine in the agrifood systems

Russia and Ukraine are ranked 11 and 55 in the world economy in terms of GDP (US$), with their top export commodities being petroleum and agriculture, respectively (OEC, 2022). Both countries are global contributors to a substantial share of agricultural commodities, including raw materials for fertilizers, and are key exporters of cereal and oilseed food crops (World Bank Group, 2022). In 2020, Russia ranked number one in wheat exports, and Ukraine ranked number one in seed oil exports (OEC, 2022). Figure 2 illustrates the economic contributions of exported commodities by Russia and Ukraine in 2021 (UN Comtrade Database Intelligence, 2021).

4. Impact of the Russia–Ukraine conflict on agrifood systems

4.1. Food export bans and restrictions

The Russia–Ukraine conflict has produced shocks in the commodity markets for food, feed, fertilizers, and energy (OECD, 2022a) and impacted agrifood systems in many areas. As of early April 2022, 16 countries had imposed food commodities export bans following the escalation of the Russia–Ukraine conflict, equating to about 17% of total calories traded globally (Glauber et al., 2022). This is to ensure a sufficient supply of food within their own countries. With the closure of main Ukrainian ports at the Black Sea and the effects of multiple global economic sanctions imposed on Russia, both countries have evidently contributed to the largest percentage of food exports restrictions, equating to 42% of total calories (European Parliament Think Tank, 2022; Glauber et al., 2022). Other countries introduced export bans on various agricultural products, such as palm oil from Indonesia (Office of Assistant to Deputy Cabinet Secretary for State Documents and Translation, 2022) and grain products from Turkey, Kyrgyzstan, and Kazakhstan (CGIAR, 2022; Donley, 2022).

While some of these export bans were temporary and have been lifted, this exercise could potentially generate a domino effect with other exporting countries then implementing their own import/export restrictions in response to deviations in food prices. This will further destabilize the food supply in global markets with almost immediate inflation of food prices, severely affecting Central Asian countries and North African countries which rely on imports of wheat and maize, while India, Pakistan, and Bangladesh rely on imports of vegetable oils (Giordani et al., 2016; Glauber et al., 2022).

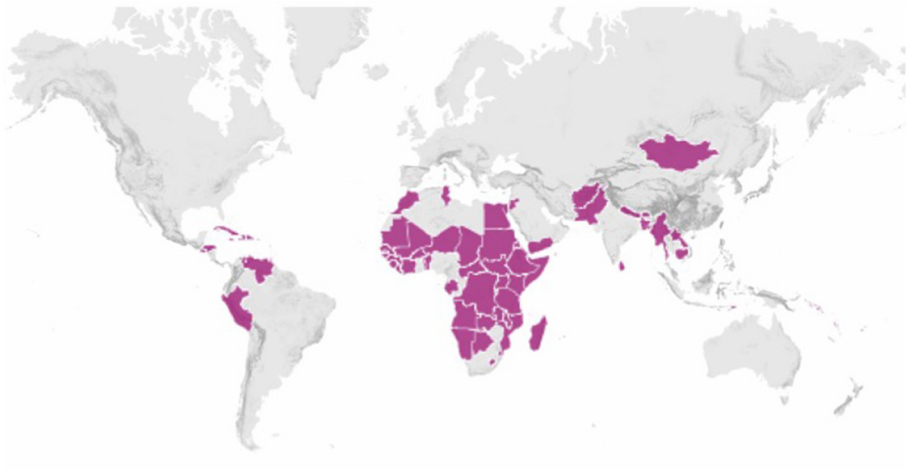

FIGURE 1
Net Food Importing Developing Countries (NFIC) vulnerable to food system disruption due to exogenous events such as the Russia–Ukraine conflict including sub-Saharan Africa, South Asia, the Middle East, North Africa, Latin America and the Caribbean, and East Asia (FAO, 2022b) (Figure re-produced with permission from FAO Copyright Office).

4.2. Food price hike

The rise in food prices is not solely a direct consequence of the Russia–Ukraine conflict, as an increasing trend has been apparent since 2020, but 2022 saw a "giant leap" in the food price index (Figure 3) (FAO, 2022c; Weersink and von Massow, 2022).

The increasing trend in food prices from 2020 to early 2022 is mainly shaped by the COVID-19 pandemic, with travel restrictions and lockdowns within and outside countries causing farm production to slow down, creating bottlenecks in the food supply chain [OECD Policy Responses to Coronavirus (COVID-19), 2020]. Other causes of food price hikes include the upward shift in food, feed, and fuel demand as the world gradually recovered from the pandemic and some crop production losses due to unfavorable weather patterns in Brazil and the USA (Sova and Man, 2021). The conflict in Ukraine during the first quarter of 2022 held back the reduction of food and energy inflation, thus increasing the global commodity prices in 2022–2023 (OECD, 2022b).

In the longer term, food prices are predicted to continue to increase even after the Russia–Ukraine conflict ends, as we continue to face reduced crop production due to volatile weather patterns induced by climate change (Cowling et al., 2019; Sultan et al., 2019; Anderson et al., 2020), such as the recent extreme heat, drought and flood conditions in Europe, the USA, the Horn of Africa and China, among others (Lodewick, 2022; WFP, 2022). Models have also predicted yield declines of up to 21.5% in maize on the US Great Plains due to erratic climate patterns (Irmak et al., 2022) and a reduction of up to 12.5% in wheat production in South Africa due to extreme heat (Shew et al., 2020). Moreover, studies have shown that extreme weather events are likely to occur more frequently and will be more intense in the future, directly and indirectly impacting crop yields and further threatening global agrifood systems and supplies with long-term implications for increasing food prices (Diffenbaugh et al., 2018).

4.3. Threat to food security

According to the Bill and Melinda Gates Foundation (BMGF) Goalkeepers Report (Bill and Melinda Gates Foundation Goalkeepers Report 2022, 2022), achieving SDG target 2 (Zero Hunger) by 2030 is too ambitious. Yet understanding the current status of global agrifood systems and food security is critical in facilitating the eradication of hunger (FAO et al., 2022).

In 2021, ~193 million people across 53 countries faced acute food insecurity at crisis level or worse (IPC/CH Phase 3 or above; 1 = minimal/non, 5 = catastrophe/famine) (Integrated Food Security Phase Classification, 2022), almost doubling from 2016 levels, with a concerning figure of 570,000 people categorized as in catastrophe conditions (IPC/CH Phase 5) in Ethiopia, South Sudan, southern Madagascar, Yemen, Afghanistan, and Somalia, where conflict is the primary driver of severe food insecurity (Global Report on Food Crises, 2022; WFP and FAO, 2022) because it disrupted agriculture-based livelihoods, restricted food access, impeded humanitarian operations and displaced populations (mainly smallholder farmers).

Even before the conflict in Russia–Ukraine, ongoing social unrest in several countries concentrated in Eurasia, namely Afghanistan, Bangladesh, Iraq, the Syrian Arab Republic, Yemen, and Ukraine, resulted in as many as 52.8 million people experiencing food insecurity at a crisis level (IPC Phase 3 or above) in 2021, up from 30.9 million in 2016, with nearly 16.8 million people displaced due to conflict (Global Report on Food Crises, 2022). That this is a continuous issue is supported by the findings that in 2014 food insecurity across sub-Saharan Africa, particularly in South Sudan and Nigeria, was driven by conflict (Anderson et al., 2021).

Based on FAO estimations, the Russia–Ukraine conflict will increase the number of undernourished people globally by 13.1 million in a worst-case scenario, added to the current 733.9 million undernourished people not impacted by the onset of the

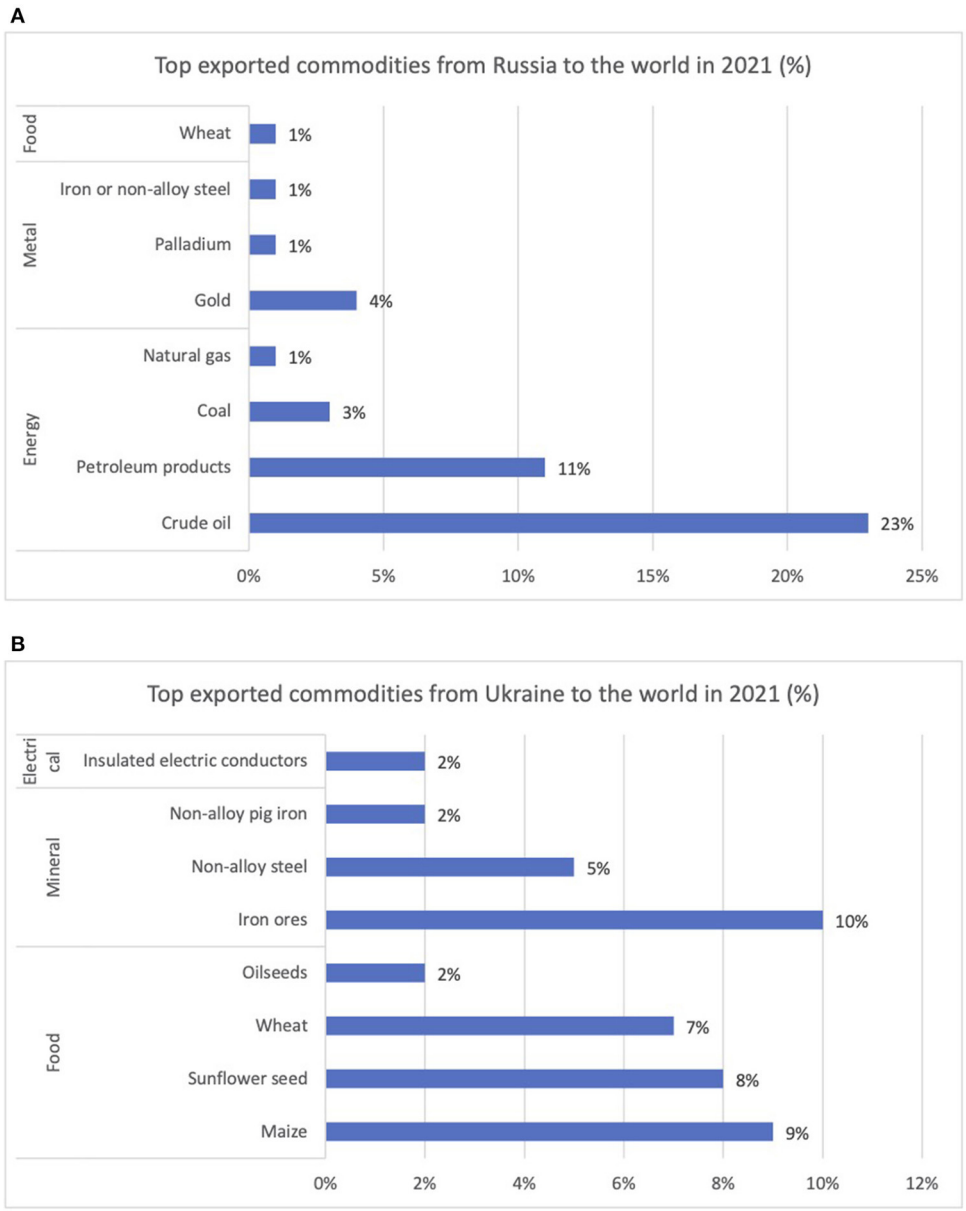

FIGURE 2
Top exported commodities in **(A)** Russia, and **(B)** Ukraine in 2021 (UN Comtrade Database Intelligence, 2021).

conflict (FAO et al., 2022). Sub-Saharan Africa, the Middle East, and North Africa are the most vulnerable population groups impacted by the Ukraine conflict (FAO et al., 2022). Adding to the malnutrition problem, food insecurity positively correlates with social unrest, particularly in developing countries, leading to further insecurity (Arezki and Bruckner, 2011; Weinberg and Bakker, 2015; Soffiantini, 2020).

4.4. Livelihood struggle among the rural poor

The Russia–Ukraine crisis has impacted poor and rural households due to fuel, food, and fertilizer price hikes. Countries such as Kenya (Breisinger et al., 2022), Egypt (Abay et al., 2022), Bangladesh (Diao et al., 2022b), and Ethiopia (Diao et al., 2022a) have witnessed declines in food consumption and diet quality. The increase in fertilizer prices also caused a heavy toll on local farmers in these countries, whose livelihoods depend on agriculture. If farmers reduce fertilizer use due to price hikes, their production often declines, impacting rural household incomes.

Typically, most farmers in developing countries in East Asia and the Pacific, South Asia, and sub-Saharan Africa are smallholders (farm owners operating agricultural land areas <2 ha). They account for 84% of global farms, contributing about 35% of the world's food (Ricciardi et al., 2018; Lowder et al., 2021). These smallholder farmers often live in remote areas and produce a wide variety of foods in addition to the main crop, but often

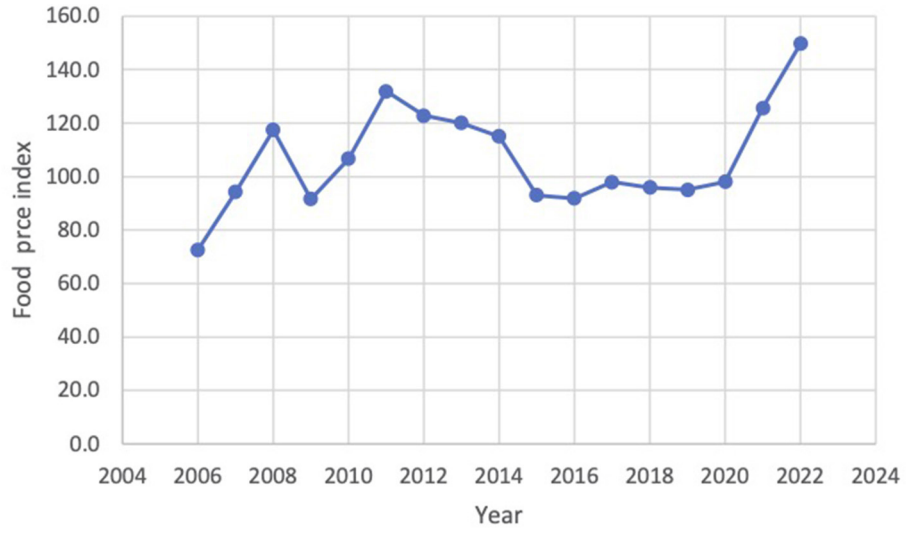

FIGURE 3
Annual FAO food price indices from 2006–2022 (FAO, 2022c).

with low productivity (Rapsomanikis, 2015). They are vulnerable to food insecurity due to sociodemographic factors (e.g., family size, education level of family members, farming experience) and have low resilience to changing circumstances, such as weather shocks and pest and disease outbreaks, as reflected in household surveys conducted in Central America (Guatemala and Honduras) (Alpízar et al., 2020) and Africa (Madagascar) (Harvey et al., 2014).

Using satellite data images of croplands in Ukraine, studying the impact of the conflict on winter wheat production across 2019–2021, Deininger et al. (2022) revealed that smallholder farmers are the most vulnerable group. They own 60% of the agricultural land and have experienced the most severe output losses, perpetuated by agricultural resource shortages such as labor, seed, fertilizers, and pesticides.

5. Over-reliance on major food exporters/importers and inequalities in agrifood business

Although the Russia–Ukraine conflict is not the sole cause of the current global food crisis, it has highlighted deeply inequitable agrifood systems (Hawkes et al., 2022). One of the inequities is the over-reliance on major food exporters, driven by the high global demand and reliance on a few major cereal crops, such as wheat, maize, and rice, much of which are consumed by populations in developing countries, and maize is also highly used for feed and biofuel applications (Figure 4).

Often, global staple food producers are concentrated in a small number of countries. For example, for the top staple commodities based on gross production value—rice, maize, wheat, and soybean—the biggest net producers and exporters are China, India, the USA, Brazil, and Russia (FAOSTAT, 2022) (Figure 5). The top rice-producing countries are China and India, producing 50% of global rice production. The top maize-producing countries are the USA, China, and Brazil, producing 60% of global maize production. China, India, Russia, and the USA produce 49.6% of the world's wheat, while Brazil and the USA produce 66.3% of the world's soybean (FAOSTAT, 2022). The Middle Eastern, North African, and East Asian regions are the largest net importers of these commodities, yet also have the highest rates of food insecurity (OECD/FAO, 2022b).

Major agrifood players are key in ensuring global food security through international trade. However, models of the relationships between population growth, food production, and trade dynamics have shown that over-dependence on food imports impairs global food security (Suweis et al., 2015). Low-income food-deficit regions, such as Africa, the Middle East, and Latin America, are most vulnerable to price shocks in food trade and least able to protect themselves against domestic food production shocks (Grassia et al., 2022). Worse still, the UN International Labor Organization said in its 2021 report that people in these countries live with much lower rates of social welfare protection. For example, Africa has the lowest level, with 17.4% of the population having access to social welfare protection, compared to Europe and Central Asia, where 84.0% of the population have access to social welfare protection (International Labour Organization, 2021). Consumers in low-income countries spend relatively more on food (40% of spending in sub-Saharan Africa) than high-income countries (17% in advanced economies) (Bogmans et al., 2022), such that food price variabilities potentially result in poor people being unable to afford enough, presenting a conundrum for these affected countries because they increasingly need to import food to meet the needs of rapid population growth (van Berkum, 2021).

The Russia–Ukraine conflict has exposed inequalities in the international agribusiness sector. In the last decades, there has been a trend toward consolidation of corporations that supply food and agricultural inputs through large-scale mergers such as Kraft and Heinz, Dow and Dupont, Bayer and Monsanto, with each company's worth reaching over US$60–100 billion after

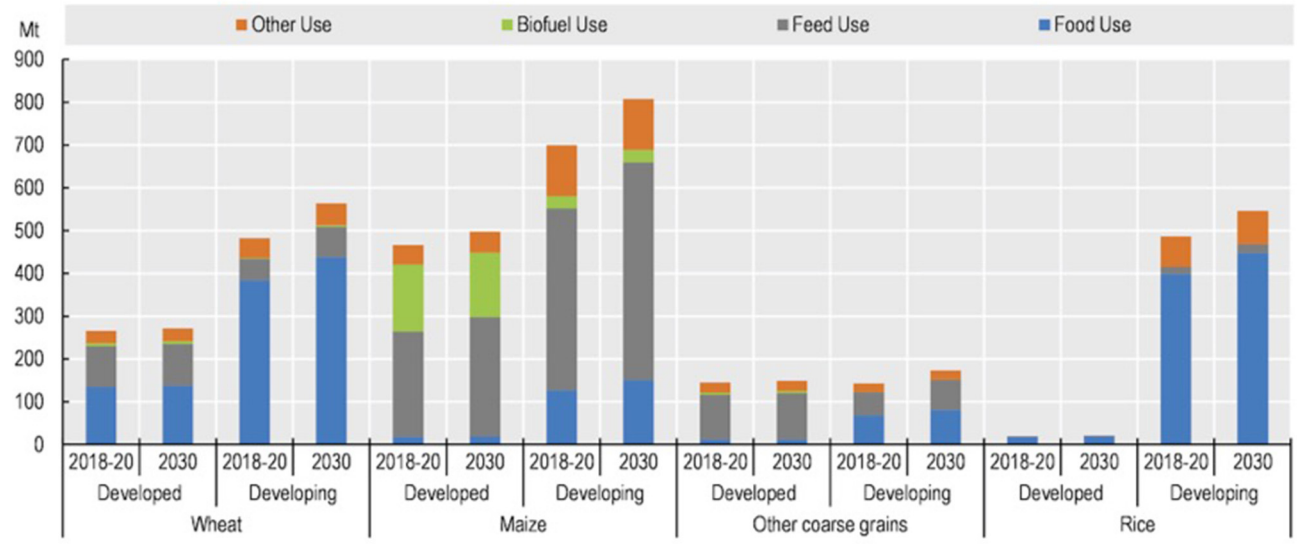

FIGURE 4
Cereal use in developed and developing countries (OECD/FAO, 2019) (Figure re-produced with permission from PubRights@oecd.org).

merging (Clapp, 2022). These companies play a crucial role in global food supply, at the same time influencing the volatility of the international price of food commodities. In the agrochemical industry, the top four companies—Syngenta Group (China), Bayer (Germany), BASF (Germany), and Corteva (USA) dominate 62% of the global agrochemical market, where Bayer and Corteva also control 40% of the global seed market (ETC Group, 2022).

6. Role of diversification in four aspects of agrifood systems

6.1. Market diversification

The projected increase in global food demand of 1.4% per annum over the coming decade, stimulated by a large growth in the world's population and *per capita* income (OECD/FAO, 2022a), will place tremendous pressure on major food exporters to ensure consistent agricultural outputs and to develop high resilience to various shocks. The main exporters of wheat and other staple products are sometimes major importers of the same crop. For example, Asia's top five wheat producers (China, India, Pakistan, Turkey, and Iran) contributed 332.94 Mt to global production, compared with 260.23 Mt in Europe in 2019. However, their wheat imports (74.19 Mt) exceeded their exports (6.61 Mt), attributed to the limited countries in Asia that meet the required growth conditions for bread wheat (Sendhil et al., 2022). However, with modern breeding technologies, many cereal crop varieties can withstand adverse climatic patterns, providing breakthroughs that allow crops to be grown outside their typical environments. For instance, high-yielding, heat-tolerant wheat varieties have been developed from large-scale field trials and germplasm screening in the Senegal River, a joint effort by ICARDA and the Swedish University of Agriculture (Bassi, 2017; Sall et al., 2018). Abandoned land in many developing countries could be used to cultivate staple food crops that fit the region's ecology, despite originating from other geographic regions.

To minimize the global impact of the food crisis, it is critical to diversify the import/export sources of food crops. For example, New Zealand has recently diversified its avocado export markets from Australia, where it previously shipped 79% of its total exports in the last 5 years, to Asian countries such as Singapore, Hong Kong, and South Korea after a decline in Australia's import demand (F+B Tech, 2022; Piggott, 2022). This is a win-win situation for establishing food resilience where the exporting country retains its role as the food supplier while the importing country benefits from securing food products to meet domestic food demands. Singapore imports 90% of its food from more than 170 countries, with food items coming from geographically diverse regions; the country continues to identify new food sources as part of its strategy to ensure market diversification with constant food supply (Teng, 2020; Singapore's Food Supply, 2022). The FAO measurement of countries with multiple food trade partners to ensure food security and nutrition—using the dietary sourcing flexibility index (DSFI)—is an attractive approach to market diversification and minimizing the adverse impact of a food crisis. The DSFI index measures food supply diversity based on multiple sourcing pathways of food commodities, imports, and available stocks. Countries with high DSFI values, such as Israel, Lebanon, Norway, and the UK, have a high capacity to absorb shocks with multiple options for food suppliers coming from diverse trade partners and multiple commodities. This contrasts with countries such as Indonesia, Madagascar, Pakistan and the Republic of Moldova with limited trade partners and fewer food commodity options (FAO, 2021).

Food market diversification on the international front requires trade agreement policies between nations, with transparent, updated information provided to all nations regarding agricultural markets. For example, the Agricultural Market Information System (AMIS), comprising G20 members with additional major exporters and importers of agricultural commodities, makes concerted efforts

FIGURE 5
Import and export quantities (kilo tons) for the four major staple crops (wheat, rice, maize, and soybean) (FAOSTAT, 2022).

to enhance international food trade policy using real-time data of food markets to prevent price hikes (Hertel et al., 2021; Agricultural Market Information System, 2022). At the regional level, for example, the project initiative "Agricultural Transformation and Market Integration in the ASEAN Region: Responding to Food Security and Inclusiveness Concerns (ATMI-ASEAN)," supported

by the International Food Policy Research Institute (IFPRI), addresses food security issues within the ASEAN region to increase smallholder farmer competitiveness in regional agrifood markets by identifying diverse crops with high impact value, with cooperation between agricultural stakeholders in member countries—Cambodia, Lao PDR, Myanmar, Viet Nam and the Philippines (Southeast Asian Regional Center for Graduate Study and Research in Agriculture, 2017). In addition, market diversification involves shifting part of the demand and supply for staples to non-staple foods such as fruits, vegetables, and pulses, considered high in protein and micronutrients, entering such food markets for a more balanced diet and nutritional outcomes (Pingali, 2015).

Another way to diversify food markets is to promote the production and commercialization of alternative foods sourced sustainably (e.g., plant-based foods). This approach has good health effects and diversity of flavors, tastes, and textures, increasing consumers' menu options and making food markets more resilient to price shocks. For example, consumers are receptive to blending wheat flour with cassava flour, indicating the potential use of minor crops as alternative foods (Owusu et al., 2017). Governments could provide funds to start-up companies involved in "ecologically friendly" food production or businesses involved in agricultural technologies to stimulate the demand for alternative crops, boosting the country's economy and supporting food security and healthy living.

Domesticating indigenous fruit tree species (IFTs), and herbaceous species within the broad traditional foods and medicinal plants can also be a good option to diversify food markets (Leakey, 2014; Leakey et al., 2022). We can achieve this by extending the food market and value chain to include nutrient-dense foods that fall under the radar of public attention, including neglected and underutilized species (NUS) and indigenous fruit tree species, such as *Strychnos madagascariensis* (fruit processed as flour) from Africa countries (Chemane et al., 2022) and *Garcinia andamanica* King (fruit suitable as a food additive) from Andaman Islands, India (Bohra et al., 2021). To increase the marketability of these alternative foods, attention should be drawn toward strengthening independent local and regional food systems. This can be achieved by providing a support network to farmers selling through a direct-to-consumer channel or in short food supply chains (SFSC) markets (Jarzebowski et al., 2020; Schreiber et al., 2022). For instance, policymakers ought to put into action the delivery of high-quality workflow for the value-added processing, storage and distribution of fresh products to local communities that can help farmers retain a larger portion of the retail value of food, and enhance resilience to shocks in the international supply chain (Enthoven and Van den Broeck, 2021).

6.2. Production diversification

Due to soaring costs, the Russia–Ukraine conflict has put immense pressure on farmers and supply chains relying on fertilizer, feed, and fuel. How we produce food crops has to be diversified as part of food sustainability strategies. Intensive agriculture, driven by the Green Revolution in the mid-20th Century, emphasized monoculture, crop hybridization, and reliance on fertilizers and other agrochemicals that increased yield. However, these developments also resulted in increased reliance on international supply chains and had unintended impacts on natural resources, such as water and land, due to the heavy use of fertilizers and other agrochemicals (United Nations, 2004; Rosa et al., 2021; Soria-Lopez et al., 2022). In contrast, sustainable intensification in the 21st Century seeks to leverage on least agricultural inputs to achieve equal if not higher crop yield without incurring the environmental impact and further expansion of cropland (Pretty and Bharucha, 2014; Campanhola and Pandey, 2019). This involves using improved crops, regenerative agricultural methods, and diversified production and distribution systems. The concept of sustainable intensification was incepted by FAO in 2011 under the "Save and Grow" model, aiming to achieve food security through balancing increasing productivity and positive outcomes for the environment (Collette et al., 2011).

Diversification of agricultural practices, such as intercropping spatially or temporally, mixed farming with crop and livestock, adding organic material or beneficial microbes in the soil, and reduced tillage, has contributed to biodiversity conservation, improved soil fertility, enhanced nutrient cycling and water regulation, and improved pest control, decreasing the environmental burden without compromising crop yield (Tamburini et al., 2020; Yan et al., 2022). For example, intercropping systems with grain legumes such as pigeonpea (*Cajanus cajan*) or leguminous tree species such as fliricidia (*Gliricidia sepium*) in smallholder maize farming in Tanzania, East Africa, has shown that the grain yield, caloric and protein yields were not inferior to monoculture maize. The other benefit is the maize-pigeonpea intercrop requires a reduced land area to produce the same grain yields under drought and well-watered conditions (Renwick et al., 2020). Agroforestry tree and shrub species in semi-arid West African parklands in which forests areas were cleared for agriculture farming purposes have been shown to restore both soil fertility and health by providing rich organic biomass through the burial of ramial wood or small branches during forest management (Félix et al., 2018). Depending on the type of tree and shrub species, for example, legume tree *Leucaena leucocephala* and berry fruit tree Phalsa (*Grewia asiatica*), when utilized as an intercrop or rotational crop with different food crops including cereals, leguminous and oilseeds, would not only improve crop yield (Sileshi et al., 2011; Rathore et al., 2022) but provide far-reaching benefits for the farmers, environment and food security. Farm diversification among smallholder farmers in Bangladesh and Central Malawi, including alternative crops, livestock and aquaculture farming, has seen a significant shift toward diversified diets and high nutrient assimilation as these farmers consume their farm produce and improve their household income and food security (Mango et al., 2018; Rehan et al., 2021).

Simulation and modeling studies of sustainable intensification in the Brazilian Amazon basin have shown that, adding soybean cultivation to livestock production areas, has multiple environmental and yield benefits, increasing soybean production from 2022/2023 forecasted 144–162 Mt without deforestation and decreasing climate warming by up to 58% (Marin et al., 2022; USDA FAS, 2022). Cropping system diversification, for example,

rotational sequences of cereals/grasses such as rice and maize with legumes such as peas and mungbean in China, India, and Bangladesh, or mixtures of pea, oilseeds, and wheat in the Boreo-Nemoral region (Scandinavian or Northern Europe countries) have improved system productivity through higher crop resource use efficiencies with great potential for increasing nutrient levels and reducing carbon footprints (Lizarazo et al., 2020; Chai et al., 2021; Emran et al., 2022; Gora et al., 2022).

Integrated pest management (IPM) for crop protection also taps into diversified strategies to prevent, avoid or reduce pests using ecologically sound methods such as crop rotation, natural and biological controls, and host plant pest resistance or tolerance, and synergies between these strategies. One example is biofumigation by burying into the soil the natural glucosinolate sourced from plant members within the Brassicaceae family to suppress the pests (Richard et al., 2022). Another example of IPM is the control of the moth *Tuta absoluta*. This South American tomato pinworm pest severely destroys tomato production worldwide, using biological agents such as bacteria, fungi, nematodes, and predatory arthropods (Desneux et al., 2022). Recently, IPM technology (IPMT) has been proposed, which expands from IPM that incorporates the components of genetically engineered cultivar and biotechnology approaches that are relevant to today's agricultural setting with the focus on monitoring, identification, assessment, and prevention of pests with minimal environmental impacts using data-driven tools (Tanda, 2022). For example, the Intelligent and Integrated Pest and Disease Management (I2PDM) system was developed to capture the presence of plant pests such as thrips and whiteflies under a controlled environment setting, which greatly enhance the efficiency of plant disease monitoring (Rustia et al., 2022).

Smallholder farmers play an important role in supplying food globally (Terlau et al., 2019). All the positive outcomes of diversification described above cannot reach their full potential impacts in addressing global or regional food security without providing strong socio-economic support to smallholder farmers and ensuring that farming activities are enriching (Giller et al., 2021). There will also need to be a transformation in agronomy knowledge whereby on top of the hard sciences, integration of social science disciplines such as sociology, economics, and policy studies is embraced for future knowledge-based sustainable farming (Struik and Kuyper, 2017; Klerkx et al., 2019). Understanding farmers' difficulties in farm practices, with strong support from government agriculture agencies offering attractive subsidies, zero- to low-interest micro-financing, proper training and guidance, and close monitoring of agricultural outputs is essential (Epule, 2019). On the national front, strong support from the government through incentives, allowances, and subsidies to smallholder farmers to reinforce crop cultivation is an effective measure for household food security.

6.3. Crop diversification

For the past 60 years, human food sources that provide macronutrients such as energy, protein, and fat have primarily come from 50 crop commodities, including wheat, rice, maize, barley, potatoes, and general vegetable and fruit commodities comprising <100 plant species (Khoury et al., 2014; Massawe et al., 2016; Shelef et al., 2017). With 7,039 known edible plant species recorded across 2,319 genera (Kew Gardens, 2020), there is still a large portion of edible plants that we could use for food diversification, including neglected and underutilized food crops (NUS) (Sogbohossou et al., 2018; Mustafa et al., 2019).

NUS currently have limited production and market values compared to major staples (Khoury et al., 2022). They have been nurtured as native crops agriculturally suited to local or regional climates and grown in domesticated forms or introduced centuries ago and are now established in their local environments. NUS are breeding candidates for advanced food crops with great economic potential (Mabhaudhi et al., 2019; Tirnaz et al., 2022). NUS cover a wide range of crop types, including cereals, roots and tubers, legumes, fruits and vegetables, seeds and spices, and were often traditionally grown by indigenous people and smallholder farmers as food for home consumption or a source of income at local markets (Padulosi et al., 2019; Heindorf et al., 2021). NUS can be found across various agroclimatic regions and landscapes suitable for agriculture. For example, 77 NUS in the form of leafy vegetables, tuber, edible wild fruits, and legumes have been found in Vietnam highlands (Vu and Nguyen, 2017).

Research into NUS has gained momentum over the years, with a focus on diversifying food crops to fight hunger and provide agricultural resilience (Li and Siddique, 2020; Mustafa et al., 2021; Siddique et al., 2021), and some could be mainstreamed into the food system, particularly those rich in protein and minerals or medicinal properties (Mudau et al., 2022). Bambara groundnut (*Vigna subterranea*) (Mayes et al., 2019; Tan et al., 2020), winged bean (*Psophocarpus tetragonolobus*) (Adegboyega et al., 2019; Tanzi et al., 2019) and amaranth (*Amaranthus* spp.) (Sarker et al., 2020; Jamalluddin et al., 2021) have high fiber content and nutrients, such as protein, carbohydrates, unsaturated fatty acids, and essential minerals. They are thus good candidates to supplement food systems to overcome malnourishment in adults and children (Talabi et al., 2022). Breeding programs have been developed to produce improved varieties of NUS crop species by initially characterizing germplasm. The African Orphan Crops Consortium (AOCC), in global partnership with biotechnology industries and research institutions, has initiated plans to assemble the genome sequence of 101 traditional African food crops for genetic improvement (Jamnadass et al., 2020; African Orphan Crops Consortium, 2022). To date, the genomes of at least 29 orphan crops in nine families have been sequenced, including Fonio (*Digitaria exilis*) (Abrouk et al., 2020), African eggplant (*Solanum aethiopicum*), breadfruit (*Artocarpus altilis*), apple-ring acacia (*Faidherbia albida*), Bambara groundnut (*Vigna subterranea*), jackfruit (*Artocarpus heterophyllus*), lablab (*Lablab purpureus*), marula (*Sclerocarya birrea*) and moringa (*Moringa oleifera*) (Chapman et al., 2022).

Indigenous fruit tree species (IFTs), which also falls under underutilized food crop, should be given equal emphasis as candidates for crop diversification. Tree commodities play a crucial role in diversifying crop production through agroforestry practices, which contribute to sustainable development goals in Africa (Mbow et al., 2014; Minang et al., 2021). Domesticated IFTs have two main benefits, the first being naturally nitrogen-fixing tree

species such as leguminous type can help restore the land and improve soil nutrient availability. Second, fruit trees offer nutritious foods, with a surplus, can also be turned into a source of income for farmers from fruit selling, on top of fuel wood and timber trades (Leakey, 2014, 2020). Both benefits of agroforestry practices have translated into overall farmers' wellbeing, as shown from interviews and discussions with subsistence farmers in western Kenya (Thorlakson and Neufeldt, 2012). IFTs are valuable for their edible fruits/nuts and most of their plant parts. For example, *Garcinia livingstonei* (African mangosteen)'s stem bark has a skin lightening effect on human skin (Mulholland et al., 2013), and its fruit contains high levels of macro and micro elements (Joseph et al., 2017). At least 29 IFT species within the South African provinces have been identified as potentials for commercialization (Nkosi et al., 2020). Domesticating IFTs through species diversity characterization could potentially close the yield gap, thereby increasing the harvest yield (Sulieman and Mariod, 2019).

Crop wild relatives and their associated weedy forms of agricultural crops are great genetic resources for trait improvement in cultivated species, including tolerance to a range of abiotic and biotic stresses, with many carrying out the C4 photosynthesis and thus adaptable to warm and dry environmental conditions (Ye and Fan, 2021). With good breeding models, prediction tools for the optimal selection of useful alleles and their introgression into elite pools with minimal linkage drag are possible (Cowling, 2013; Cowling et al., 2017). An initiative to collect wild, weedy, or landrace materials representing 29 target crops sourced from their country of origin and other exotic places was carried out by the Crop Trust Crop Wild Relatives Project, with expertise from 170 worldwide research institutes and breeding programs in 70 countries to conserve valuable wild germplasm in *ex-situ* collections, for plant breeders, researchers and farmers (Khoury et al., 2010; Crop Trust Annual Report 2021, 2022). Output from the project includes the collection of eggplant *Solanum* genus wild relatives from partners in 12 countries, 17 samples of wild Bambara groundnut from Nigeria not found in genebanks previously, and pre-breeding lines derived from crop wild relatives and landraces of grasspea and finger millet, with more than 14,000 pre-bred lines from 19 crops available to crop researchers and farmers (Crop Trust, 2019; Crop Trust Annual Report 2021, 2022).

6.4. Technology diversification

Advances in agricultural practices and plant breeding methods are key to securing food for the future. Collaborative networks between farmers, private and government research institutions, agronomists, researchers, and industry professionals in breeding programs drive knowledge and technology transfer through active dialogues and participatory research. Such an example includes the sorghum network in Mali involving ICRISAT and farmer organizations to strengthen the seed system (Rattunde et al., 2021). Supported by reliable international, regional, or local agricultural research funding bodies and expertise, integrating farmers' indigenous in-farm knowledge with modern scientific knowledge in plant breeding will stimulate innovation and real-life application to boost sustainable agriculture productivity (Dawoe et al., 2012; Pagliarino et al., 2020). Farmer field school offers an experiential learning approach where a group of farmers works together with the facilitator, discussing regularly the various situations encountered in the field and coming up with solutions of empowering farmers' capability in agrosystem management and expand their knowledge base (Bakker et al., 2021, 2022).

Cutting-edge biotechnology tools, such as genome sequencing, pangenomics, SNP marker discovery, and genotyping, genome-wide association studies, and genomic selection approaches, have revolutionized crop breeding with smarter and more targeted ways to improve crop productivity (Bayer et al., 2021; Marsh et al., 2021), as seen by the advances in many major crop species and application in NUS crops (Tay Fernandez et al., 2022). These tools will benefit crop breeding, provided sufficient plant material is available that covers a wide genetic diversity for each crop species (major and NUS) (Khan et al., 2020; Mohd Saad et al., 2021).

Viable plant materials from the world's food crops are well conserved in genebanks worldwide. Online resources such as Genesys, containing the genebank database, make it convenient for researchers to perform research and studies (Genesys, 2022). For example, the current wheat germplasm collection contains more than 800,000 accessions held in 80 different collections, with CIMMYT hosting the largest wheat collection worldwide (Crop Wild Relative Diversity, 2022). This large pool of genetic resources, with as many as 80,000 wheat accessions sourced from tetraploid species, wild relatives, and landraces, has been studied for its genetic diversity using DArTseq and SilicoDArT approaches (Sansaloni et al., 2020). The global genetic yield gap for wheat is estimated at 51% due to suboptimal crop and soil management, indicating that there is room to improve crop productivity through genetic improvements by tapping into the large wheat germplasm resources (Senapati et al., 2022). Another example is the genotyping of the entire collection of barley accessions from the German *ex-situ* collection, with 22,626 accessions, using genotyping-by-sequencing to differentiate and track redundant material in the genebank (Milner et al., 2019). Combining high-throughput genotyping with high-throughput phenotyping (Danilevicz et al., 2021) using machine learning (Khotimah et al., 2020) makes it possible to accurately identify the diversity underlying agronomic traits.

Maize, wheat, and soybean productivity can be improved to reduce import requirements by combining various modern breeding techniques, such as genomics-assisted breeding, phenomics, artificial intelligence, and gene editing (Naqvi et al., 2022), to overcome the limitations of climate-dependent food crops by developing tropical varieties. Besides, investing in the latest breeding technologies would facilitate knowledge transfer from lab to the field, potentially improving crop productivity. For example, Japan, Korea, and China are the origin sites of domestication for soybean; on-site plant materials collection and data analysis supported by genomics facilities means cost-saving in terms of time and resources at the same time, translating research outputs into improving soybean production in their own countries (Li et al., 2020). The International Maize and Wheat Improvement Center (CIMMYT) developed maize hybrids acclimated to South and South East Asia climate zones (CIMMYT, 2019).

Crop pangenomics resources are useful for plant breeding and improvement, revealing valuable information for breeders to tap into from the large diversity of a species (Golicz et al., 2016; Bayer

et al., 2020, 2022a; Zanini et al., 2022). For example, the soybean pangenome from the USDA collection revealed more genes with lower frequencies, such as those controlling plant architecture and seed composition, than those with higher frequencies, such as those controlling flowering time and stress tolerance traits; this gives breeders an idea of which genes to select from which accession during the selective breeding process ("smart" breeding) (Bayer et al., 2022b). In addition to genomes and pangenomes being developed for major crops, they are also being constructed for crops important in developing countries, such as banana (Rijzaani et al., 2022), yam bean (Tay Fernandez et al., 2021), sorghum (Ruperao et al., 2021), chickpea (Varshney et al., 2013) and pigeonpea (Zhao et al., 2020). Ongoing efforts have been made to build pangenomics resources for developing climate-ready crops (Marsh et al., 2021; Petereit et al., 2022).

Crop mutation breeding, a plant breeding technique that uses induced mutation in plants for better adaptability to the environment, generates genetic variation for crop improvement (Forster and Shu, 2012). The Plant Mutation Breeding Network for Asia and the Pacific established by the Joint FAO/IAEA Center successfully released improved varieties of cowpea in Zimbabwe using the irradiation method, with improved drought tolerance and insect resistance and increasing yields by 10–20% (Dixit and Slavchev, 2018). With the development of genome editing techniques, it is possible to generate precise modifications in genomes. When this technology is combined with the knowledge of pangenomes and associated traits, it is possible to accelerate the production of climate-ready crops to support future food security (Mohd Saad et al., 2021; Varshney et al., 2021a,b; Derbyshire et al., 2022).

In summary, by considering the diversification in four aspects of agrifood systems, we believe the goal of attaining a more sustainable, shock-resilient, and improved global food security is not far-reaching (Figure 6).

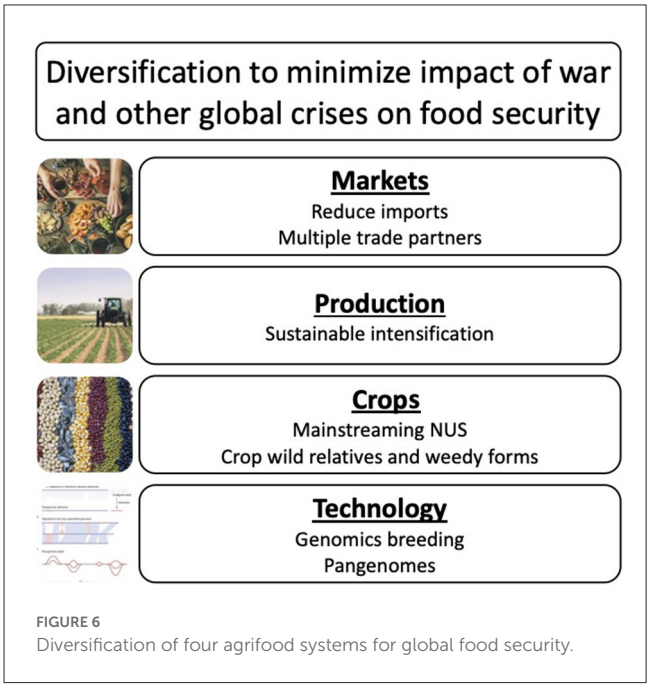

FIGURE 6
Diversification of four agrifood systems for global food security.

7. Future perspectives and conclusion

The Russia–Ukraine conflict has highlighted the vulnerability of global food security and underscored the critical need to achieve food resilience by transforming and diversifying agrifood systems. We propose diversification in food markets, production, crop, and technology to secure global food supply and build resilience toward future shocks. Specifically, there should be stronger support for increasing market demand for alternative foods. It is important to consider sustainable intensification in producing sufficient food to feed the growing global population with minimal risks to the natural ecosystems. Concerted efforts at the global, regional, national, and local levels are needed to fulfill the mandate of global food security through policymaking, increased consumer awareness, knowledge of food markets, adding value with NUS crops, and research investments using advanced biotechnology tools to enhance crop productivity. At the smallholder farmers' level, the efficiency and productivity of production and processing markets for food crops, including indigenous fruit trees, could be improved by creating platforms for farmers to distribute their fresh harvest directly to consumers. Food system experts indicate that food resilience research should focus on prediction tools and high-quality, local-scale on-the-ground data collection to determine the impact of extreme events on food security (Mehrabi et al., 2022). Within the context of long-term food crop trials, practical implementation *via* participatory on-farm research using real-time farming challenges could provide solutions for NGOs, consumers, academia, policymakers, and value chain experts (Riar and Bhullar, 2020). Incorporating all these roles, carried out by diverse players in the agri-food industry, should combat hunger by 2030 and fight the global food crisis.

Author contributions

TN and FM conceptualized the study. TN wrote the first draft of the manuscript. BKS wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Publisher's note

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Building the resilience of agri-food systems to compounding shocks and stresses: A case study from Melbourne, Australia

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Introduction: The war in Ukraine is causing significant disruption to global agri-food systems, which are still recovering from the effects of the COVID-19 pandemic. In Australia, these global shocks followed a series of localized climate-induced crises from forest fires, floods and drought. There is a pressing need to increase our understanding of ways to strengthen the resilience of agri-food systems to multiple shocks and stresses that co-occur or follow on each other. The aims of this study in Melbourne, Australia, were to investigate how forest fire and pandemic shocks affected the agri-food system, to identify vulnerabilities in the system, and to explore opportunities to build resilience to future shocks and stresses.

Methods: Semi-structured interviews were conducted during 2020-21 with 41 key stakeholders from government, industry and civil society organizations.

Results and discussion: Vulnerabilities identified in agri-food supply chains included geographic and corporate concentration, complex "just in time" supply chains, critical infrastructure and logistics, and workforce availability. Strategies identified to build the resilience of agri-food systems include increasing the diversity of supply chains, decentralization, collaboration throughout agri-food supply chains, and ensuring sustainable livelihoods.

Conclusion: Our study highlights the cascading effects of multiple shocks and stresses on agri-food systems, and the need for greater policy focus on transformative actions that build the resilience of agri-food systems to any future shock, and that counter the cumulative effects of underlying environmental stresses.

KEYWORDS

climate change, pandemic, policy, adaption, transformation

1. Introduction

The war in Ukraine is significantly affecting global agri-food systems, disrupting agricultural production and supply chains, and contributing to the rising cost of fuel, fertilizer and food (FAO, 2022b; Mottaleb et al., 2022). This latest disruption adds to the impacts of the COVID-19 pandemic and climate shocks and stresses on global food systems (Béné et al., 2021; Romanello et al., 2022). Disruption to agri-food systems is driving sharp increases in global food insecurity and hunger (FAO, 2022; von Grebmer et al., 2022).

There is a pressing need to increase our understanding of ways to strengthen the resilience of agri-food systems as climate events, including drought, fire, and flood, are projected to increase in frequency and severity in coming years (IPCC, 2022). Multiple and concurrent shocks are also compounding the impacts of shocks to agri-food systems and the challenges of strengthening their resilience (Quigley et al., 2020). However, relatively little research has been undertaken into the resilience of agri-food systems, and our understanding of what makes agri-food systems resilient is only just emerging (Biehl et al., 2018; Vieira et al., 2018; Hecht et al., 2019; Bene, 2020).

Researchers have called for more empirical evidence about food system resilience that builds on conceptual understanding (Ericksen, 2008; Tendall et al., 2015; Ali et al., 2022). There is also a need for more holistic research that investigates resilience across the whole agri-food system, rather than one part of the system in isolation (James and Friel, 2015; Zurek et al., 2022). However, to build resilience, it is important to understand how agri-food systems are affected by shocks and what that tells us about their vulnerabilities (Quigley et al., 2020; Stephens et al., 2020). It also requires consideration of underlying environmental stresses. The natural resource base that underpins global food production is under pressure from the degradation of land and water systems (Fan et al., 2021a), biodiversity loss (IPBES, 2019), high levels of food waste (UNEP., 2021), and declining availability of agricultural land (Fan et al., 2021a). There are interactions between these long-term environmental stresses and sudden shocks (Zurek et al., 2022), and there is a need for empirical studies of food system resilience that consider both.

This paper aims to address these research gaps by investigating food system resilience to climate and pandemic shocks and stresses in Melbourne, the capital city of Victoria in south-east Australia. Melbourne has a population of around 5 million people (Australian Bureau of Statistics., 2021), and is experiencing rapid growth and urbanization on its peri-urban fringe. Melbourne's city region comprises 31 local government areas in the metropolitan area and another 9 local government areas that form a peri-urban ring around the city (Murphy et al., 2022). The study began during the 2019-2020 Australian "black summer" forest fires. These fires were of unprecedented scale and intensity, burning more than 24 million hectares of land and killing three billion animals, with an estimated financial cost of more than $10 billion (Commonwealth of Australia, 2020). The fires occurred during Australia's hottest and driest year on record, when much of the country was already drought affected (Commonwealth of Australia, 2020). As the fires were receding, the COVID-19 pandemic outbreak started with the first case in Victoria detected in January 2020 (Storen and Corrigan, 2020).

This case study analyzes the effects of multiple shocks and stresses on Melbourne's food system and identifies the features of the food system that contribute to resilience. It highlights the importance of taking actions that strengthen the resilience of food systems to a wide range of potential shocks and that also build the long-term resilience of food systems to ongoing environmental stresses. This paper begins with a review of the literature about the concept of resilience in food systems and it provides an overview of empirical studies that have investigated the resilience of food systems to shocks and stresses.

1.1. The concept of resilience in food systems

A food system comprises the actors and activities involved in producing, processing, distributing, retailing, disposing and consumption food, and the interactions within the system (Ericksen, 2008; HLPE, 2017). Tendall et al. (2015) define resilience of a food system as the "capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances" (Tendall et al., 2015). Their food system resilience action cycle emphasizes preventive action to build robustness to withstand a disturbance, and reactive action to absorb the disturbance, act flexibly and recover from the disturbance with resourcefulness and adaptability (Tendall et al., 2015). The concept of resilience emerged from the study of socio-ecological systems and their capacity to absorb a disturbance, to adapt and learn in the face of change (Folke, 2006), and it has only been applied to food systems relatively recently (Béné et al., 2016; Constas et al., 2022).

The United Nations conceptualizes resilience as the ability of systems, institutions and people to prevent, resist, absorb, adapt, respond and recover when confronted with risk (United Nations., 2020). Applying this definition to food and agriculture, the FAO noted that agri-food systems require absorptive, adaptive, anticipating, preventive and transformative capacities to overcome multiple overlapping shocks and stresses, achieve food security for all, and decent livelihoods for actors within the agri-food system (FAO, 2021).

1.2. Features of resilient food systems

A number of empirical studies have investigated the resilience of food systems in the context of specific shocks, particularly climate-related events and the COVID-19 pandemic (for example, Smith et al., 2016; Béné et al., 2021). Several studies investigated the resilience of food supply chains in Queensland, Australia, following widespread flooding in 2011 (Smith and Lawrence, 2014; MacMahon et al., 2015; Smith et al., 2016). Other studies have investigated the resilience of foods systems in Christchurch, New Zealand after an earthquake (Berno, 2017); in New York City, USA after a hurricane (Chan et al., 2015); and in northern Bangladesh after flooding (Smith and Frankenberger, 2018).

These empirical studies of climate and pandemic events reveal some features of resilient food systems. Multi-stakeholder coordination across supply chains and strong networks of food system actors promoted resilience during flooding (MacMahon et al., 2015; Smith et al., 2016). Community resilience—the collective capacity to respond—strengthens food security and the resilience of food systems (Smith and Lawrence, 2014; Chan et al., 2015; Berno, 2017; Smith and Frankenberger, 2018). Home gardening, community gardening and urban agriculture play a role in building community resilience and support food security during climate and pandemic shocks to food systems (Chan et al., 2015; Lal, 2020; Niles et al., 2021). Studies of food supply chain resilience during the COVID-19 pandemic in Canada and the US (Hobbs, 2021), and Australia (Snow et al., 2021; Jones et al., 2022) also

showed that strong interpersonal relationships and networks across supply chains strengthen resilience.

Diversity in agri-food systems emerges as a hallmark of resilience. Diversity of crops, suppliers and production methods supported resilience during the Queensland floods, as well as the ability to respond to the shock quickly and flexibly (Smith et al., 2016). Love et al. (2021) found that diversity at the community, company and industry level built the resilience of the global seafood industry during the COVID-19 pandemic. Other studies of food system resilience during the COVID-19 pandemic have also noted the importance of diversity in food supply chains (Bisoffi et al., 2021). Flexibility and adaptability were identified as key to supply chain resilience in both long and short food supply chains (Chenarides et al., 2020; Hobbs, 2021). In the US, local and regional food supply enterprises were able to flexibly switch to new logistics and distribution approaches, including direct to consumer produce boxes and online marketplaces (Thilmany et al., 2020; Marusak et al., 2021).

Other studies have investigated the resilience of city food systems using a vulnerability assessment approach (Blay-Palmer et al., 2018). Vulnerability assessments have been used to identify geographic areas and population cohorts most vulnerable to food insecurity in the event of a shock to the food system (Zeuli et al., 2018). A study in Toronto, Canada assessed the vulnerability of the city's food system to three extreme weather scenarios linked to climate change and found that interdependencies between the food system and other systems, such as transportation and telecommunications, were a key vulnerability (Zeuli et al., 2018). A study in the US city of Baltimore found that preparedness, relationships and communication, diversity, redundancy and post-event learning were key to resilience in a disaster scenario (Hecht et al., 2019). While these studies provide insights into the features of resilient food systems in the face of a single shock, there is a need to understand how food systems are affected by multiple shocks and stresses and the features of food systems that strengthen resilience under these circumstances.

The aims of the present study were to: (i) investigate how the forest fire and pandemic shocks affected Melbourne's food system; (ii) identify food system vulnerabilities to these shocks; and iii) identify features of the agri-food system that strengthen resilience. Our analysis includes a focus on the perceived impacts of shocks and stresses in Melbourne's city region and in other areas of Victoria which are important to the city's food supply.

2. Methods

2.1. Theoretical approach

The study draws on findings from a three-year research project that was informed by the City Region Food System (CRFS) approach (Carey et al., 2022; Murphy et al., 2022). The CRFS approach focuses on strengthening linkages between cities and their surrounding peri-urban and rural areas to improve the resilience of food systems, and to safeguard food security and livelihoods (Blay-Palmer et al., 2021; FAO, 2022a). The CRFS approach offers potential for conceptualizing more sustainable food systems by engaging multi-sectoral actors from across the food system to identify integrated policy action across the city region (Blay-Palmer et al., 2018). We take an integrated "food systems" approach to examining resilience through food supply chains, recognizing that changes in one part of the food system can have unanticipated consequences in other parts of the system (Ingram, 2011). We distinguish between shocks, which are sudden events that disrupt agri-food systems, and longer-term stresses, which have more gradual impacts (Zurek et al., 2022).

2.2. Data collection

We conducted 34 semi-structured interviews with 41 participants from May 2020 to March 2021, to gain an in-depth understanding of participant perspectives on the resilience of Melbourne's food system to shocks and stresses. Semi-structured interviews were considered appropriate as they have a flexible structure that uses open-ended questions to explore a topic, and allows for follow-up questions to probe participant responses (Roulston and Choi, 2018). The interview guide sought to collect data on the perceived impacts of climate and pandemic shocks and stresses on the food system, and opportunities and barriers to strengthening the resilience of Melbourne's food system to future shocks and stresses (Table 1). All interviews were conducted with two members of the research team present (MM, RC, LA), using online communications platforms (Zoom or Microsoft Teams). All interviews were audio-recorded and transcribed. Participants were given the opportunity to review and amend a transcript of their interview.

2.3. Sampling and recruitment

We used purposive sampling and snowball sampling to select interview participants from government (local and state), industry and civil society organizations who were engaged in one or more parts of the food system (production, processing, distribution, retailers, consumption, waste). Purposive sampling selects information-rich cases for in-depth study and understanding of the phenomena of interest (Patton, 2002; Liamputtong, 2019). Potential participants were identified through organizations' websites, the authors' networks, and through the professional networking site (www.linkedin.com). Participants were approached by email with a plain language statement and consent form attached. Signed consent forms were obtained prior to interview. Snowball sampling was used at the end of interviews whereby participants were asked to identify others who may be useful to interview. Ethics approval for the study was granted by the University of Melbourne (Ethics ID: 2056495.2).

2.4. Participants

There were 41 interview participants from government, industry and civil society organizations. Interviewees had professional roles and responsibilities that focused on each stage of the food system: production, processing, distribution,

TABLE 1 Interview guide.

Introduction	Tell us about your interest in the resilience of the food system to climate or pandemic shocks and stresses and any involvement or experience in your current role in issues related to the resilience of the food system to shocks and stresses.
Roles	What role does your organization play in the event of a disruption to the food system? What plans does the organization have in place for those events?
Impacts	What types of impacts have you seen from climate-related shocks and stresses or pandemic stress on our food system? Who has been most affected by the impacts? What steps were taken to address the impacts and how effective were they?
Governance	What is the role of state and federal government and the food industry in managing supply issues relating to COVID-19 or other shocks? What is the governance around building resilience of the food system in the longer term?
Policy	What are the policies and strategies that provide direction in the short term? What plans or strategies are in place to build the resilience of the food system in the longer term? What steps do we need to take to increase the resilience of the city's food system to climate shocks and stresses? To pandemic stress?
Opportunities and barriers	What are some of the opportunities that could be leveraged to make progress on that? What are the barriers to making progress? How could those barriers be addressed?
Preparedness	What are the "other" shocks that you worry about, those that we may not have experienced yet? What are the policies and strategies we need in place to safeguard against future scenarios?

retail, consumption and waste resources. Four participants had responsibilities that covered the whole food system. The average interview length was 53 min. Table 2 presents the participant characteristics by sector and food system stage.

2.5. Analysis

Data were analyzed qualitatively by the researchers (MM, RC, LA) using thematic analysis (Braun and Clarke, 2022). Data were initially assigned into categories by food system node and by shock or stress by the lead author (MM) using open coding and focused coding approaches (Skeat, 2013; Bryman, 2016). Through an iterative process, recurring patterns and themes that emerged from the data were discussed and refined by all authors (MM, RC, LA) during and after the interview period, consistent with a thematic analysis approach (Liamputtong, 2019). The interview guide was revised and tailored during the interview period to interrogate emerging issues. Data were analyzed in NVivo 12 qualitative data analysis software (QSR International).

3. Results

3.1. Perceived impacts of shocks and stresses across the agri-food system

Participants reported their experiences of the impacts from the forest fires and the COVID-19 pandemic across the agri-food system.

3.1.1. Fire

The 2019-2020 forest fires affected the agri-food system in rural and regional areas of Victoria and other states, which influenced food flows into Melbourne. According to participants, immediate effects on agricultural production included loss of livestock and crops in the fires, and smoke-tainting of agricultural produce. Participants reported that smoke haze persisted for weeks after the fires "adding seven to 9 days to their growing season for [vegetable] products" (interview 26, industry), and that there were concerns about the longer-term impacts on agri-food production.

The fires disrupted agri-food distribution and retail in fire-affected areas because roads were blocked by fallen trees or damaged by heat.

> *In the case of the bushfires, the normal food supply trucks literally couldn't get into places like Mallacoota, so we had to work with them to establish alternative supply routes, we had to find alternative ways to supply the supermarkets and shops. - Interview 8, government*

Participants described how some communities were completely isolated for several weeks and how power and telecommunications outages affected retail in fire-affected areas. Participants reported that food relief organizations coordinated the provision of food "for people in all of the fire-affected areas, which included the airdrops of food into isolated communities" (interview 6, civil society). Participants experienced increased food loss and waste due to delays in harvesting fruit and vegetables, and power outages that led to the loss of food stocks in stores and in homes.

3.1.2. Pandemic

While climate shocks such as fires and flooding are generally localized to specific geographic areas, the COVID-19 pandemic had nationwide and global impacts. All stages of the agri-food system were directly affected by the pandemic or by responses put in place to reduce transmission of the virus. Agricultural production was heavily impacted by the closure of international borders, which reduced the workforce available to harvest produce.

> *Normally, we have 141,000 [working holidaymakers] in the country. We're now down to about 80,000...Growers are concerned that they can't get the product that they've already got planted off - so picked and packed and into the supply chain. - Interview 26, industry*

The COVID-19 pandemic affected food processing, manufacturing and distribution in several ways. Imports slowed

TABLE 2 Participant characteristics.

	Food system stage						
	Production	Processing and distribution	Retail	Consumption	Waste resources	All	
Government	10	2	0	3	2	3	20
Industry	2	5	4	0	0	0	11
Civil society	2	0	1	6	0	1	10
	14	7	5	9	2	4	41

during the early months of the pandemic, which led to shortages of some raw ingredients and food packaging used in food processing.

> *We don't grow tea or coffee here in Australia in any volume. We don't grow cocoa for chocolate, so they're key ingredients…then there are also specialist flavours, food additives, vitamins and minerals that go into food products. Then there's packaging - the material…a lot of that comes from overseas. - Interview 3, industry*

Food manufacturers and wholesalers sought to import goods from elsewhere. However, as one participant noted, "the problem with pandemics is that it affects everyone, so those options for alternative sourcing aren't necessarily there" (interview 8, government). Agri-food exports from Australia declined as international ports closed or operated under restricted conditions. The grounding of passenger aircraft had a significant impact on perishable exports, such as horticultural produce and seafood.

> *Ninety per cent of our freight [fruit and vegetables] goes out under passenger aircraft and there's no passenger aircraft going. It's simply not cost-effective to go by freighter, dedicated freighter plane. - Interview 16, industry*

Food processing and distribution were affected by pandemic lockdowns and social distancing measures that restricted the number of workers allowed in some workplaces. For example, restrictions on workforce capacity in meat processing plants led to meat supply problems in supermarkets in Victoria, which forced retailers to look to other states to fill supply gaps.

> *In Victoria, we went to 60 per cent capacity at our meat plants, so that really did drive some challenges from meat supply in Victoria. We were bringing meats in from WA, Queensland and other places - Interview 34, industry*

There were rising food prices and supermarkets ran out of some staple foods, including pasta, rice, fruits, vegetables, poultry and meat. The hospitality sector was heavily impacted as restaurants, cafés and pubs were forced to close, leading to significant food waste and loss, as described by these interviewees from businesses and farms supplying into hospitality.

> *We're talking millions of dollars of stock that they were sitting on, that overnight the government said you can't supply these outlets any longer. - Interview 23, industry*

> *It was a lot of farmers losing their markets with the closure of hospitality industries, some of them not knowing where they're going to divert their produce to, and particularly some of those bigger ones just who exclusively supply to hospitality being faced with ploughing crops back into the soil. - Interview 13, civil society*

While some of the stock normally destined for the hospitality sector was diverted into supermarkets or food relief, participants explained that capacity to do this was limited due to differences in product size and volume for hospitality vs. household use. Widespread job losses and loss of income, particularly in the food industry, led to a steep rise in food insecurity and demand for food relief, including from those who had never accessed food relief before.

> *Demand is coming from a number of areas, one is young people, another is asylum seekers and international students, and the third one is entirely new cohorts of people that have never…sought help in the past. - Interview 7, civil society*

Figure 1 depicts participant perspectives on the impacts of the fires and the pandemic across the agri-food system.

3.1.3. Multiple compounding shocks

The compounding effects of multiple shocks to the food system was a key concern raised by participants. Years of drought were followed by the 2019–2020 Australian forest fires. While communities were still dealing with the aftermath of the fires in early 2020, the COVID-19 pandemic began. As the pandemic lockdowns and restrictions continued into 2021, extreme flooding affected large parts of eastern Australia. Participants highlighted the effects of these concurrent and overlapping shocks on communities and their workforces.

> *In the midst of COVID, the town's now under water but it was bushfire-ravaged in December-January. So, these poor people have just been kicked in the guts…for some period of time. There's the human toll that it takes and…also the economic and the business toll. - Interview 23, industry*

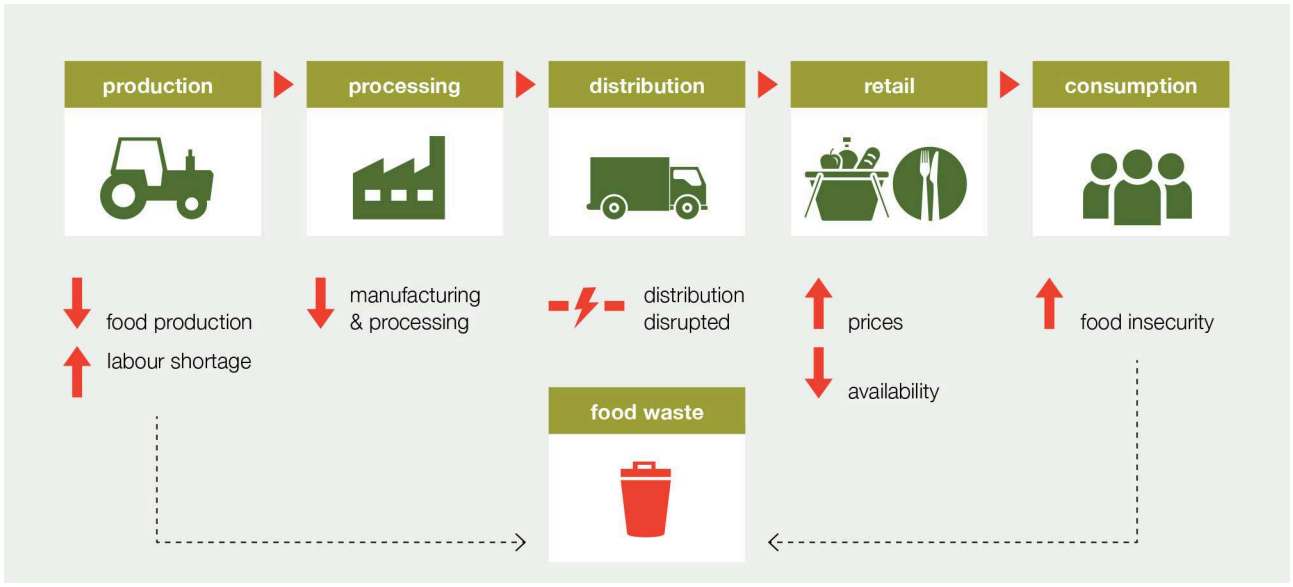

FIGURE 1
The reported impacts of forest fires and the COVID-19 pandemic across the agri-food system (from Murphy et al., 2022).

Participants noted that the compounding effects of successive shocks were greatest on those already experiencing disadvantage.

> *The people who are just scraping through beforehand are the ones who are going to be the most vulnerable when an acute shock hits. - Interview 6, civil society*

3.2. Vulnerabilities in the agri-food system

The forest fires and COVID-19 pandemic revealed critical vulnerabilities in Melbourne's city region food system.

3.2.1. Geographic and corporate concentration

The concentration of food processing and distribution centers clustered in particular geographic locations around Melbourne's city region is a vulnerability in the city's system of food distribution. One interviewee identified how a potential shock affecting a major bridge connecting one side of the city to the other is a key risk.

> *If [the West Gate bridge] ever stopped, it would be horrendous…all our fuel is in the west of Melbourne, all our [food] warehousing is in the west of Melbourne. How is it going to get to the east of Melbourne where half to two thirds of the population of Melbourne live? - Interview 17, industry*

Corporate concentration in supermarket distribution and retail was also identified as a vulnerability. During the pandemic, closure of supermarket distribution centers in Victoria for deep cleaning when staff tested positive for COVID-19 was perceived to be a pressure point.

> *It just takes a break-out at one of the distribution warehouses at [supermarket chain A] or [supermarket chain B] and then…they're going to run out of vegetables…it's concentrated in a very small amount of hands at distribution. I think there's a real risk around that longer term - Interview 20, government*

3.2.2. "Just in time" supply chains

Long and lean supply chains were perceived to be a key vulnerability during the pandemic. Surges in consumer demand for food during lockdowns led to a "five-fold uplift in demand of product" that could not be met because the major food retailers "run a very tight supply chain" (interview 3, industry). Participants reported that manufacturers increased production by working 24 h a day, seven days a week to meet increased consumer demand. However, capacity constraints in distribution networks slowed delivery to supermarkets.

> *When we get a rush in demand, the distribution centres don't have an ability to change gear…all of a sudden they need 200 trucks in [that] they haven't got the capacity to take. - Interview 17, industry*

Disruption to road and transportation networks in fire-affected areas also delayed deliveries of food to some supermarkets during the 2019–2020 forest fires. Participants described similar disruption to road and rail networks during other climate shocks, such as floods, which affected food deliveries.

3.2.3. Critical infrastructure

Agri-food systems are closely linked to and highly dependent on the continuing functioning of other systems, including energy, telecommunications, banking, transportation networks and logistics. Each of these systems was impacted in some way by the 2019–2020 forest fires or COVID-19 pandemic, compromising the food supply. During the fires, participants reported breakdowns in power, telecommunications, and banking that limited access to fuel, food and other groceries. Road and rail closures during fire and flood disrupts movement of food and livestock and impacts the quality and availability of fresh produce.

> *There's 257 kilometres of railway track impacted by floods in the last couple of weeks. That really restricts the ability to move product around the country. - Interview 34, industry*

One participant noted that even in ordinary times, "we have one of the most difficult tasks in Australia to supply goods over a long distance" (interview 31, industry) with high ambient temperatures, low population density, and long-haul freight distances to travel. Interstate border closures in Australia during the COVID-19 pandemic also delayed food freight at times.

3.2.4. Workforce

The workforce in agri-food production, processing, distribution, retail and food relief sectors were all affected by the pandemic, and to some extent by forest fires. Participants described labor shortages in agriculture when international borders closed during the COVID-19 pandemic. Workforce density limits were also introduced in meat processing plants and supermarket distribution centers, and there were complete shutdowns across the hospitality sector. The food relief sector lost its volunteer workforce "almost overnight" because "the bulk of our workforce—the volunteers—are over 65, and at higher risk in the COVID environment" (interview 12, civil society). Loss of income and employment led to rising food insecurity, including in the food industry workforce. One participant noted:

> *Covid-19 has helped put in people's mind the fragility of their own employment status and how anyone can find themselves in this predicament. - Interview 4, civil society*

One participant perceived workforce availability as the most significant vulnerability revealed during the COVID-19 pandemic, "we've got the resilience in the supply chain if we can overcome the labor elements" (interview 34, industry).

Climate and pandemic shocks exposed vulnerabilities in the agri-food system that led to temporary food shortages, rising prices for some foods, and growing food insecurity. However, overall, the food system continued to supply enough food to feed most Victorians and showed aspects of resilience. The following section identifies the features of the agri-food system that contributed to resilience.

3.3. Features of a resilient agri-food system

Participants discussed factors that contributed to a more resilient agri-food system with capacity to withstand and recover from shocks and stresses.

3.3.1. Diversity

Diversity was identified by interviewees as a feature that helps agri-food systems to withstand a sudden shock. Diversity in where food is produced can build resilience as food can be sourced from other growing regions when one region experiences a shock, such as an extreme weather event. Diversity in where food is sourced from also provides contingency if disruptions in transportation networks or other infrastructure impede food deliveries to or from particular geographic areas. Diversity in types of transportation builds redundancy into food systems, as described by this participant.

> *From a transport side of things, we have a diversified network to support major disruptions, which can switch between rail, road, coastal shipping and air freight to ensure adequate supply is available. - Interview 21, industry*

Diversifying the type of crops grown can safeguard against climate change by spreading risk. For one participant, diversity in production meant reducing reliance on imported foods and ingredients and "growing as much [as possible] of what we want to eat in Australia within Australia" (interview 28, industry). Another participant acknowledged there was diversity in production but had concerns about the lack of diversity in food processing and manufacturing.

> *There's two major meat processors in the country - there's heaps of growers so there's diversity of production, but the key bottlenecks are [meat processors]. Same with dairy, we've only got six dairy processors. - Interview 16, industry*

Diversity in the scale, length and types of supply chains also strengthened resilience. During the first Omicron wave of the COVID-19 pandemic in early 2022, supermarkets ran short of many fresh foods due to the number of workers isolating through food supply chains, while small independent grocers and food markets often had good supplies as they sourced foods through shorter, more localized supply chains. One participant explained:

> *A small-scale autonomous business able to duck and weave, to protect itself, to represent itself, to tell its story, to change course if necessary and have strong relationships, both with customers and its peers and its cohort. I think it makes for a very robust group of people and businesses. - Interview 5, industry*

Another participant noted that, "we want to make sure that we've got a range of supply chains, not just relying on the bigger, traditional chains…I guess, armouring ourselves

with as many sources of food as we can" (interview 12, civil society).

3.3.2. Decentralization

Some interviewees perceived that decentralized agri-food systems increase their resilience by spreading food processing, distribution and retail across a greater number of organizations and locations. This responds to vulnerabilities associated with concentrating food system infrastructure in a small number of geographic areas and food industry workers and power in a small number of organizations.

> *Whether it's a workforce shutdown, a pandemic, a bushfire, or whatever else, you've got multiple [nodes] that are carrying 10 per cent of volume each rather than two big nodes which are 50/50. - Interview 16, industry*

Decentralizing food systems creates redundancy and supports diversity. It can also strengthen local and regional food supply chains that more directly connect producers and consumers by investing in small-scale food processing facilities in regional areas.

3.3.3. Adaption and innovation

Adaption and innovation are positive responses among food system actors that strengthen resilience and promote recovery after a shock. Major retailers adapted to the forest fires by rerouting food freight away from major highways in fire-affected areas to alternate transport routes. They established "pop-up" distribution centers to respond to increased consumer demand for food during the COVID-19 pandemic and by-passed distribution centers altogether at times.

> *The supply chain had to adapt…the classic distribution is manufacturer, distribution centre…and out to supermarkets. They were circumventing that by sending trucks straight from the manufacturer directly to supermarkets, to keep the supply up. - Interview 3, industry*

There was also innovation and adaptation in short food supply chains that connect producers directly to consumers. Many small-scale growers who sold through farmers markets and farmgate shops moved quickly to online sales during the COVID-19 pandemic.

> *A lot of organisations are incredibly resilient, they're incredibly adaptable and flexible. We've certainly seen that during this COVID-19 period where organisations have really pivoted…they've just switched the service delivery from face to face to on the phone to online. - Interview 7, civil society*

3.3.4. Networking and collaboration

Networking and collaboration between stakeholders throughout agri-food systems was perceived to be a key feature of resilience. Partnerships foster a collaborative way of working and "collaborative policy responses across organizations" (interview 1, government). Networks based on strong relationships and trust can support a rapid response when activated in times of crisis.

> *The point of these networks is that when you get a call in the middle of the night, it's from somebody that you know and trust…so when you come together, there's not that necessary storming piece. You've already formed. - Interview 8, government*

Participants from government, industry and civil society all emphasized the importance of networks and collaboration. Strong community networks build resilience by fostering local solutions.

> *I think we're going to need to move to a place of local networks and network solutions and resilience systems, rather than try to go macro. - Interview 6, civil society*

3.3.5. Sustainable livelihoods

The COVID-19 pandemic magnified existing vulnerabilities in workforce availability in the agricultural and food industries. Several participants emphasized the need for a reliable "dedicated workforce to work in horticulture" year-round in Victoria (interview 26, industry). Another participant highlighted challenges to the viability of farming, arguing that if farmers were "properly remunerated for their product" (interview 12, civil society), it would increase the resilience of the agri-food system.

> *I think a resilient food system is where people know who grows their food, they have a relationship with them, the farmers are paid fairly, therefore they have a better chance of running a viable business and can continue to adapt and evolve and innovate. - Interview 13, civil society*

Sustainable livelihoods in food enterprises and farming underpin a resilient food system. However, the experience of the COVID-19 pandemic points to the need for greater action to support fair farmgate prices and fair and safe working conditions.

3.4. Preparedness

Participants in our research emphasized the importance of learning from shocks such as forest fires and the COVID-19 pandemic to strengthen the resilience of agri-food systems to future shocks. Interviewees noted that food systems are now experiencing multiple and concurrent shocks and stresses, and that there is a need for more strategic, long-term planning to build the resilience of food systems.

> *I think they [the government] need to think strategically and do long-term planning and not just look at the next two to three years but look at 5 to 10 years. Because if you take the [forest fires] and floods, we see it on a regular basis…the pandemic can happen again. I think we need to start thinking longer term. - Interview 21, Industry*

Participants spoke about need to use the experience of the COVID-19 pandemic and recent climate shocks as a moment for "transformational thinking".

> *The tip of the iceberg is just getting by from cycle to cycle, from disaster to disaster and keeping your head above water. The next level down is systemic change, changing how you do things to better respond to be better prepared. Then there's a whole iceberg of transformational adaptation where you're fundamentally re-imagining your objectives in the first place… those sorts of really big questions, sometimes space is created for them off the back of a disaster. - Interview 19, government*

In addition to taking action to prepare agri-food systems for future climate and pandemic shocks, our interviewees were conscious of the need to prepare for other potential shocks such as "geopolitical events [that] can just shut supply chains" (interview 3, industry), and cyber-attack "with the potential for massive disruption [and] damage to food supply chains" (interview 8, government).

Participants emphasized that preparedness planning should focus on actions that will build the resilience of agri-food systems to any future shock, to "future-proof ourselves by keeping those (community resilience) principles hazard blind" (interview 6, civil society). Another participant noted:

> *These sorts of overlapping shocks and stresses… what is their common denominator? What is the thing that is going to strengthen us to better prepare for any of those things happening, and then, which is more of a hazard agnostic approach? - Interview 1, government*

Participants highlighted the importance of also taking action to address the impacts of underlying environmental stresses on agri-food systems, such as biodiversity loss, decline in pollinators and pressure on the availability of water and agricultural land.

> *Deteriorating environmental conditions remains the slow-burn shock that most policy makers are really thinking about. - Interview 2, government*

Some of our interviewees recognized that there are interactions between climate and pandemic shocks and the long-term environmental stresses facing Melbourne's food system that were of significant concern.

> *This whole question of the integration between climate and ecology is going to be a big [issue]. The fact that we're losing our ecosystems at a really rapid rate is going to be one of the biggest issues as we go forward. - Interview 29, government*

4. Discussion

This study investigated stakeholder perspectives on the impacts of climate and pandemic shocks on the agri-food system in Melbourne, Australia. Our findings showed that there were short-term, localized impacts from the forest fires throughout the food system, which was able to recover within a timeframe of weeks to months. By contrast, the pandemic placed significant stress across the whole agri-food system that was not bound by geographic area, and that continued over time. A key goal of a resilient food system is to provide food security for all (Tendall et al., 2015). Food insecurity increased during the COVID-19 pandemic due to lockdowns, loss of income and rising food prices (Louie et al., 2022). A Foodbank Australia survey in 2022 found that 21 % of Australian households had experienced severe food insecurity in the previous 12 months, and that almost one third of households with children had experienced severe food insecurity (Foodbank Australia, 2022). Our findings show how the compounding effects of multiple, overlapping shocks and stresses on the agri-food system contributed to food insecurity.

We identified vulnerabilities across the agri-food system to these shocks. Geographic and corporate concentration in meat processing, supermarket distribution and retail reduced capacity within the system to absorb the shocks and offered little redundancy within supply chains to switch to other options. MacMahon et al. (2015) and Love et al. (2021) also identify concentration in agri-food systems as a vulnerability with potential to increase food insecurity. Similar to other studies, long and lean supply chains were identified as a vulnerability (MacMahon et al., 2015; Zeuli et al., 2018; O'Meara et al., 2022), as well as international supply chains and logistics networks (Ali et al., 2022; Jones et al., 2022). Consumer demand surges on Melbourne's "just in time" food supply chains during the pandemic led to food shortages and heightened food insecurity (Carey et al., 2020; Louie et al., 2022). The failure of other systems that food supply chains rely on—such as transportation, energy, telecommunications, and banking—heightened the risks of "just in time" food supply chains and compromised the functioning of the agri-food system. The vulnerability inherent in interdependencies between agri-food systems and other critical infrastructure is widely acknowledged (Zeuli et al., 2018; Newell and Dale, 2020), and has led to the development of critical infrastructure resilience networks and plans (Victorian Government, 2022). Labor availability and workforce issues in the agri-food system were a vulnerability during the COVID-19 pandemic, as highlighted by similar studies in Australia (Snow et al., 2021; Jones et al., 2022), and internationally (Luckstead et al., 2020; Hobbs, 2021; Waltenburg et al., 2021).

Features of the agri-food system that supported resilience included diversity and decentralization. Diversity of commodities, actors and sources of food is central to the resilience of food systems in the context of multiple shocks and stresses (FAO, 2021). In the present study, there was diversity in production and sources of food, in transportation and food distribution networks, and in the scale, length and type of food supply chains. When the long supply chains of the major supermarkets ran short of fresh foods, the shorter supply chains of independent grocers, farmers markets and fresh produce markets were able to continue supplying these foods. Other studies have similarly found that long and complex supply chains were particularly impacted during the COVID-19 pandemic (Rivera-Ferre et al., 2021; Stoll et al., 2021). A number of studies have highlighted the importance of local decentralized food supply chains to resilient agri-food systems, as they are nimble and flexible and can adapt and innovate quickly (Thilmany et al., 2020; Blay-Palmer et al., 2021; Marusak et al., 2021; Cattivelli, 2022). A

combination of long and short supply chains can strengthen the resilience of agri-food systems to shocks and stresses and their capacity to promote food security (James and Friel, 2015; Smith et al., 2016; FAO, 2021).

Innovative responses from food system actors can build resilience to shocks and contribute to food security (FAO, 2021). Innovative adaptions were evident in both long and short supply chains in the present study. They included the "pop-up" distribution centers established by the major retailers during consumer demand surges, and the new online distribution channels established to support small-scale farmers who supply direct to consumers and businesses. These innovative responses were facilitated by networks and collaboration among food system actors, a finding supported by other studies (Snow et al., 2021; Jones et al., 2022). Multi-sectoral collaborative approaches are important to build the resilience of agri-food systems, together with integrated policy approaches that consider how interdependencies with other systems impact the resilience of agri-food systems (FAO, 2021).

Sustainable livelihoods in agri-food enterprises were also revealed as a central feature of resilient food supply chains through our study. Work in the agri-food industries in Australia is frequently casualised and insecure, with low pay and poor working conditions (Jones et al., 2022; Murphy et al., 2022). Our findings highlight the importance of policy action to address workforce issues for food system resilience (Carey et al., 2022). Other studies have also recommended policy action to ensure labor availability and sufficient farm income, and for social protection to protect livelihoods (Savary et al., 2020; Fan et al., 2021b).

Our study highlights how resilient agri-food systems need to be prepared to cope with the compounding impacts of multiple shocks and stresses that co-occur or overlap. Agri-food systems are currently ill-prepared for the increasing frequency and severity of shocks (Fanzo et al., 2021). In Australia, the compounding shocks of forest fires and the COVID-19 pandemic—and more recently, extensive flooding and Russia's invasion of Ukraine—have challenged the capacity of the agri-food system to deliver food security for all and protect livelihoods (Murphy et al., 2022). The main focus in resilience building in agri-food systems has been on reactive strategies that build capacity to cope with shocks over the short term, There now needs to be a greater focus on longer-term adaptive and transformative strategies (Love et al., 2021).

As shocks to food systems increase in frequency and severity, there are growing calls for food system transformation to increase resilience, promote global food security and build equitable and sustainable food systems (HLPE., 2020; FAO, 2021). Food system transformation moves beyond adaptive responses that adjust or incrementally change activities within specific stages of the food system such as agricultural production. Instead, it changes the outcomes of the overall system, including food security, environmental outcomes and socio-economic outcomes (Ingram and Thornton, 2022). Many researchers have noted the potential for transformative change in global food systems following the COVID-19 pandemic (Blay-Palmer et al., 2020; Rippon et al., 2020; Savary et al., 2020). Transformative change that strengthens the resilience of agri-food systems is needed to progress the United Nations Sustainable Development Goal to End Hunger (FAO, 2021).

Our study has shown that resilient agri-food systems need to be prepared for any shock, both known risks, such as forest fires during summer in south-east Australia, and those that are unforeseen. Our study has also shown that resilience building in agri-food systems requires a greater focus on building resilience to both sudden shocks and underlying environmental stresses, and to the cascading impacts that result from interactions between both (Zurek et al., 2022). This study makes an important contribution to research about the perceived impacts of multiple shocks and stresses on agri-food systems. To our knowledge, this is one of the first empirical studies that has investigated the views of multi-sectoral food system stakeholders on the impacts of multiple shocks and stresses on the agri-food system in an Australian context.

Our study had a number of strengths. First, it adopts a multi-sectoral approach with participants from government, industry and civil society, who shared perspectives on the effects of recent shocks on the effects of recent shocks throughout the agri-food system, from production to consumption and waste. Second, the timing of the study—which commenced as forest fires and the COVID-19 pandemic were disrupting the agri-food system—provided insights into the impacts of multiple, overlapping shocks and stresses on the agri-food system as events were unfolding. However, this is also potentially a limitation of the study. If participants had longer to reflect on the events, their perspectives may have been different. The study was also situated in a city region of a high-income country. Hence, the generalizability of findings to other contexts, particularly low- and middle-income countries, may be limited.

5. Conclusion

This study investigated the resilience of agri-food systems to shocks and stresses using a case study from Melbourne, Australia. Compounding shocks to agri-food systems from climate events, pandemics, geopolitical conflict, and the ongoing decline of natural ecosystems highlight the need for a better understanding of ways to build food system resilience. Food resilience planning and policy initiatives are needed at all levels of government to promote diversity within agri-food systems, decentralization, adaption and innovation, networking and collaboration, and sustainable livelihoods.

Our study found that the resilience of agri-food systems needs to be strengthened to a range of future shocks and stresses, and to the cascading effects of interactions between them. Further research is needed to investigate interactions between the effects of climate and pandemic shocks on agri-food systems and the effects of ongoing environmental stresses, including biodiversity loss and declining natural resources. Policy to promote the resilience of agri-food systems will also increasingly need to focus on transformative actions that build long-term resilience to any future shock.

Data availability statement

The datasets presented in this article are not readily available because of participant privacy. The data consists of transcripts of semi-structured interviews. Through the participant consent process, we agreed to protect the

anonymity of participants. Participants may be identifiable from the transcripts, and so the data cannot be made publicly available. Requests to access the datasets should be directed to MM, maureen.murphy@unimelb.edu.au.

Ethics statement

The studies involving human participants were reviewed and approved by the University of Melbourne Human Research Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

Author contributions

RC conceived of the study and wrote sections of the manuscript. MM, RC, and LA performed qualitative interviews and analyzed qualitative data. MM wrote the first draft of the manuscript. All authors reviewed and edited drafts of the manuscript, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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A resilience analysis of the contraction of the accommodation and food service sector on the Scottish food industry

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The Scottish economy, such as the United Kingdom (UK) economy, has been exposed to several adverse shocks over the past 5 years. Examples of these are the effect of the United Kingdom exiting the European Union (Brexit), the effects of the COVID-19 pandemic, and more recently Russia–Ukraine war, which can result in adverse direct and indirect economic losses across various sectors of the economy. These shocks disrupted the food and drink supply chains. The purpose of this article is 3-fold: (1) to explore the degree of resilience of the Scottish food and drink sector, (2) to estimate the effects on interconnected sectors of the economy, and (3) to estimate the economic losses, which is the financial value associated with the reduction in output. This article focuses on the impact that the sudden contraction that the "accommodation and food service activities", resulting from the pandemic, had on the food and drink sectors. For this analysis, the study relied on the dynamic inoperability input–output model (DIIM), which takes into account the relationships across the different sectors of the Scottish economy over time. The results indicate that the accommodation and food service sector was the most affected by the COVID-19 pandemic lockdown contracting by approximately 60%. The DIIM shows that the disruption to this sector had a cascading effect on the remaining 17 sectors of the economy. The processed and preserved fish, fruits, and vegetable sector is the least resilient, while preserved meat and meat product sector is the most resilient to the final demand disruption in the accommodation and food service sector. The least economically affected sector was the other food product sector, while the other service sector had the highest economic loss. Although the soft drink sector had a slow recovery rate, economic losses were lower compared to the agricultural, fishery, and forestry sectors. From the policy perspective, stakeholders in the accommodation and food service sector should re-examine the sector and develop capacity against future pandemics. In addition, it is important for economic sectors to collaborate either vertically or horizontally by sharing information and risk to reduce the burden of future disruptions. Finally, the most vulnerable sectors of the economy, i.e., other service sectors should form a major part of government policy decision-making when planning against future pandemics.

KEYWORDS

COVID-19, Scotland food and drink industry, dynamic interoperative input–output model, dynamic recovery, input–output analysis

1. Introduction

The food and drink industry is a major contributor to Scotland's economy, with a turnover of approximately £14,748.2 million (representing 9% of total GDP) in 2020 and accounting for one in five manufacturing jobs. Scotland has approximately 17,450 food and drink businesses, which employed approximately 129,000 (4.9% of total employment in Scotland) people in 2021.

The Scottish economy suffered greatly in 2020 due to the global COVID-19 pandemic. This was reflected in high absenteeism from work due to fear of infections, lockdowns preventing people from assessing their place of work, or sickness due to infections. Estimates of the monthly gross domestic product (GDP) indicated that it fell by approximately 22% using 2016 as the baseline. In addition, there was also a contraction of several final demand components. For instance, a recent estimate shows that exports between April and June 2020 were 31.1% lower than that recorded in the same period in 2019 (Scottish Government, 2022a).

The economic impact of disruptions such as COVID-19[1] on the economy manifested on two fronts: the labor market and the final demand (i.e., consumption of households, exports, and government expenditure). A labor shortage in a productive sector can render it inoperable and since different sectors are mutually dependent, they become indirectly affected because of their linkages. Similarly, the contraction of the final demand of a sector or several of them generates a contraction in the output of sectors not only directly affected but also the interrelated sectors.

The impact of the pandemic has been disproportionate, with some sectors being heavily affected while others were mildly or not affected. For instance, the food retail sector performed well throughout 2020 but the accommodation and food services showed the worse performance with the greatest drop in 2020 (Scottish Government, 2022b).

The accommodation and food service sector or hospitality sector provides approximately 5 billion pounds in gross value added to the Scottish economy. In addition, it is the largest employing sector of the economy employing approximately 200,000 jobs before the COVID-19 pandemic. The COVID-19 pandemic had a significant impact on both employment/jobs and total output from the sector; a loss of 85% of output between February and May 2020, and a 23% loss in the number of jobs between March and December 2020. It is expected that this will have implications for associated sectors such as the food and drink sector, tourism sector, and event businesses.

Haimes and Santos (2014) used a dynamic inoperability input–output model (DIIM) to analyze the impacts of an influenza pandemic on the workforce and associated economic sectors. The present study follows their approach to examine the impact of the contraction of the final demand of the "accommodation and food service activities" sector due to COVID-19 on interrelated sectors of the Scottish economy. The choice of the sector was due to its close relationship with the agricultural and food processing sectors. Two metrics were used to assess the impact of the COVID-19 pandemic on the economic sectors: inoperability, which measures the percentage difference between as-planned and actual output, and economic loss, which is the monetary value of the output loss. In addition, this article estimates the coefficient of resilience and recovery pathways, which indicate how fast the interrelated sector recovers from the disruption.

The structure of the research article is as follows. It starts with a brief literature review. Next, it summarizes the empirical approach used in the research, namely the methodology and the data used for the estimation. It is followed by a presentation and discussion of the results. The final section presents the research conclusion.

2. Literature review

The purpose of this section is 2-fold: first to provide an overview of the Scottish economy during the COVID-19 pandemic period, and second to briefly review the literature about the aggregated measurement of resilience.

2.1. The Scottish economy during the COVID-19 pandemic period

The Scottish economy has been exposed to several adverse shocks over the past 5 years. Examples of these are the effect of the United Kingdom exiting the European Union (Brexit), the effects of the COVID-19 pandemic, and more recently Russia–Ukraine war. For this study, we concentrate on the impact of COVID-19. The impacts are 2-fold: (1) employment and (2) gross value added.

The imposition of lockdown during the crucial periods of the pandemic affected labor flows both within Scotland and from elsewhere in Scotland. The accommodation and food service sector is considered the industry with the proportion of non-UK nationals in the workforce (∼19%). The COVID-19 lockdown restricted the inflows of migrant labor especially those from Eastern Europe (Scottish Government, 2022b). Statistics show that 42% of businesses in the accommodation and food service sector reported that they were experiencing a shortage of workers in the period between 15 and 28 November 2021, compared with 38% for the economy overall (Scottish Government, 2022c).

Figure 1, which presents the evolution of the monthly onshore gross domestic product (GDP) for Scotland from 2018 to 2022, shows that COVID-19 was a massive shock to the economy. In April 2020, the monthly GDP decreased by ∼21% with respect to the average of January to March 2020 levels.

The pattern shown in the aggregated GDP can also be viewed in the panels as presented in Figure 2, which shows the evolution of 18 production sectors, all of them, in different measures though, showing the impact of the COVID-19 shock. From all the sectors, the most important impact of COVID-19 was on the

1 The impact of Brexit was isolated from our analysis because *according to Trades Union Congress (2020), in most cases, it is likely that that the regions and sectors most affected by the economic impact of COVID-19 are not the same as the regions and sectors likely to be the most exposed to Brexit (though there are some exceptions). They argued that the manufacture of automotive, transport equipment, chemicals and chemical products and textiles, and services such as finance and communications are the most exposed sectors to Brexit. Hospitality, tourism, transport, and arts and entertainment are the most exposed sectors in relation to economic impact of COVID-19.*

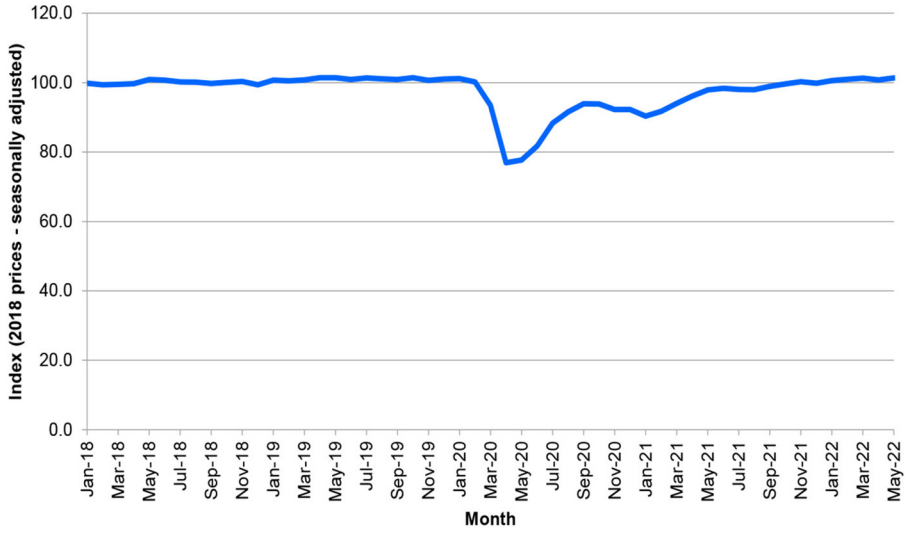

FIGURE 1
Scotland—monthly evolution of the gross domestic product. Source: Scottish Government.

accommodation and food service sectors. In April 2020, this sector contracted by approximately 78% with respect to the average of January and February 2020.

Under the coronavirus job retention scheme, commonly known as the "furlough scheme", companies were allowed to place staff on leave during a determined period set by the Government while ensuring that those affected still have a source of income. As part of the scheme, employers had to notify staff members in writing before their period of furlough begins. Once on leave, the company had to pay affected employees no <80% of their regular monthly income, up to a cap of £2,500. These funds could later be claimed back through the job retention scheme. While furloughed, individuals remained formally employed by the company, meaning that they were entitled to their usual protection from unfair dismissal, and redundancy pay should the company cease trading.

2.2. Accommodation and food service sector

The accommodation and food service sector is made up of establishments providing customers with lodging and/or preparing meals, snacks, and beverages for immediate consumption. Between the fourth quarter (Q4) of 2019 and the second quarter (Q2) of 2020, the gross value added (GVA) by the accommodation and food service sector reduced by 80.1% compared to the 22% drop for the whole of Scotland's economy over the same period (Watts, 2022). This sector alone generated approximately 5 billion pounds (representing 3.4% of the Scottish onshore economy) in GVA in Scotland in 2019. Despite the small contribution to the overall GVA, it is the largest employing sector with approximately 200,000 jobs before the COVID-19 pandemic.

Figure 3 shows the evolution of the GVA for the accommodation and food service sector. The contribution of the sector has been growing from January 2010 to February 2020 when it experienced a shape decline. The lowest-ever GVA for the sector was recorded in April and May 2020. Workforce data from the Office of National Statistics (ONS) shows that the number of jobs in this sector fell by approximately 50,000 (approximately 23%) between March 2020 and December 2020.

Figure 4 shows the impact of COVID-19 on the accommodation and food service sector's workforce. The total number of workforce jobs fell from 216,000 in March 2020 to 169,000 in December 2020.

According to the Labor Force Survey in 2019, the average hourly is the lowest in Scotland when compared to the remaining industry sectors. As a result, the poverty rate among workers in this sector is estimated to be higher than the Scottish average.

It is expected that workers in this sector would therefore be greatly affected by COVID-19 disruption. Moreover, the interdependency between this sector and other industrial sectors of the economy would escalate the impact. As such, the goal of the current study is to show how interdependent sectors are affected by disruptions to one sector of the economy.

2.3. Measuring sector resilience and interdependence

This section focuses on aggregated models that measure the resilience of sectors. Specifically, it refers to models that use the input–output tables to track the effects of a shock (on supply or demand). According to Zhang et al. (2022), the use of input–output models has many advantages including the ability to identify system vulnerabilities and provide scientific insight for the development of industry management strategies.

As pointed out by Leontief (1987), the "input–output analysis is a practical extension of the classical theory of general interdependence which views the whole economy of a region, a country, or even the entire world as a single system and sets out to describe and to interpret its operation in terms of directly observable basic structural relations". The model presents

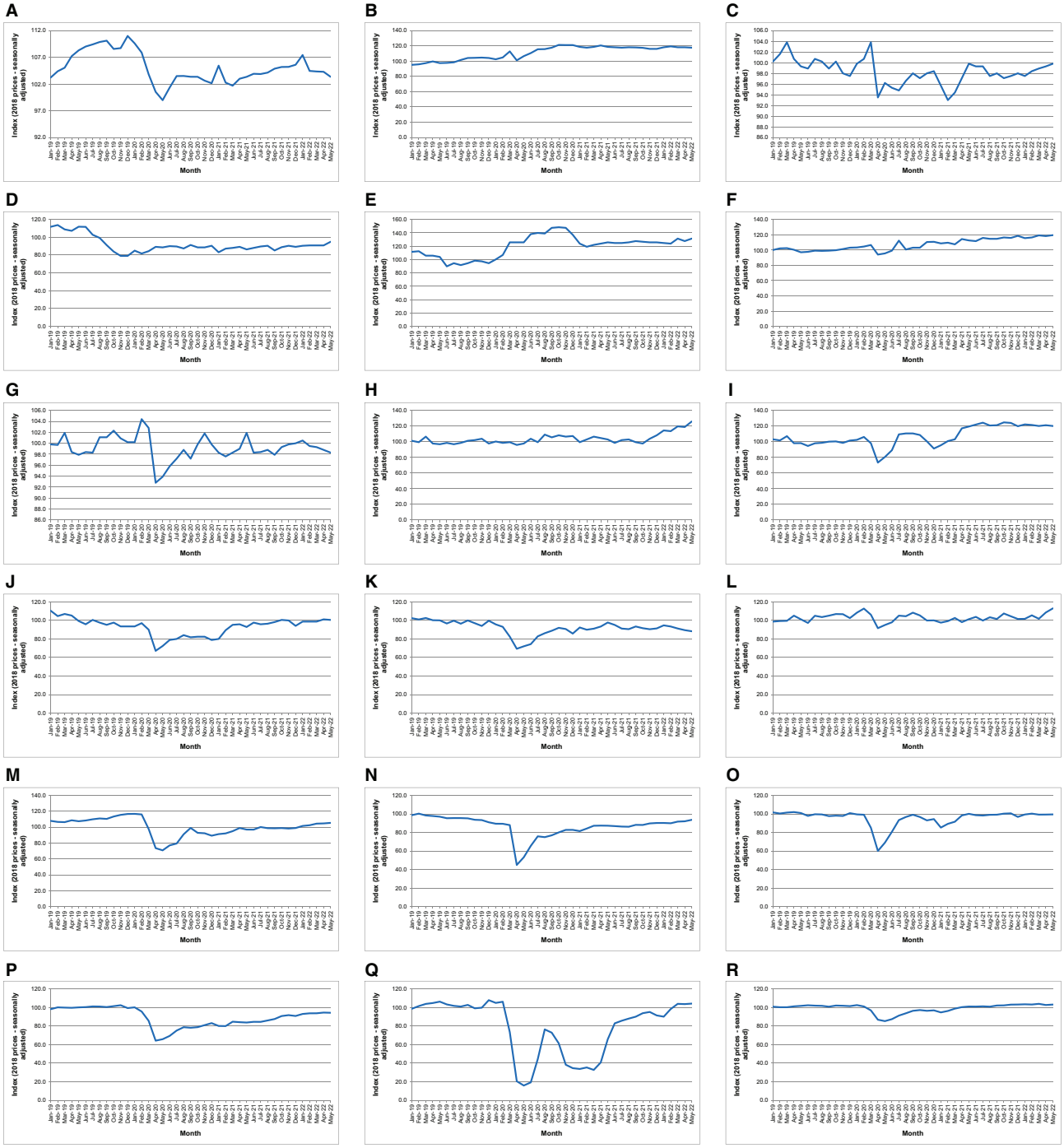

FIGURE 2
Evolution of the gross domestic product by production sector. **(A)** Gross domestic product - Agriculture, fisheries and forestry. **(B)** Gross domestic product - Preserved meat and meat products. **(C)** Gross domestic product - Processed and preserved fish, fruit and vegetables. **(D)** Gross domestic product - Manufacture of dairy, vegetable and animal oils and fats. **(E)** Gross domestic product - Grain mill products, starches and starch products. **(F)** Gross domestic product - Bakery and farinaceous products. **(G)** Gross domestic product - Other food products. **(H)** Gross domestic product - Prepared animal feeds. **(I)** Gross domestic product - Alcoholic beverages and tobacco products. **(J)** Gross domestic product - Soft drinks. **(K)** Gross domestic product - Other manufacturing. **(L)** Gross domestic product - Energy supply, water and waste. **(M)** Gross domestic product - Mining and quarrying. **(N)** Gross domestic product - Construction. **(O)** Gross domestic product - Wholesale and retail trade and repairs. **(P)** Gross domestic product - Transport and storage. **(Q)** Gross domestic product - Accommodation and food service activities. **(R)** Gross domestic product - Other services.

a framework capable of describing the extent of interconnectedness among different sectors of the economy (Haimes et al., 2005). This feature is key to understanding the network type of relationships that are observed among supply chains.

Haimes and Jiang (2001) extended the Leontief model by focusing on the spread of operability into a networked system—input–output inoperability model (IIM). While the Leontief model was used to explain the level of interdependencies

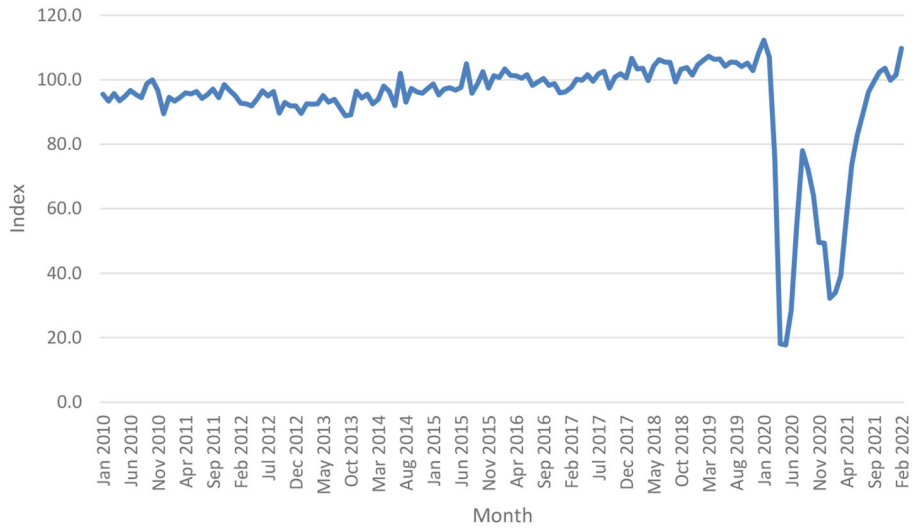

FIGURE 3
Evolution of the Gross Value Added for Accommodation and food service sector in Scotland. Source: Office for National Statistics (2020).

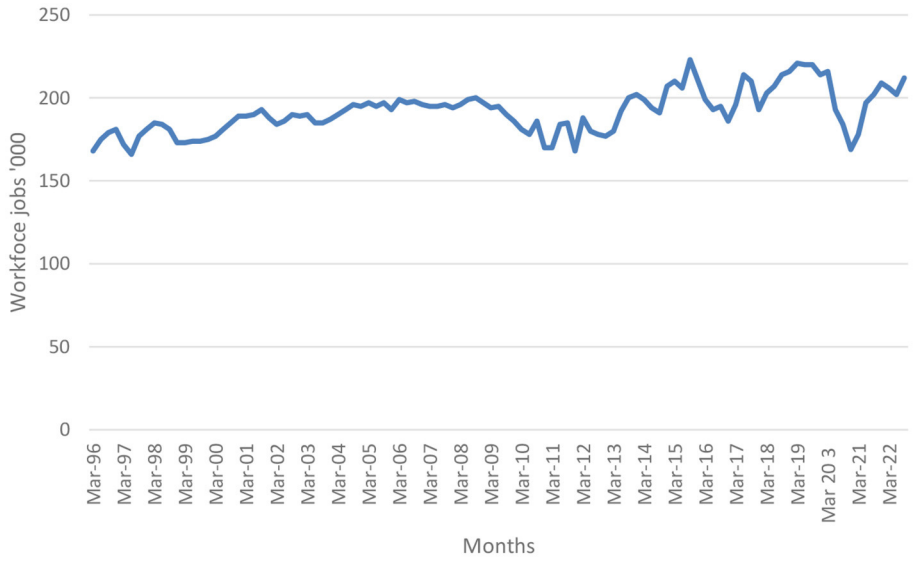

FIGURE 4
Evolution of workforce jobs in the Accommodation and food service sector. Source: Office for National Statistics (2020).

among sectors in the economy, the inoperability model can assess how catastrophic disasters in one sector affect other sectors of the economy (Lian and Haimes, 2006). In addition, the model offers insights into the sensitivity of economic systems to various classes of disruptions guiding policymaking activities (Santos, 2006). Finally, results from the inoperability input–output model allows for the ranking of the disrupted and interconnected sectors according to their degree of vulnerability to perturbations, which can serve as an important input to risk management (Lian and Haimes, 2006).

Setola and De Porcellinis (2007) cited examples of how a disruption in one sector of the economy cascade to other sectors. First, in 1998 in the United States, the failure of the telecommunication satellite Galaxy IV caused more than 40 million pagers to be out of service. In addition, 20 United Airlines flights were without the required data about high-altitude weather conditions, resulting in take-off delays. Second, in 2004 in Italy, a failure of the Telecom Italia node in Rome disrupted the operations of both fixed and mobile TLC systems, approximately 5,000 bank branches and 3,000 post offices, and air transport check-in operations were disrupted.

Setola and De Porcellinis (2007) defined inoperability as the inability of a given system to perform its intended functions. Mathematically, it is estimated as the percentage loss of a system's function relative to its ideal output. It has a value between 0 and 1, where 0 corresponds to a flawless operation

while 1 is a complete failure (Santos and Haimes, 2004; Santos, 2006).

The IIM is capable of "(1) estimating the impact of initial disruptions to a sector (or group of sectors) to other 'external' sectors; (2) assessing the cascading impacts of disruptive events for various regions; and (3) presenting various perspectives of impact, including inoperability and economic loss, which can provide insights for risk management" (Santos, 2006).

The IIM has been used in economic literature to study the impact of disruptions such as terrorism, power outages, and pandemics. For instance, Santos and Haimes (2004) used the IIM to study the impact of a 10% reduction in demand for air transport as a result of terrorism on interconnected economic systems. Similarly, Lian and Haimes (2006) assessed the risk of terrorism to interdependent infrastructure systems in the United States using the dynamic input–output inoperability model. Jung et al. (2009) used international trade (IT)-IIM to investigate the international trade inoperability for all industry sectors resulting from disruptions to a major port of entry.

In the IT sector, Hyatt and Santos (2022) used the inoperability input–output model to determine the inoperability and economic impact of IT on interdependent industries in the United States. The authors found that the IT sector is susceptible to various forms of malicious attacks.

For the energy sector, Guo and Hou (2019) used the IIM to analyze the vulnerability and recoverability of the energy sector in China in the presence of demand and supply perturbation.

It is important to note that the interdependence among various sectors of the economy may take the form of flows of information, shared security, and physical flows of commodities (Haimes et al., 2005). The growing dependence of one sector of the economy on other sectors makes the whole economy vulnerable to unexpected side effects, making it complex and prone to disruptions (Setola and De Porcellinis, 2007). The socio-economic effects of disruptions can be considerably larger when the cascading effects and interdependencies among sectors are taken into account (Kjølle et al., 2012).

Despite the potential benefits of using the IIM, it does not allow researchers to perform intertemporal analysis because IIM is a static model. The dynamic inoperability input–output model (DIIM) was, therefore, proposed to account for the limitations of the IIM.

According to Lian and Haimes (2006), the DIIM addresses the following pertinent questions that are overlooked in the static model as follows: (1) How does the disrupted sector(s) recover over time?; (2) What are the associated economic losses during the recovery period?; and (3) What can be carried out to minimize the losses during the recovery period after the disruption?

The DIIM uses the industry interdependence index to measure the degree to which sectors are dependent on each other in an interconnected economy. This is a function of hardening, prevention, and redundancy—resilience factors. In addition, the DIIM uses an estimated industry resilience coefficient to determine the speed with which industries recover after a disruption. The model also allows researchers to represent the dynamic behavior of disrupted and interdependent sectors in the recovery duration.

For the energy sector, Guo and Hou (2019) used the DIIM (in addition to the IIM) to analyze the recovery dynamics of the energy sector in China due to demand and supply perturbations. Zhang et al. (2022) also used the DIIM to assess industrial water network vulnerability in China.

Santos et al. (2009) assessed the economic losses due to the 2009 H1N1 pandemic for the Commonwealth of Virginia. Results show that even a moderate 15% attack rate scenario could lead to a $5.5 billion loss. Yaseen et al. (2020) assessed sector inoperability and the economic impact of workforce absenteeism due to flooding. They concluded that the impact of flooding through workforce absenteeism can render the whole economy inoperable.

In what follows, this study uses the DIIM to study how disruption due to the demand faced by the accommodation and food service due to the COVID-19 pandemic could affect the economic performance of the food and drink sector and other interdependent sectors.

3. Empirical approach

This section starts by presenting a brief version of the dynamic inoperability input–output model (DIIM), which will be used for the empirical work, and it is followed by introducing the data used.

3.1. Method

The starting point of the DIIM is the dynamic version of the Leontief input–output, which is written as in equation (1):

$$x(t) = Ax(t) + c(t) + B\dot{x}(t), \tag{1}$$

where $x(t)$ is the output vector, A is the matrix of technical coefficients, $c(t)$ is the final demand vector (i.e., households, government, exports, and investment), and $\dot{x}(t)$ is the change in the vector of output. The dimension of the vectors is (nx1), where n is the number of sectors in the economy and A is an *nxn* matrix. Matrix B can be described as the willingness of the economy to invest in capital resources. Haimes et al. (2005), citing Ramos Carvajal and Blanc Díaz (2002), argued that the economic system would only be stable when the elements of the B matrix are either zero or negative. $B = -I$, where I is the identity matrix and, in that case, the economy quickly adjusts its production levels following information about mismatches in supply and demand yielding as follows:

$$\dot{x}(t) = Ax(t) + c(t) + x(t). \tag{2}$$

To model the industry sectors' dynamic recovery behaviors and dynamic interactions caused by demand reduction or labor disruptions in industry sectors, we start with a diagonal matrix of the capital coefficient matrix B as follows:

$$B = diag\left(b_i\right) \quad \forall\, i = 1, 2, \ldots, n. \tag{3}$$

Let a matrix K be equal to

$$K = diag\left(k_I\right) \quad \forall\, i = 1, 2, \ldots, n. \tag{4}$$

Relating diagonal matrices K and B yields

$$K = -B^{-1} \leftrightarrow k_i = \frac{1}{b_i}; \qquad \forall\, i = 1, 2, \ldots, n. \tag{5}$$

Merging equations (5) and (1) give

$$\dot{x}(t) = K[Ax\,(t) + c\,(t) - x\,(t)]. \tag{6}$$

Or in discrete form,

$$x\,(t+1) - x\,(t) = K\,[Ax\,(t) + c\,(t) - x\,(t)]\,. \tag{7}$$

Transforming equation (7) into the normalized inoperability form results in the following equation (8) (Haimes et al., 2005) as follows:

$$q\,(t+1) - q(t) = K[A^* q\,(t) + c^*\,(t) - q\,(t)]. \tag{8}$$

Matrix A^* is the normalized interdependency matrix, $c^*\,(t)$ is the normalized final demand vector at time t; $q(t)$ is the inoperability vector at time t, and K is the industry resilience coefficient that measures the resilience of sector i in the presence of disruption in demand and supply. From Equation (8), the greater the value of the resilience coefficients (i.e., diagonal values of the matrix K), the higher the recovery speed of the sector. An intuitive view of this can be obtained from the fact that the term $A^* q\,(t) + c^*\,(t) - q\,(t)$ represents the difference between supply and demand (in inoperability terms), thus, the greater the resilience coefficients, the smaller will be the difference between $q\,(t+1) - q(t)$, indicating that the system is reaching a steady state.

The inoperability vector at time t after a disruption is defined as the vector of normalized economic losses and be derived as follows:

$$q = [diag\,(x)]^{-1}[x - \tilde{x}], \tag{9}$$

where x is the as-planned level of output and $\tilde{x}$ is the degraded level of output and its elements have values between 0 and 1. The interdependency matrix, A^*, is defined as the additional inoperability that sectors contribute to each other due to their interaction. It is defined in equation (10) as follows:

$$A^* = [diag\,(x)]^{-1} A\left[diag\,(x)\right]. \tag{10}$$

The initial demand perturbation vector c^*, which is the normalized demand vector is derived as follows:

$$c^* = [diag\,(x)]^{-1}\left[c - \tilde{c}\right], \tag{11}$$

where c is the as-planned level of final demand and $\tilde{c}$ is the degraded level of final demand resulting from the exogenous system disruption.

The sectoral resilience coefficient k_i can be derived as shown in equation (12) (Lian and Haimes, 2006)

$$k_i = \frac{\ln\left(\frac{q_i(0)}{q_i(T)}\right)}{T(1 - a_{ii}^*)}, \tag{12}$$

where $q_i\,(0)$ is the initial operability, $q_i\,(T)$ is the inoperability after the T period from the shock, and a_{ii}^* is the sector's coefficient in the interdependency matrix.

The recovery pathway can be used to derive the economic loss during recovery from each sector. The cumulative economic loss for each industry i is given by $Q_i\,(t\,)$

$$Q_i\,(t) = x_i \int_{t=0}^{T} q_i(t)dt, \tag{13}$$

where x is the as-planned output rate of industry i; $q_i(t)$ is the inoperability of industry i by time t. In discrete terms, equation (13) can be expressed as in equation (14),

$$Q_i\,(t) = x_i \sum_{t=0}^{T} q_i\,(t). \tag{14}$$

3.2. Data

The present study is based on input–output data obtained from the Scottish supply, use, and input–output tables from 1998 to 2019 (Scottish Government, 2022c). The table provides a complete picture of the flows of goods and services in Scotland's onshore economy each year.

The original 98 economic sectors of the Scottish input–output tables were aggregated (to simplify the calculations) into 18 industries. The 2019 input–output table for Scotland is presented in Table 1. To account for the dynamic behavior of the sectors across the years, the simulation is based on averages of the interdependency matrix from 1998 to 2019 input–output tables.

The aggregated sectors were as follows: agriculture, fisheries, and forestry; preserved meat and meat products; processed and preserved fish, fruits, and vegetables; manufacture of dairy, vegetables, and animal oils and fats; grain mill products, starches, and starch products; bakery and farinaceous products; other food products[2]; prepared animal feeds; alcoholic beverages and tobacco products; soft drinks; other manufacturing; energy supply, water, and waste; mining and quarrying construction; wholesale and retail trade and repairs; transport and

2 This comprises of manufacture of sugar; manufacture of cocoa, chocolate, and sugar confectionery; processing of tea and coffee; manufacture of condiments and seasonings; manufacture of prepared meals and dishes; manufacture of homogenized food preparations and dietetic food; and manufacture of other food products.

TABLE 1 Aggregated version of the Scottish input–output table–2019.

Industry	Agriculture fisheries and forestry	Preserved meat and meat products	Processed and preserved fish, crustaceans molluscs fruit and vegetables	Manufacture of dairy vegetable and animal oils and fats	Grain mill products, starches and starch products	Bakery and farinaceous products	Other food products	Prepared animal feeds	Alcoholic beverages and Tobacco products	Soft drinks	Other manufacture	Energy supply water and waste	Mining and quarrying (Section B)	Construction (Section F)	Wholesale and retail trade and repairs	Transport and storage	Accommodation and food service activities	Other services	Total intermediate demand	Households	Non-profit institutions serving households	Central government	Local authorities	Gross fixed capital formation	Valuables	Changes in Inventories	Exports			Total demand for products at basic prices
																											Non-resident households	Rest of UK	Rest of world	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Agriculture, fisheries and forestry (1)	602.4	393.7	355.8	85.9	22	2.7	7.4	59.1	59.8	2.1	192.1	28	3.5	29.2	48.4	8.5	35	81.5	2,016.90	1,381.10	4.9	0.3	8.5	188.2	−0.5	220.4	107.3	1,163.50	884.7	5,975.30
Preserved meat and meat products (2)	5.3	53.1	0.4	0.5	0	4.4	7.3	1.6	0.2	0.1	1.7	0.1	0.1	0.3	16.1	4	74.3	21.9	191.2	331.1	0	0	0	0.6	0	0.6	8.6	673.2	84.7	1,290.00
Processed and preserved fish, fruit and veg. (3)	1.6	1	81.6	0.4	0.8	8.2	11.8	1.3	1.4	2.5	1	0.1	0.1	0.3	2.4	1.1	54.3	15.1	185.1	259.5	0.1	0	0	1.2	0	0.5	4.7	809.2	424.3	1,684.60
Manufacture of dairy, vegetable and animal oils, and fats (4)	0.1	0.4	0.6	3.3	0.1	8.7	3.7	0.3	0.1	0.1	0.7	0	0	0.2	0.9	0.8	7.9	3.4	31.4	108.8	0	0	0	0.3	0	1.5	3.4	187.9	49.6	383
Grain mill products, starches, and starch products (5)	0	0.2	0.2	0	0.6	5	0.5	2.5	11.4	0	0.2	0	0	0	0	0	0.9	0.5	22.1	9.8	0	0	0	0	0	0.6	0.2	53.3	8	94.1
Bakery and farinaceous products (6)	0.6	0.7	2.8	0.1	0.1	5.7	7.3	0.3	1.1	0.4	1.6	0.2	0.2	0.6	4.7	0.6	41.3	15.4	84	418.5	0	0	0	1.4	0	0.4	21.8	494.7	127.7	1,148.50
Other food products (7)	0.6	3.2	4.8	0.3	0.3	8.4	9.6	0.9	2.5	2.9	2.7	0.2	0.1	0.7	1.6	0.7	23.7	10.4	73.6	140.5	0	0	0	1.5	0	−1	4.2	309.3	141.1	669.3
Prepared animal feeds (8)	199.3	0.2	0	0.2	0	0.1	0.1	31.9	0	0	0	0	0	0	0	0	0.2	2.1	234.2	104.3	0	0	0	0.4	0	5.8	0.4	42.8	65.4	453.3
Alcoholic beverages and tobacco products (9)	6.8	2.2	4.4	0.5	0.2	1.4	0.9	0.8	38.4	0.5	29.8	2.2	1.8	11.4	6.8	3.5	28.9	34	174.3	241.2	0.2	0	0	22.6	0	−1.6	43.9	606.9	3,827.90	4,915.40
Soft drinks (10)	0.2	0.1	0.4	0	0	0.2	0.1	0	1.2	8.1	0.8	0.1	0.1	0.3	0.4	0.2	33.4	10.3	55.7	156.5	0	0	0	0.4	0	0.9	10.6	146	13	383

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TABLE 1 (Continued)

Industry	Agriculture fisheries and forestry	Preserved meat and meat products	Processed and preserved fish, crustaceans molluscs fruit and vegetables	Manufacture of dairy vegetable and animal oils and fats	Grain mill products, starches and starch products	Bakery and farinaceous products	Other food products	Prepared animal feeds	Alcoholic beverages and Tobacco products	Soft drinks	Other manufacture	Energy supply water and waste	Mining and quarrying (Section B)	Construction (Section F)	Wholesale and retail trade and repairs	Transport and storage	Accommodation and food service activities	Other services	Total intermediate demand	Households	Non-profit institutions serving households	Central government	Local authorities	Gross fixed capital formation	Valuables	Changes in Inventories	Exports			Total demand for products at basic prices
																											Non-resident households	Rest of UK	Rest of world	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Other manufacturing (11)	247.2	18.8	29.5	5.4	1.9	30.3	18.2	11.9	171.6	16.8	2,420.70	295.4	141.2	878	331.6	281.9	64.9	1,517.30	6,482.60	2,456.50	6.2	215.9	0	1,538.50	−43.6	15.1	131.7	7,023.70	8,417.50	26,244.10
Energy supply, water, and waste (12)	74.4	17.1	25.2	9.1	2.7	34.2	13.5	7.3	110.7	11.1	456.7	4,438.50	38.2	174.8	476.5	106.4	242.7	1,478.10	7,717.20	3,031.40	1.1	0	818.8	88.7	0	10.6	38.3	4,313.40	386.2	16,405.80
Mining and quarrying (13)	10.4	1.9	3.6	0.6	0.2	1.6	1	0.7	9	1.2	90.9	7	218.5	188.8	28.3	16.1	3.4	62.7	645.8	99.8	0.2	0	0	32.4	0.3	−1.2	13.7	2,319.80	517.5	3,628.40
Construction (14)	85.9	1.7	1.2	0.1	0	0.4	0.2	0.1	2.3	0.2	130.7	271.1	48.6	4,435.30	257.7	36	20.7	1,814.80	7,107.10	327.2	1.4	0	0	11,002.80	0	−76.8	62.8	1,995.40	424	20,844.00
Wholesale and retail trade and repairs (15)	349.4	95.9	184.7	20.4	7.2	71.8	47.7	40.9	214.8	22.9	1,602.60	125	93.2	511	663.7	256.3	276.6	1,506.80	6,090.90	10,135.30	16.1	0	18.2	1,161.70	0.7	−0.1	601.5	2,753.50	2,619.40	23,397.30
Transport and storage (16)	147.4	17.2	31.7	10.5	2.2	19.5	11.1	7.4	91.1	16	394.7	98.6	72.5	47.8	1,162.70	1,159.40	25.4	1,404.80	4,720.00	2,336.70	1	704.9	0	23.2	0	−0.1	248.6	2,498.80	1,484.10	12,017.30
Accommodation and food service activities (17)	4.6	0.4	0.6	0.2	0	1.9	0.4	0.2	2.7	0.4	25.2	5.7	8.4	21	35.2	46.2	38.3	632.2	823.5	4,899.30	1.2	0	0	19.8	0	−0.1	2,549.30	23	10.6	8,326.60
Other services (18)	398.7	25.2	51.7	11.3	2.5	44.6	43.2	9.6	200.7	15.9	1,128.80	793.3	506.8	1,214.90	1,940.70	1,093.80	651.4	18,971.80	27,105.00	31,538.00	4,379.70	26,723.40	13,517.80	2,796.10	7	−51.3	738	21,978.80	11,747.20	140,479.60
Total domestic consumption	2,134.90	633	779.3	148.8	40.6	249.2	184.1	176.8	919	101.1	6,480.90	6,065.50	1,133.30	7,514.70	4,977.70	3,015.70	1,623.20	27,583.00	63,760.70	57,975.50	4,412.30	27,644.50	14,363.20	16,880.10	−36.1	124.3	4,589.00	47,393.20	31,232.80	268,339.60
Imports from rest of UK	1,028.60	227.2	309.5	59.1	24.3	318.7	187.9	136.1	930.6	95.2	3,975.70	2,558.10	601	2,881.20	2,811.70	1,758.20	1,062.80	14,408.20	33,373.90	23,880.90	0	556.3	0	8,606.30	8.1	240.9	553.8	1,594.50	314.8	69,129.40
Imports from rest of world	434.8	150.3	160.7	35.6	10	105.3	70.4	34.2	381.5	49.5	4,209.80	619.8	413	1,341.90	1,203.10	883.9	391.1	6,081.00	16,575.90	11,779.90	0	285.8	0	4,607.80	12.7	230.1	397.8	1,435.00	0	35,324.90
Total intermediate consumption at basic prices	3,598.30	1,010.50	1,249.50	243.5	74.9	673.2	442.4	347.1	2,231.10	245.8	14,666.40	9,243.30	2,147.30	11,737.70	8,992.40	5,657.80	3,077.10	48,072.20	113,710.50	93,636.30	4,412.30	28,486.60	14,363.20	30,094.10	−15.4	595.3	5,540.50	50,422.70	31,547.60	372,793.90

(Continued)

TABLE 1 (Continued)

Industry	Agriculture fisheries and forestry	Preserved meat and meat products	Processed and preserved fish, crustaceans molluscs fruit and vegetables	Manufacture of dairy vegetable and animal oils and fats	Grain mill products, starches and starch products	Bakery and farinaceous products	Other food products	Prepared animal feeds	Alcoholic beverages and Tobacco products	Soft drinks	Other manufacture	Energy supply water and waste	Mining and quarrying (Section B)	Construction (Section F)	Wholesale and retail trade and repairs	Transport and storage	Accommodation and food service activities	Other services	Total intermediate demand	Households	Non-profit institutions serving households	Central government	Local authorities	Gross fixed capital formation	Valuables	Changes in Inventories	Exports			Total demand for products at basic prices
																											Non-resident households	Rest of UK	Rest of world	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Taxes less subsidies on products	95.1	0.5	4.4	1.1	0.2	8.3	1.8	1.5	192.8	7.5	413.7	583.8	21.1	121.4	248.9	497.5	199.5	3,343.40	5,742.50	11,779.00	0	4.5	0	867.2	0.1	2.5	834.1	15.1	0	19,245.00
Taxes less subsidies on production	−479.8	2.8	2.7	0.3	0.1	5.9	2.4	0.6	11	2.2	183	339.4	21	138	1,007.00	196	297	581	2,310.50											
Compensation of employees	798	227	308.1	94.3	14	322	153.7	57.5	872.2	72.3	7,493.00	2,024.30	1,102.00	4,785.00	8,592.00	4,285.00	3,545.00	49,295.00	84,040.30											
Gross operating surplus	1,963.80	49.3	119.9	43.7	4.8	139.2	69	46.6	1,608.30	55.3	3,488.00	4,215.10	337	4,062.00	4,557.00	1,381.00	1,208.00	39,188.00	62,535.90											
Gross value added	2,282.00	279	430.7	138.3	18.9	467.1	225.1	104.7	2,491.50	129.8	11,164.00	6,578.70	1,460.00	8,985.00	14,156.00	5,862.00	5,050.00	89,064.00	148,886.70											
Total output at basic prices	5,975.30	1,290.00	1,684.60	383	94.1	1,148.50	669.3	453.3	4,915.40	383	26,244.10	16,405.80	3,628.40	20,844.00	23,397.30	12,017.30	8,326.60	140,479.60	268,339.60											

Source: Own aggregation based on the Scottish 2019 input–output Table.

storage; accommodation and food service activities; and other services.[3]

It should be mentioned that due to data confidentiality, the Scottish Government aggregates some of the food sectors and it is not possible to break them down into more meaningful sectors. Examples of this are the groups of "preserved meat and meat products"; "processed and preserved fish, fruits, and vegetables"; "manufacture of dairy, vegetables, and animal oils and fats".

To analyze the evolution of the food and drink sector, in this study, the estimated monthly GDP by sector was used (the series were presented in Figure 2). The GDP is not the total sectoral output (this is only estimated annually and the latest figures are for 2019), it is only the value-added part; however, it has a close relationship with the total output, see Arrow (1974). Moreover, it is possible to compute changes in the value added using a multiplier (see the Ghosh model in Miller and Blair, 2009).

4. Results

The starting point of the analysis is to estimate how resilient the accommodation and food service sector is following approximately 60% contractions in final demand due to COVID-19. This had not only impacted its own sector but also its connections with other sectors to the rest of the economy.

Annex Table A1 in the Annex presents the information used for the estimation of the resilient coefficients for all sectors. It should be mentioned that to isolate the impact of Ukraine–Russia conflict, the ending period was fixed after 10 months of period 0, set in most of the cases in April 2020. Going beyond January 2021 would have also implied considering the effects of the conflict.

The resilient coefficients for the accommodation and food service sector and interconnected sectors are shown in Figure 5, "processing of meat and meat products" and "agriculture, fisheries, and forestry" were the sectors with the highest resilience coefficient, i.e., the ones to reach faster the steady state. However, the other food processing industries and the soft drink industry showed small resilient coefficients, all of them (except the bakery sector) less than 0.1.

The processed fish, fruits, vegetables, dairy, vegetable oils, and soft drink industry appear as particularly in a sensitive position given their relationship with the accommodation and food sector. The result from the analysis is very relevant because it reveals the speed at which the remaining sectors respond to shocks in the accommodation and food service sector. The low degree of resilience for grain mill products, starches, and starch products; mining and quarrying; transport and storage; and prepared animal feed sector reveals that supply chain shocks have lasting impacts and recover slowly, especially for these sectors.

Figure 6 presents the results for the recovery analysis—how long it takes for each sector to return to its initial output level before the shock. For this analysis, the estimated interdependence matrix (presented in the Annex Table A2) is crucial because it represents the interrelation between the different sectors. The evolution of the sectors is given by the difference equation as represented in equation (8).

As shown in the figures and anticipated from the analysis of the resilience coefficients, the soft drink, and the dairy and vegetable oil sector are the ones with the slowest recovery paths. As shown, agriculture and processed meat are less affected. An interesting aspect of all these sectors is that all the sectors follow a convergent path to the steady state, this is slow in all the cases, indicating that the shocks are persistent in the sector.

Figure 7 shows how fast the agrifood and related sectors converge. As shown in the figure, agriculture, preserve meats, and alcoholic beverages' inoperability is reduced by more than half after 10 months. For instance, the soft drink sector's inoperability was reduced by approximately 25% compared to approximately 200% for the agricultural, fisheries, and forestry sectors. This disparity suggests that shocks are persistent in certain sectors, especially for the processed meat and preserved fruit and vegetable sector, and the other food product sectors.

The last part of the calculation is the estimation of economic losses, which follows equation (14) and is presented in Table 2.

Table 2 shows the losses in monetary terms and also in relative terms (as a share of the planned output of the sector). In monetary terms, the food and drink sector; agriculture, fisheries and forestry, and alcoholic beverage and tobacco product sectors showed the greater losses (£962.2 and £899.8, respectively). However, the losses as a share of total sector output (column 5) provide an easier way to compare the magnitude of the losses across economic sectors. For instance, while the accommodation and food service sector has losses that are similar to wholesale and retail trade and repairs, in relative terms, the former is above two times the latter. Moreover, the soft drink sector shows a ratio of planned output to economic losses above 4 indicating the importance of the losses for the sector.

5. Discussion

The present study presents three important results as follows: (1) the extent of the resilience of sectors of the Scottish economy when one sector is adversely disrupted; (2) the duration or time required for disrupted sectors to bounce back their initial level of production; and (3) the economic losses due to the disruption. The relevance of the current results is that it exposes the most vulnerable sectors as well as the extent to which industries or companies are closely connected across the globe or countries (Shahidi, 2020).

Sector rankings provide insights into which sectors are required to develop stronger capabilities to deal with future disruptions. For instance, the ranking of resilience coefficients in Figure 4 shows that the top three sectors resilient to the shock are as follows: preserved meat and meat products; agriculture, fisheries, and forestry; and other manufacturing are the sectors with well-developed capabilities to bounce back quicker in the presence of disruption. These sectors have the highest capacity to bounce back quicker in the event of a disruption.

Another plausible explanation for the high resilience coefficient of the two agricultural sectors—preserved meat and meat products, and agriculture, fisheries, and forestry—is that the closure of the accommodation and food service sector pushed demand toward

3 This comprises of services furnished by membership organizations; repair services of computers and personal and household goods; and other personal services.

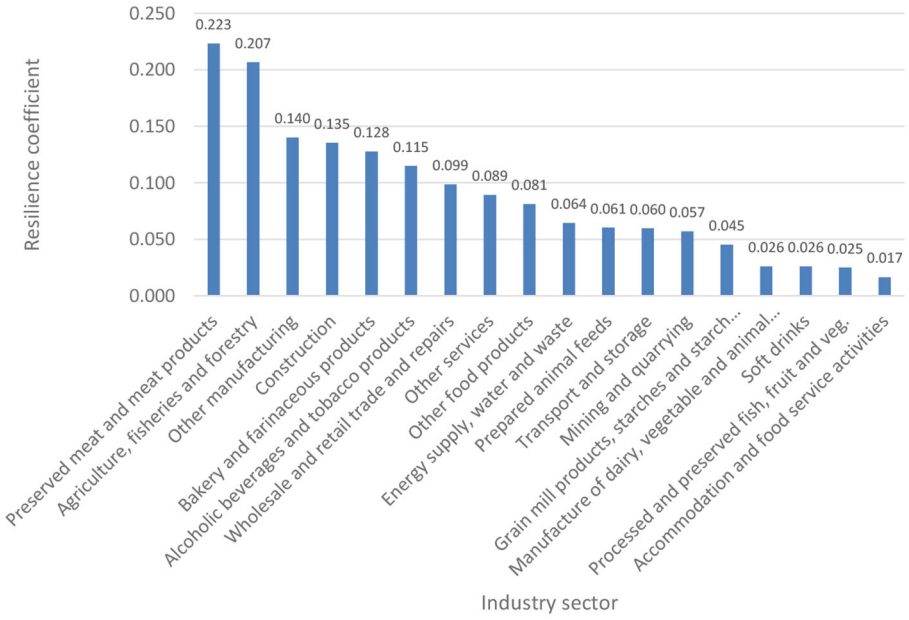

FIGURE 5
Estimated resilience coefficient by sector following a contraction of the accommodation and food service sector. Source: Own computation based on the Scottish input–output tables from 1998 to 2019.

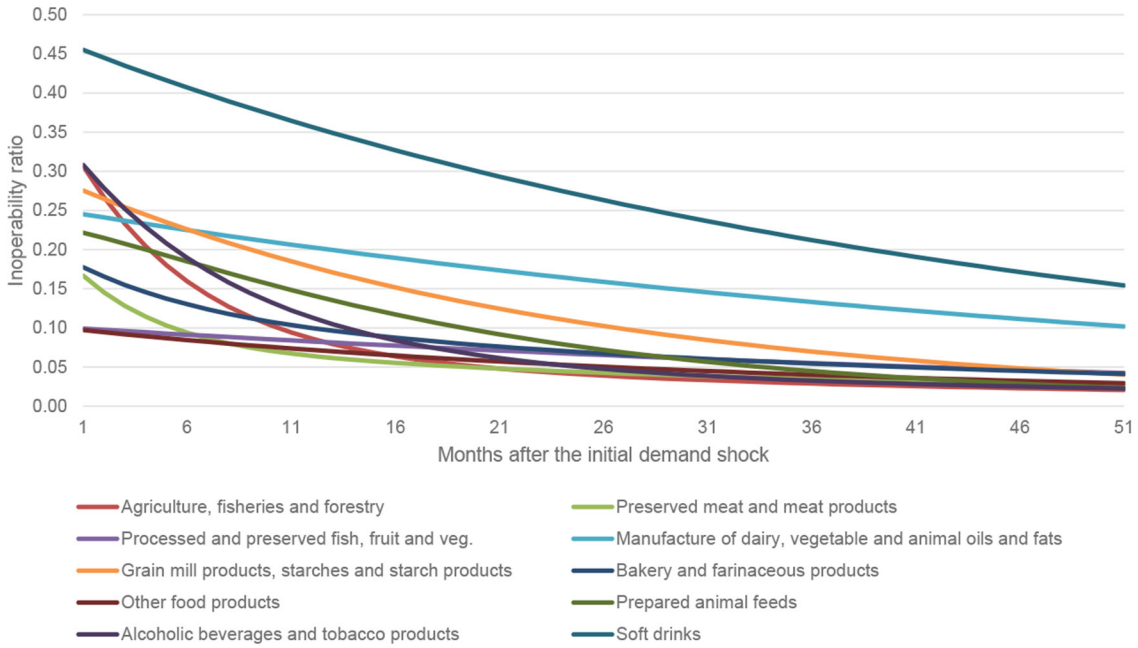

FIGURE 6
Inoperability dynamic recovery path for agrifood sectors of the Scottish economy. Source: Own computation based on the Scottish input–output tables from 1998 to 2019.

household demand and restaurant/local deliveries which offset the impact of the drop in final demand. For instance, Butu et al. (2020) showed that local deliveries of fruits and vegetables in Romania increased significantly during and after the COVID-19 lockdowns. Moreover, the agricultural and food sectors developed rapid response measures to prevent the spread of the virus quicker than most sectors (Aday and Aday, 2020).

However, sectors like the manufacture of dairy, vegetable and animal oils, and fats; soft drinks; and processed and preserved fish, fruits, and vegetable sectors are required to develop stronger

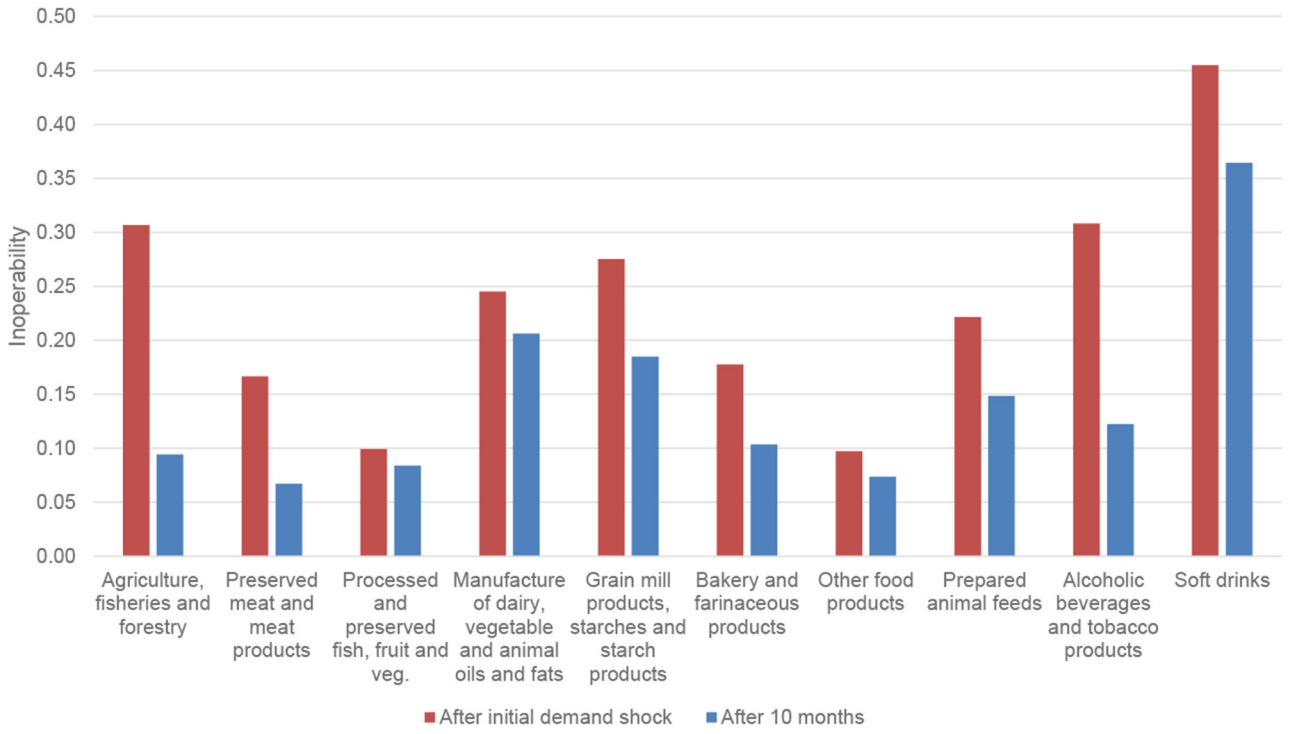

FIGURE 7
Initial and after 10 months of inoperability for agrifood and related sectors. Source: Own computation based on the Scottish input–output tables from 1998 to 2019.

TABLE 2 Estimated economic losses for the first 10 months (£ million).

	Planned output	Sum q(t) 1/	Economic losses	Losses 2/
Agriculture, fisheries, and forestry	497.9	1.93	962.2	1.93
Preserved meat and meat products	107.5	1.13	121.7	1.13
Processed and preserved fish, fruit, and veg.	140.4	1.01	141.2	1.01
Manufacture of dairy, vegetable and animal oils, and fats	31.9	2.48	79.1	2.48
Grain mill products, starches, and starch products	7.8	2.50	19.6	2.50
Bakery and farinaceous products	95.7	1.48	141.4	1.48
Other food products	55.8	0.93	52.1	0.93
Prepared animal feeds	37.8	2.04	76.9	2.04
Alcoholic beverages and tobacco products	409.6	2.20	899.8	2.20
Soft drinks	31.9	4.49	143.3	4.49
Other manufacturing	2,187.0	2.25	4,929.1	2.25
Energy supply, water, and waste	1,367.2	1.46	1,993.1	1.46
Mining and quarrying	302.4	3.34	1,010.3	3.34
Construction	1,737.0	3.78	6,560.9	3.78
Wholesale and retail trade and repairs	1,949.8	3.11	6,068.4	3.11
Transport and storage	1,001.4	3.46	3,461.3	3.46
Accommodation and food service activities	693.9	8.98	6,233.1	8.98
Other services	11,706.6	1.38	16,113.6	1.38

1/ Sum of inoperability from period 0 to 10. 2/ Share of the planned output.

capabilities to deal with future pandemics. There is a need to build and reconfigure both internal and external competencies to deal with future disruptions such as COVID-19. According to Hendry et al. (2018), these competencies could be built through proactive strategies such as building security, supplier development, and increasing visibility and through reactive strategies such as redundancy, logistics re-routing, and flexibility.

The recovery pathways show that the recovery times differ for different food and drink sectors. One possible reason for the slow recovery of the soft drink sector could be due to the shift from unhealthy eating behavior toward healthy eating (Grunert et al., 2021). There was a lot of media information on how the consumption of fruits and vegetables could boost immune systems and reduce susceptibility to diseases (Aman and Masood, 2020). These media messages could have affected the demand and the recovery of the soft drink sector. In addition, the soft drinks industry levy had come into effect further reducing the demand for the sector's output. Similarly, the slow recovery of the manufacture of dairy, vegetables, animal oils, and the fat sector could be attributed to the stringent measures imposed by governments on the dairy subsector (Bhattacharya and Jyothi, 2021).

The other service sectors, the construction sector, and the accommodation and food service activities contributed more than 60% of the total Scottish GDP in 2019. Losses in the industry's revenue translate into losses in gross domestic revenue. The economic loss estimates show the cost of the pandemic to both industry players and the government as a result stakeholders must take steps to improve the resilience of the most economically vulnerable sectors. According to O'Connor (2021), the impact of COVID-19 on tourism-related output was driven by the decline in rural tourism in Scotland. However, this is expected to change as the demand for staycation continues to rise.

6. Conclusion

The COVID-19 pandemic had a significant impact on the accommodation and food service sector. There was a massive loss in output and employment during the early days of the pandemic. The impact of the pandemic on this sector is expected to propagate across interdependent sectors of the economy. The goal of the present study was to examine how the COVID-19 disruptions to final demand in the accommodation and food service sector affected interrelated sectors focusing on the agricultural and food sectors using input–output tables from 1998 to 2019. The impact of the pandemic was measured in terms of operability and economic losses. In addition, we estimated resilient coefficients (how quickly sectors return to their initial production level) and recovery pathways for the agricultural and food sectors.

The accommodation and food service sector was the most affected by the COVID-19 pandemic lockdown contracting by approximately 60%. This is because the sector relies heavily on the movement of human and human resources as its primary input. Workforce absenteeism and lockdown restricting the movement of persons had a significant impact on turnover during the early period of the pandemic. According to the results, sectors that are related to the accommodation and food service sector are the most impacted in terms of inoperability. In addition, sectors with the largest economic loss are those that have a significant total output.

The resilience coefficient shows the speed with which disrupted sectors return to full operation. For the agricultural and food sectors, the processed and preserved fish, fruits, and vegetable sector is the least resilient while preserved meat and meat product sector is the most resilient to final demand disruption in the accommodation and food service sector. Less resilient sectors need to develop capabilities to overcome future pandemics. One area that could potentially reduce the impact of future pandemics is reducing the reliance on human resources. Moreover, these sectors need to develop collaboration with buyers outside of Scotland to ensure supply continuity when there are localized disruptions.

The dynamic recovery curve shows that recovery is quicker for the agricultural, fishery, and forestry sectors after 10 months compared to the remaining sectors, especially the soft drink sector. This suggests that the impact of the disruption is persistent in vulnerable sectors and takes a long time for these sectors to recover.

The least economically affected sector was the other food product sectors while the other service sectors had the highest economic loss. Even though the soft drink sector had a slow recovery rate, economic losses were lower compared to the agricultural, fishery, and forestry sectors.

From the policy perspective, we have shown that the most disrupted sector by the COVID-19 pandemic is the accommodation and food service sector. Stakeholders in the accommodation and food service sector should re-examine the sector and develop capacity against future pandemics. In addition, since the disruption to one sector affects the other, it is relevant for sectors to work closely together (either vertically or horizontally) by sharing the risk or cost of future pandemics. For instance, the accommodation and food service sector rely on the agricultural and fishery sector for raw materials. A future contract between these two that does not accommodate the potential impact of disruptions to demand could make only one sector bear the full cost of the disruption. However, the impact will be minimal if costs are shared. Industries should be interested in what goes on in other sectors of the economy. Managers should effectively perform network planning, transparency of inventory levels, capacity, and flexibility that can give a lens into bottleneck issues. The most vulnerable sectors of the economy, i.e., other service sectors should form a major part of government policy decision-making when planning against future pandemics.

The present study faced some limitations. First, the input–output table used is from 1998 to 2019, which is before the pandemic. It is, therefore, not possible to perform a difference-in-difference analysis that compares the performance of economic sectors before, during, and after the pandemic. To be able to complete our simulation analysis, we have assumed that supply and demand as well as structural relationships remained constant during and after the pandemic. Second, there may be other factors that may have contributed to the significant drop in the demand for the accommodation and food service sector's output, which are not addressed in the present manuscript. Finally, future research could examine and compare the isolated and combined effects of Brexit, COVID-19, and Russia–Ukraine war on the Scottish economy. In addition, an analysis of the structural changes that the economic sector might have occurred as a result of the pandemic is necessary.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.gov.scot/publications/input-output-latest/ and https://www.gov.scot/publications/about-gdp/.

Author contributions

CR-G: conceptualization, data preparation, investigation, visualization, formal analysis, writing—original draft, and writing—review and editing. WD: conceptualization, investigation, and writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1095153/full#supplementary-material

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Research on sustainable development of agricultural product cold chain logistics under public safety emergencies

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Under a sudden public security event, as agricultural cold chain logistics has the characteristics of many participating subjects and wide spatial and temporal distribution, it is extremely vulnerable to shocks. Even minor disruptions in logistics can result in a significant impact on the daily lives of residents. Therefore, improving the resilience of agricultural cold-chain logistics is crucial for sustainable development. This paper studies the sustainable development path of agricultural cold chain logistics from a resilience perspective. Through rooting theory, the process of resilience in agricultural cold chain logistics under sudden public safety events is explored. Based on the knowledge meta-model, three elements of resilience events, resilient subjects, and resilience measures are used to contextualize the resilience process, and finally, using Bayesian networks and fuzzy set theory, a contextual derivation model of the resilience process of agricultural cold chain logistics under sudden public safety events is created. The results show that the resilience process of sustainable development consists of a resistance period, an adaptation period, a readjustment period, and an innovation period, during which the government and enterprises jointly take measures to effectively resist the impact of public emergencies, and further enhance the resilience through innovative development to ensure the sustainable development of agricultural cold chain logistics.

KEYWORDS

public safety emergencies, cold chain logistics resilience, rooting theory, knowledge metamodel, bayesian networks

1. Introduction

In recent years, with the continuous development of China's economy and society, people's living standards have been improving, consumers' demand for fresh agricultural products has been rising, and the National Development and Reform Commission and other 12 departments have issued implementation opinions on further optimizing the development environment to promote the circulation of fresh agricultural products (Zengjun, 2022), the coupling and coordination degree of cold chain logistics and economic development is steadily increasing (Xie et al., 2022). Cold chain logistics involves multiple subjects and links, and there are many service providers, which easily leads to cold chain breakage, restricting the expansion of the scale of agricultural cold chain operation. Cold chain logistics must enhance the market operation ability of the operators through sustainable development, further improve the standardization system of the cold chain industry, and continuously improve the level of standardized services (Luo et al., 2021). In recent years, sudden public security events have occurred frequently, and

it is necessary to improve the resilience of agricultural cold chain logistics under sudden public security events and avoid the risk of interruption (Xing et al., 2020). In addition, to achieve the sustainable development of fresh agricultural products cold chain logistics, it is also necessary to clarify the causes of cold chain logistics breakage, and put forward corresponding countermeasures and suggestions to enhance the resilience of cold chain logistics (Zhang and Huo, 2021). Given the problem of evaluating the emergency logistics capacity of agricultural products under disaster conditions, some scholars adopt a combination of qualitative and quantitative research methods based on analyzing the factors affecting the emergency logistics capacity of far products under natural disasters, the evaluation index system of emergency logistics capacity of agricultural products under natural disaster conditions is constructed to evaluate the emergency logistics capacity of agricultural products to provide a technical basis for improving the emergency logistics capacity of agricultural products under natural disaster conditions (Zou et al., 2013). The risk assessment index system can also scientifically reflect the critical risk factors of agricultural product cold chain logistics. The disaster progress assessment method proposed by the key risk factors can predict the risk scientifically and reasonably (Zhang et al., 2017).

Resilience is considered one of the critical characteristics of current supply chain systems to cope with the uncertainty caused by the latest environmental, economic, and social crises. Especially in the agri-food supply chain, there is an urgent need to build a more resilient and adaptive agri-food supply chain system. The research on the resilience of agricultural cold chain logistics could be better. Some scholars have only studied the critical success factors of building a resilient agri-food supply chain (Kontopanou et al., 2021). Given the problem that the theoretical system is not sound in the research of agricultural product logistics, some scholars use the rooted theory to build a theoretical system rooted in accurate data and phenomena (Shu and Hu, 2020), which provides ideas for the research on the resilience of agricultural product cold chain logistics. Resilience is the ability of things to return to their initial state, which can be divided into engineering resilience, ecological resilience, and evolutionary resilience (Holling, 1973; Pimmsmm, 1984; Ramlogan and Metcalfe, 2006). As an economic activity, the resilience of cold chain logistics of agricultural products is evolutionary (Martin et al., 2016). Many resilience elements in evolutionary resilience can be used to enhance resilience. However, their selection and implementation must be carefully matched to the relevant stages of disruption and assessed against their broader supply chain impact. Research must focus on the overall impact on the supply chain (Stone and Rahimifard, 2018). Combined with the characteristics of many participants and complex systems in the cold chain of agricultural products (Mingfei and Xin, 2018), some scholars draw on the reliability analysis ideas in reliability engineering theory and concretize the abstract problem of cold chain logistics system failure according to the operation characteristics of the cold chain logistics system and the causal relationship between events, and construct its fault tree. Bayesian networks are generated based on fault trees to estimate the operational reliability of cold chain logistics systems and reveal the leading causes of system failures (Guo et al., 2015). The resilience evolution process is regarded as an uncertain event, and Bayesian networks are used to deduce (Qiu et al., 2011). Bayesian network modeling and simulation are used to identify and perform sensitivity analysis on major influencing factors to analyze the entire cold chain logistics system and risk events (Zheng et al., 2021). Based on Bayesian theory, some scholars have constructed a topology of the risk of interrupting new cold chain networks. Fuzzy set theory is used to predict and calculate the probability of each root node to determine essential risk factors. Strategies to reduce the risk of broken chains were explored (Chen et al., 2021).

Currently, the majority of studies on agricultural cold chain logistics center around risk and efficiency (Yuan et al., 2020; Lin, 2021), but most scholars study the resilience of agricultural cold chain logistics from a static perspective (Huang et al., 2020; Wenping and Yuwan, 2022; Xu and Tang, 2022). There is a significant gap in the dynamic research on the resilience development of agricultural cold chain logistics. Previous studies have mostly employed Bayesian networks (Zhang et al., 2017) and system dynamics (Xu et al., 2021) to analyze the risk and efficiency of cold chain logistics. While the scope of these studies differs from that of the present paper, they do provide a theoretical framework for analyzing contextual evolution and uncertainty. This paper addresses the problem that the process of resilience of agricultural cold chain logistics is not clear, combines previous research results, collects relevant information, constructs the process of resilience of agricultural cold chain logistics under unexpected public events by using the rooting theory, contextualizes the process by using the knowledge meta-theory, and finally constructs a dynamic evolutionary inference model by using Bayesian networks. Considering the subjectivity problem in the process of Bayesian network construction, this paper processes the evaluation of experts and scholars through fuzzy set theory to obtain the conditional probability of Bayesian network. The study visualizes the process of the role of resilience, and provides reference for government enterprises to enhance the resilience of agricultural cold chain logistics and resist the impact of unexpected public events.

2. Exploring the process of the resilience of agricultural cold chain logistics under sudden public safety events

2.1. Research methodology

Rooting theory intervenes in the environment of the problem under study through participant observation and interviews to obtain primary data. It constructs a theoretical system rooted in accurate data and phenomena from the bottom up through the graded induction and refinement of the primary materials (Shu and Hu, 2020). Jia (2016) made moderate methodological innovations and refinements to the rooting theory, organically integrated qualitative and quantitative research methods, and proposed the basic model of the Chinese management rooting research paradigm. Most of the current research on agricultural cold chain logistics focuses on exploring the efficiency and vulnerability of agricultural cold chain logistics from a static perspective. Less research analyzes the dynamic evolution mechanism of the toughness of agricultural cold chain logistics from a dynamic evolutionary perspective, and most of them draw on the previous research results and the mechanism of the role of the toughness of agricultural cold chain logistics under the sudden public safety events in China is not thoroughly studied. Therefore, this paper uses the constructive rooting theory to study the evolutionary process

of the toughness of agricultural cold chain logistics under sudden publicity time to explore its resilience mechanism further.

2.2. Research methodology

To ensure the reliability and systematicity of the data, this study explores the evolutionary process of the toughness of agricultural cold chain logistics through expert interviews, literature, policies and regulations, and news material analysis in October 2022. In terms of expert interviews, considering that cold chain logistics is a complex system project with a potent combination of practical and theoretical characteristics, the interviewees of this paper were selected as experts and scholars in the field of logistics, executives of logistics enterprises, and cold chain logistics staff, etc. Fifteen interviews were obtained through semi-structured interviews. In terms of literature collection, the keywords "cold chain logistics," "cold chain logistics resilience," "logistics resilience," "public safety emergencies" etc. were used in the research of domestic and international databases. The keywords "cold chain logistics," "cold chain logistics resilience," "logistics resilience," "sudden public safety events" etc., were searched in domestic and international databases for relevant literature from January 2020 to October 2022, from which 65 Chinese and English literature were selected. In terms of policies and regulations, relevant policies and regulations were collected from the official websites of the State Council, Ministry of Commerce, Ministry of Transportation, local governments, and relevant functional departments with keywords such as "cold chain logistics" and "agricultural product." At the level of news materials, we collected relevant news reports from January 2020 to the present on the websites of People's Daily Online, Xinhua Online, China Agriculture Network, China Logistics and Purchasing Network, etc. After comparing and deweighting, we finally collected 30 relevant materials. Two randomly selected from each expert interview, literature, policy, regulations, and news materials were tested for saturation.

2.3. Open codes

The collected textual information was decomposed paragraph by paragraph and sentence by sentence, and the contents related to the resilience of cold agricultural chain logistics were selected and conceptualized. The concepts were categorized and analyzed to derive the categories, and finally 89 concepts and 14 categories were extracted. The open coding is shown in Table 1, and the categories obtained from the open coding categorization process are shown in Table 2.

2.4. Spindle type code

The initial concepts and categories obtained from the previous coding analysis were summarized, and the laws were refined and summarized more deeply. In this study, 14 initial categories are

TABLE 1 Example of results of conceptualization analysis of open codes.

Number	Original material	Properties	Conceptualization	Initial scope
a1	Since the outbreak of the epidemic, many places in the country have reported positive tests for the new coronavirus from the cold chain food packaging or cold chain environment, mainly imported frozen food	XW01	Positive for environmental testing A1	Cold chain logistics impacted S1
a2	Viruses tend to survive longer in cold environments. In addition, for some time, we often hear in the news that "new coronavirus is detected on the outer packaging of cold chain food"	FT03		
a3	Found two positive cases, a domestic cold chain logistics temporary closure control	XW01	Regional temporary closure A2	Cold chain logistics prevention and control S2
a4	The infection rate can be effectively reduced by cutting the transmission chain through timely containment of the virus-contaminated environment	WX02		
a5	Pinggu logistics base: fruit and vegetable cold chain four times before entering the warehouse	XW04	Cold chain logistics environmental disinfection A3	
a6	All regions are cold chain food production enterprises, cold storage, convenience stores, and other key places, and practitioners regularly carry out nucleic acid testing, increasing the frequency of testing and screening of imported cold chain food vehicles	FT07	Personnel security detection A4	
a7	In the whole process of cold chain logistics, it is necessary to minimize unnecessary personnel contact while the staff is fixed as much as possible and pays attention to daily protection	FT06	Cargo security inspection A5	
a8	At the beginning of the outbreak, there was a shortage of agricultural products and other fresh food all over the world, so we coordinated supplies from the source through integrated arrangements and ensured the security of supplies and personnel safety using closed-loop transportation	FT08	Closed-loop transport A6	
…	…(186 statements in total)		…(186 statements in total)	…(14 initial categories in total)

TABLE 2 Open coding categorization processes the resulting categories.

S1 Cold chain logistics impacted	S6 Integration of resources	S11 Digital transformation
S2 Cold chain logistics prevention	S7 Formation of the emergency reserve system	S12 Flexible Supply Chain
S3 Builds emergency security mechanism	S8 Resume work and production	S13Multi-collaboration mechanism
S4 Guarantee transportation	S9 Infrastructure construction	S14 Personnel Training
S5 State-owned enterprises to attack	S10 Government subsidies	

obtained through inductive analysis, such as cold chain logistics epidemic, cold chain logistics epidemic prevention and control, emergency assurance logistics, guaranteeing transportation, state-owned enterprises taking charge, coordinating logistics resources, and forming an emergency reserve system.

This study considers that the cold chain logistics resilience of agricultural products is the economic toughness of the industry studied from the meso level. Among the existing studies, a more accurate and accepted definition of economic resilience comes from study of Martin et al. (2016). This study argues that economic resilience to recessionary shocks should include four aspects, namely, resistance (the degree of sensitivity and response of the economy to recessionary shocks), resilience (the speed and degree of economic recovery from recessionary shocks), readjustment capacity (the ability of regional economies to restructure in the face of recessionary shocks), and the ability to create economic growth paths (the ability of the economy to open new stable growth paths) after suffering shocks (the ability of the economy to open a new stable growth path after a shock). The process of resilience in cold chain logistics evolves gradually over time. Therefore, this paper will study the resilience process of cold chain logistics from the perspective of evolutionary resilience and further summarize the initial categories based on evolutionary resilience theory, as shown in Table 3.

According to the process of the action of resilience, the 14 initial categories were grouped into four aspects in the formation of the master categories: resistance period, recovery period, readjustment period, and innovation period, as shown in Table 4.

2.5. Selective coding

Selective coding is the process of selecting the core category, systematically linking it to other categories, verifying the relationships between them, and completing the conceptualization of those categories that are not fully developed. Through inductive abstraction during the resistance period, recovery period, readjustment period, and path creation period, the core category was finally identified as "the process of resilience of agricultural cold chain logistics under public safety emergencies," and a theoretical model of the process of resilience of agricultural cold chain logistics under public safety emergencies was constructed, as shown in Figure 1.

TABLE 3 Resistance period main category formation ideas.

Initial scope	Ideas	Main category
S1 Cold chain logistics under attack	These two initial categories reflect the period when the resilience of the agricultural cold chain logistics under public safety emergencies first came into play	Resistance period
S2 Cold chain logistics prevention and control		

2.6. Saturation test

The eight selected text materials were tested for theoretical saturation to determine the comprehensiveness of the theoretical model constructed using the zapping method. Concepts and categories were extracted from the eight texts according to the three-level coding of the rooting method, and the analysis results were compared with the previously constructed "the process of the resilience of agricultural cold chain logistics in the context of public security emergencies" and no new concepts and categories were found. The results do not reveal any new concepts and categories, which indicate that the categories defined in this study can effectively reflect the process of the resilience of agricultural cold chain logistics in the context of public safety events.

3. Situational representation based on knowledge metatheory

3.1. Knowledge metatheory

Knowledgeable element is the basic knowledge unit that can effectively, independently, and freely identify, process, and combine knowledge of knowledge management (Wen, 2007). The knowledge of the resilience action process of agricultural cold chain logistics under sudden public security events is composed of each independent knowledge element related to agricultural cold chain logistics by the mechanism of resilience action. Using the standard knowledge model to express the resilience action process, the standard knowledge model can be expressed as follows:

$$K_m = \left(N_m, A_m, R_m\right) \forall m \in M \tag{1}$$

Equation (1) expresses the tenacity process consisting of multiple entity variables. Where N_m denotes an attribute, A_m denotes an attribute, and R_m denotes an inter-attribute relationship.

If an attribute a ∈ A, the attribute knowledge metamodel is used to describe its attribute state as follows:

$$K_a = \left(p_a, d_a, f_a\right) \tag{2}$$

In which p_a is the feature of the object attribute, d_a is the magnitude of the attribute, and f_a denotes the time-varying function of the

TABLE 4 Results of spindle type coding.

Main category	Initial scope	Connotation
Resistance period	S1 Cold chain logistics impacted	Outbreaks found in agricultural cold chain logistics
	S2 Cold chain logistics prevention	Cold chain logistics economic measures to deal with the risk of prevention and control
Recovery period	S3 Builds emergency security mechanism	Take emergency security measures for the supply of agricultural products to the masses
	S4 Guarantee transportation	Guarantee the smooth transportation of agricultural products through cold-chain logistics
	S5 State-owned enterprises to attack	Large state-owned enterprises to ensure normal living needs
	S6 Integration of resources	Coordinate the main body of resources and centralized deployment
	S7 Formation of emergency reserve system	Point-to-point supply of local reserve resources
Readjustment period	S8 Resume work and production	Organize compliant enterprises to resume work and production in an orderly manner
	S9 Infrastructure construction	The government takes the lead in guiding enterprises to improve the level of infrastructure construction
	S10 Government subsidies	Reduce taxes and fees for enterprises to help them recover
	S11 Digital transformation	Digital and the intelligent transformation of agricultural cold chain logistics
Creation period	S12 Flexible supply chain	Use infrastructure and digital construction to build a flexible supply chain
	S13 Multi-collaboration mechanism	Coordinate logistics resources of all subjects
	S14 Personnel Training	The digital working ability of employees under unexpected public events

attribute state. Finally, the relational knowledge meta-model is used to describe object knowledge meta-attributes specifically see the relation:

$$K_r = \left(p_r, A_r^I, A_r^O, f_r \right) \tag{3}$$

Where p_r is the relational attribute, A_r^I, A_r^O is the set of input and output attribute states, and f_r is the mapping function.

3.2. Knowledge meta-representation of scenarios

According to the results of the previous research on the process of resilience action of agricultural cold chain logistics under unexpected public safety events using the rooting theory, the knowledge meta-model is used to deeply explore the action process, interconnection, and developmental evolution mechanism of the resilience of agricultural cold chain logistics, identify the key factors affecting the action of resilience, and make scenario representation of the action process of resilience to lay the foundation for the construction of Bayesian network. In this paper, referring to the research results of scholars on evolutionary resilience and drawing on the classification method of Zhang on unexpected events (Zhang et al., 2013), the scenario of the resilience action process is divided into three knowledge bodies: resilience event (C_i), resilience measure (M_i), and resilience subject (M_i), as shown in Figure 2.

Combined with the above study, a phased scenario description of the resilience process of agricultural cold chain logistics under public safety emergencies is shown in Table 5.

4. Bayesian network construction and inference for resilient action processes

The sustainable development of agricultural cold chain logistics under a sudden public safety event is a process in which the resilience elements in each scenario interact and work together. The scenario projection of the resilience process is a process of analyzing the relationship between the various elements in the context of the current scenario development status to obtain the input elements for the next scenario. In situations where governments and enterprises are responding to public safety emergencies, it is difficult for decision-makers to accurately grasp the development situation or the resilience process due to many reasons, such as the untimely receipt of information and unreliable sources. In the case of public safety emergencies, it is clear that the resilience projection of agricultural cold chain logistics is carried out under conditions of incomplete knowledge or uncertainty of information, and the information available is generally qualitative in the description. This makes it impossible to rely on formulaic models for mathematical reasoning about agricultural cold chain logistics resilience under public safety emergencies. The construction of a Bayesian network requires the determination of the nodal variables and the interrelationships between the nodal variables of the resilience action process, i.e., conditional and prior probabilities. Whether the probabilities of the nodal variables are assigned scientifically and rationally is directly related to the accuracy of the inferred results. Research shows that in an uncertain environment, based on fuzzy set theory, the method of transforming the event probabilities described by fuzzy language into triangular fuzzy numbers or trapezoidal fuzzy numbers to finally obtain comprehensive evaluation results is practical and feasible (Chaoguang et al., 2003). The cold chain logistics resilience action scenario is used as an abstract expression and the adoption of this theoretical approach applies to the practical situation of Bayesian network derivation.

This paper extracts the key knowledge elements of the resilience process and represents them as nodal variables in a Bayesian network. The nodal variables that have a causal relationship with the development stage of resilience are connected to form the resilience scenario network of agricultural cold chain logistics under sudden public security events. GeNle software is utilized to calculate the state probability of the corresponding nodal variables and derive the resilience process of agricultural cold chain logistics under sudden

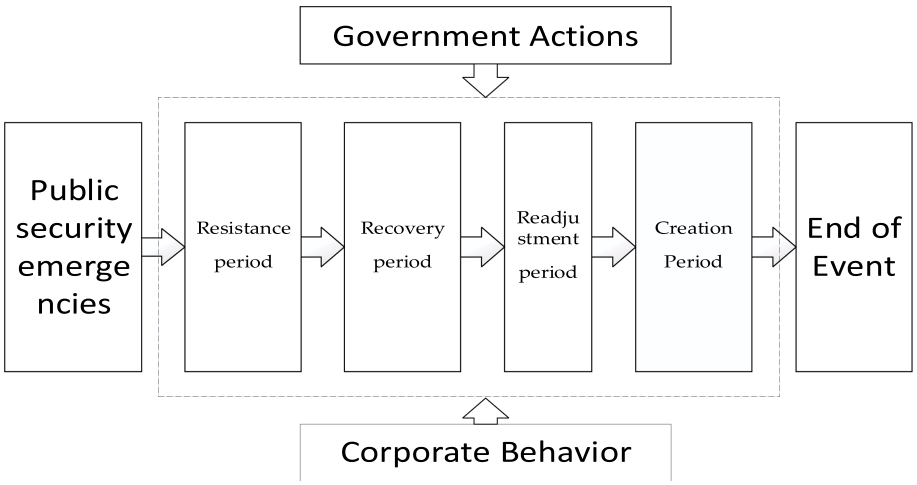

FIGURE 1
The process model of the resilience of agricultural cold chain logistics under emergency events.

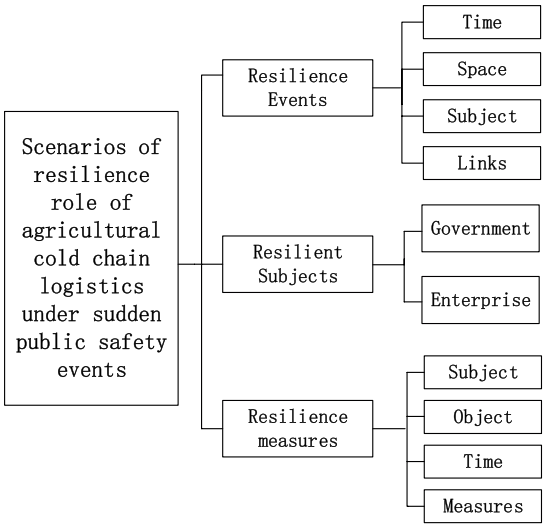

FIGURE 2
Knowledge of agricultural cold chain logistics resilience under sudden public safety events.

public security events. By projecting the action process of the resilience of agricultural cold chain logistics under sudden public safety events, the network is designed to explore the nodes and mechanisms of each measure from a global perspective, effectively addressing the problems of information asymmetry among decision-makers and an inaccurate understanding of the resilience development stage.

4.1. Bayesian network

Bayesian network (Bayesian Network) is a probabilistic graphical model describing the dependencies between variables, which can make inference from incomplete and uncertain knowledge, and is one of the most compelling ethical models in the field of uncertain knowledge representation and inference. As shown in Figure 3, the Bayesian network is a Directed Acyclic Graph (DAG), which consists of nodes and directed edges. Each node represents a random variable X_i of an event, and the directed edges represent the interrelationships among the node variables, X_1, X_2, X_3 respectively. $\mathrm{P}\left(X_3|X_1\right)$ represents the probability of X_3 occurring under the condition that scenario X_1 occurs, and the node variables without parent nodes can be expressed as prior probabilities.

Given a joint conditional probability distribution $\mathrm{P}\left(X_1, X_2, \cdots X_n\right)$ and an ordering of variables. At level I from the set $x_i\left\{x_i \subseteq X_1, X_2, \cdots X_{i-1}\right\}$ of X_i parent nodes, a set of directional lines are drawn linking to X_i and represented quantitatively by the $\mathrm{P}\left(X_i|x_i\right)$ conditional probabilities, resulting in a directed acyclic graph that can be used to represent many independent relationships embodied in $\mathrm{P}(X_1, X_2, \cdots X_n)$, which is called a Bayesian network. The $\mathrm{P}\left(X_i|x_i\right)$ contains all the information necessary to reconstruct the original distribution function, in the specified order, constitutes the joint probability distribution of all nodes in the Bayesian network:

$$\mathrm{P}(X_1, X_2, \cdots X_n) = \mathrm{P}\left(X_i|,,X_1|,,X_2|,,\cdots X_{i-1}\right) \cdots \mathrm{P}\left(X_2|X_1\right) \mathrm{P}\left(X_1\right) \quad (4)$$

4.2. Bayesian network construction

According to the above, the construction of Bayesian network needs to determine the node-year amount of resilience action and the relationship between each node, i.e., the joint probability distribution of the Bayesian network is constructed by obtaining the prior probability and conditional probability. This paper contextualizes the process of resilience action by applying rooted theory and knowledge meta-model, which is divided into four scenarios (resistance period, recovery period, readjustment period, and path creation period). Each scenario consists of three components [resilience event (C_i), resilience measure (M_i), and resilience subject (H_i)], and the interaction among the component factors drives the scenario development. The relationship between the nodal variables is explored through data collection and analysis

TABLE 5 Knowledge meta-expression of the resilience role of agricultural cold chain logistics under sudden public safety events.

Evolutionary context	Connotation
Resistance period	Resilience event: major public safety event hits agricultural cold chain logistics H_1
	Resilience measures: cold chain logistics impacted M_1, cold chain logistics prevention and control M_2
	Resilient subject: enterprise C_1
Recovery period	Resilience event: government emergency supply of cold chain agricultural products H_2
	Resilience measures: emergency safeguard mechanismM_3, safeguard transportation trafficM_4, state-owned enterprises to attack M_5 , coordinate resource system M_6 , and build emergency reserve system M_7
	Resilient subject: government C_2
Readjustment period	Resilient event: the government organized agricultural cold chain logistics enterprises to resume work and production in an orderly manner H_3
	Resilience measures: conditionality reviewM_8, infrastructure development M_9,and government subsidies M_{10}
	Resilient subject: government C_3
Creation period	Resilience event: corporate innovation development H_4
	Resilience measures: digital transformation M_{11}, flexible supply chain M_{12}, multiple collaboration mechanism M_{13}, and personnel training M_{14}
	Resilient subject: enterprise C_4
End of event	Resilience event: agricultural cold chain logistics enters a new normal H_5

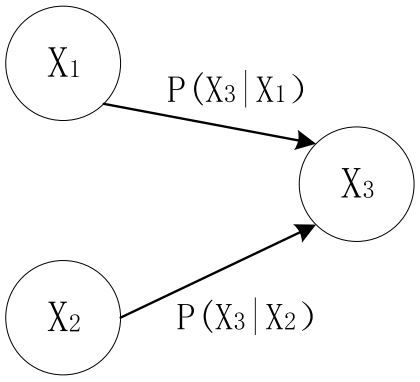

FIGURE 3
Bayesian network.

and expert scoring. A Bayesian network is constructed based on the knowledge meta-model of the resilience of agricultural cold chain logistics under unexpected public safety events, as shown in Figure 4.

4.3. Bayesian network construction

The scientific validity of the Bayesian network inference results directly depends on the accuracy of the probabilities of the nodal variables. While the prior probabilities in the text can be determined by collecting historical data, the conditional probabilities cannot be obtained precisely due to problems in data collection. Therefore, usually, the selection of conditional probabilities requires inviting experts from all walks of life to make descriptive evaluations of the relationships among nodal variables using abstract terms based on their own experiences, and cannot directly give accurate quantitative evaluations.

In this paper, 10 experts and scholars are invited to pay the conditional probability of each nodal variable by qualitative descriptive evaluation based on their own experience and expertise, and the expert evaluation is processed by using fuzzy set and DS (Dempster-Shafer) theory to find out the clear probability value of each variable. It has been shown that the probabilistic speculation accuracy of Bayesian networks modified by DS evidence theory is around 90%, which indicates the scientific nature of using this method to guide decision subjects to take relevant measures (Zou and Yue, 2020).

To improve the accuracy of Bayesian network probability values, we first apply fuzzy set theory to transform qualitative evaluations into fuzzy numbers and represent fuzzy probabilities as fuzzy subsets. Next, we apply DS theory to fuse each expert's fuzzy probabilities and reduce cognitive uncertainty resulting from subjective factors. We use triangular and trapezoidal fuzzy numbers to represent seven qualitative evaluation variables: very high, high, high, medium, low, low, and very low, and obtain clear probability values using the integrated value method, as shown in the following equation:

$$P_{\mathrm{L}}(X_i)=\frac{1}{2}\left[\sum_{\lambda=0.1}^{1}F_{\mathrm{L}}(X_i)\Delta\lambda+\sum_{\lambda=0}^{0.9}F_{\mathrm{L}}(X_i)\Delta\lambda\right] \quad (5)$$

$$P_{\mathrm{R}}(X_i)=\frac{1}{2}\left[\sum_{\lambda=0.1}^{1}F_{\mathrm{R}}(X_i)\Delta\lambda+\sum_{\lambda=0}^{0.9}F_{\mathrm{R}}(X_i)\Delta\lambda\right] \quad (6)$$

Where $\mathrm{F}(X_i)$is the arithmetic mean of the evaluation results of each expert, $P_{\mathrm{L}}(X_i)$, $P_{\mathrm{R}}(X_i)$is the integral values of the inverse functions of the affiliation functions around the fuzzy numbers, λ is the threshold value, the set consisting of elements with affiliation

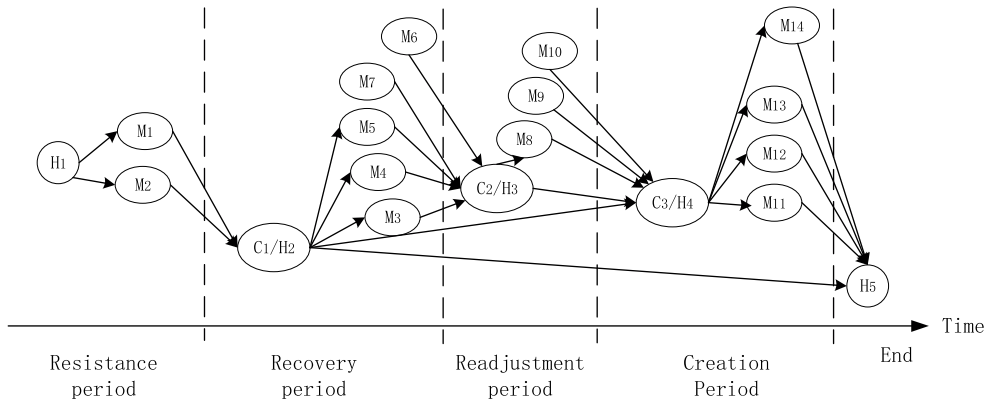

FIGURE 4
Bayesian network of resilient action process of agricultural cold chain logistics under sudden public safety events.

greater than λ is the λ-level intercept set of the fuzzy set, and $F_{\mathrm{L}}(X_i)$, $F_{\mathrm{R}}(X_i)$ denote the upper and lower bounds of the fuzzy probability of the node variable X_i, respectively.

$$P_{\lambda}(X_i) = \alpha P_{\mathrm{L}}(X_i) + (1-\alpha) P_{\mathrm{R}}(X_i) \tag{7}$$

The formula $\alpha \in (0, 1)$, when $\alpha = 0.5$, $P_{\lambda}(X_i)$ is the representative value of X_i solution fuzzy value.

In this paper, 10 experts and scholars are invited to pay the conditional probability of each node variable according to their own experience and expertise by qualitative description evaluation, and the expert evaluation is processed by using fuzzy set theory to find out the exact probability value of each variable. Assume that the independent trust functions are P_1 and P_2, the mess functions are m_1 and m_2, and the focal elements of the trust functions A and B are: $A_1, A_2, A_3 \ldots$; B_1, B_2, $B_3 \ldots B_{\mathrm{j}}$. The DS-theoretical fusion equation is:

$$m_{DS}(A) = \begin{cases} \dfrac{\sum_{A_i \cap B_j = A} m_1(A_{\mathrm{i}}) m_2(B_{\mathrm{i}})}{1 - \sum_{A_i \cap B_j = \varnothing} m_1(A_{\mathrm{i}}) m_2(B_{\mathrm{i}})}, A = \varnothing \\ 0, A = \varnothing \end{cases} \tag{8}$$

If there are three independent states A, B, and C in a Bayesian network of the resilience of agricultural cold chain logisticsunder unexpected public safety events, the fuzzy probabilities empirically derived by i experts are assigned to the three independent states: $\{m_1(\mathrm{A}), m_1(\mathrm{B}), m_1(\mathrm{C})\}$, $\{m_2(\mathrm{A}), m_2(\mathrm{B}), m_2(\mathrm{C})\}$, Bringing the $\{m_3(\mathrm{A}), m_3(\mathrm{B}), m_3(\mathrm{C})\}$, above experts' assignments into the $m_{DS}(A)$ formula respectively, the fusion probability values of the three states can be found, as shown in Table 6.

4.4. Bayesian network deduction

Using the Bayesian network and conditional probability table constructed above, the software GeNle is used to deduce and obtain the probability of each node variable in the case of forward and reverse deduction, as shown in Figures 5, 6. The probability of each node variable is summarized and compared, as shown in Table 7.

4.5. Deduction results

According to the analysis of the deduction results of the Bayesian network, it is found that the situation of the resilience process of agricultural products cold chain logistics under major public security incidents is from the government's emergency supply of cold chain agricultural products, the government's organization of orderly resumption of production of agricultural products cold chain logistics enterprises, the innovation and development of enterprises and the cold chain logistics of agricultural products into the new normal, with the probability of 91, 75, 64, and 71%, respectively. The results show that the government's emergency supply of cold chain agricultural products is very likely to have occurred, and the government's organization of orderly resumption of production of agricultural products cold chain logistics enterprises, the innovation and development of enterprises and the cold chain logistics of agricultural products into the new normal are developing steadily. It shows that the deduction process is highly consistent with the actual situation in China. According to the specific situation deduction results, the probability of the government's emergency supply of cold chain agricultural products is 91%, indicating that the sudden public security incidents have caused a more significant impact on the cold chain logistics of agricultural products. The government must intervene and guide the industry to effectively deal with the impact and maintain the stable operation of the logistics. In terms of the orderly resumption of work and production of cold chain logistics enterprises of agricultural products organized by the government, due to the problematic epidemic situation abroad, China is facing the dual pressure of "external defense input, internal defense rebound," so the resumption of work and production of cold chain logistics enterprises is still facing intermittent pressure; in the face of enterprise innovation and development, due to the particularity of the industry, agricultural products cold chain logistics enterprises suffered a considerable impact, enterprises are facing pressure to survive. At the same time,

TABLE 6 Conditional probability table after fuzzy set processing.

Node variables	True	False	Node variables	True	False
H_1	1.000	0	M_5		
M_1	True	False	$H_2 = T$	0.8816	0.1184
$H_1 = T$	0.8315	0.1685	$H_2 = F$	0.5839	0.4161
$H_1 = F$	0.0732	0.9268	M_6	True	False
M_2	True	False		0.7174	0.2826
$H_1 = T$	0.9350	0.0650	M_7	True	False
$H_1 = F$	0.6525	0.3475		0.6749	0.3251
C_1 / H_2	True	False	C_2 / H_3	True	False
$M_1 = T, M_2 = T$	0.9626	0.0374	$M_3 = T, M_4 = T, M_5 = T, M_6 = T, M_7 = T$	0.9146	0.0854
$M_1 = T, M_2 = F$	0.8346	0.1654	$M_3 = T, M_4 = T, M_5 = T, M_6 = T, M_7 = F$	0.7767	0.2233
$M_1 = F, M_2 = T$	0.5520	0.4480	$M_3 = T, M_4 = T, M_5 = T, M_6 = F, M_7 = T$	0.7937	0.2063
$M_1 = F, M_2 = F$	0.0090	0.9910	$M_3 = T, M_4 = T, M_5 = F, M_6 = T, M_7 = T$	0.7946	0.2054
M_3	True	False	$M_3 = T, M_4 = F, M_5 = T, M_6 = T, M_7 = T$	0.8471	0.1529
$H_2 = T$	0.9135	0.0865	$M_3 = F, M_4 = T, M_5 = T, M_6 = T, M_7 = T$	0.8045	0.1955
$H_2 = F$	0.1270	0.8730	$M_3 = T, M_4 = T, M_5 = T, M_6 = F, M_7 = F$	0.4450	0.5550
M_4	True	False	$M_3 = T, M_4 = T, M_5 = F, M_6 = T, M_7 = F$	0.5628	0.4372
$H_2 = T$	0.9723	0.0277	$M_3 = T, M_4 = F, M_5 = T, M_6 = T, M_7 = F$	0.5138	0.4862
$H_2 = F$	0.7535	0.2465	…		

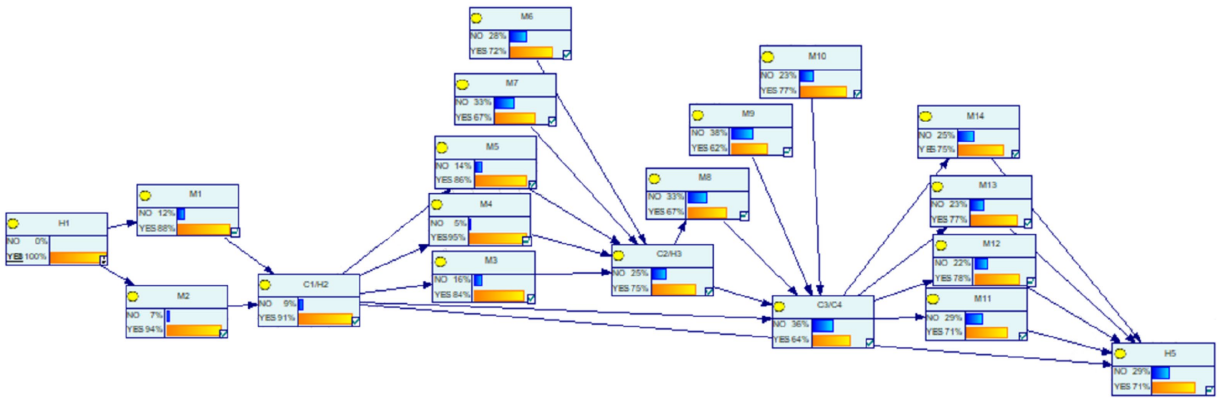

FIGURE 5
Forward inference Bayesian network diagram.

the impact of sudden public safety incidents has not entirely disappeared. The current primary goal of enterprises is stability rather than innovation. Most enterprises choose to maintain the adjusted operation mode. On the other hand, some enterprises are also actively exploring new technologies and operating models to enhance their resilience to sudden public safety incidents after adaptation and adjustment. Therefore, the inference results of the Bayesian network in this paper align with the reality of enterprise development.

Through the analysis of the results of the resilience measures, it can be found that the government tends to adopt the way of ensuring transportation (95%), emergency guarantee mechanism (84%), and state-owned enterprises (86%) to supply cold chain agricultural products urgently. The government prefers the method of government subsidy (77%) in organizing enterprises to resume production. There are still deficiencies in long-term mechanisms such as "building an emergency reserve system (67%)" and "infrastructure construction

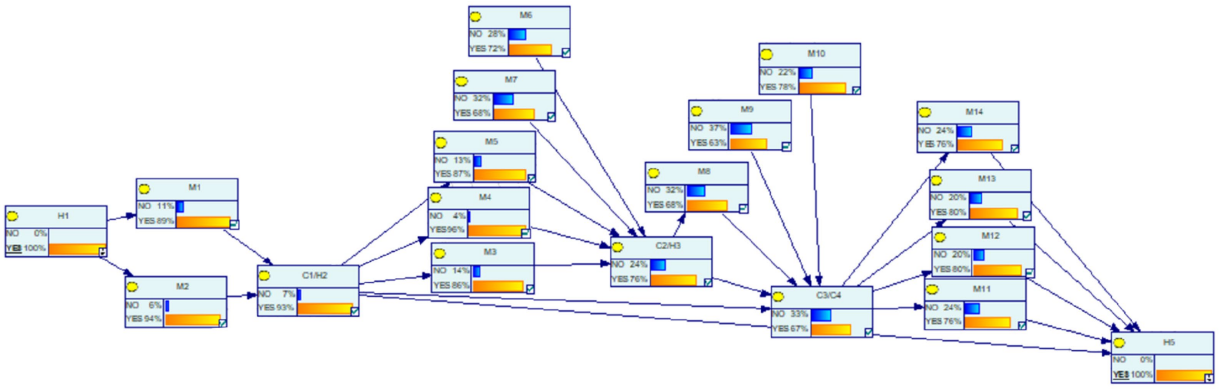

FIGURE 6
Reverse inference Bayesian network diagram.

TABLE 7 Node variable probability table.

Node	True		False		Node	True		False	
	Prior	Posterior	Prior	Posterior		Prior	Posterior	Prior	Posterior
M_1	88%	89%	12%	11%	M_8	67%	68%	33%	32%
M_2	94%	94%	6%	6%	M_9	62%	63%	38%	37%
C_1/H_2	91%	93%	9%	7%	M_{10}	77%	78%	23%	22%
M_3	84%	86%	16%	14%	C_3/H_4	64%	67%	36%	33%
M_4	95%	96%	5%	4%	M_{11}	71%	76%	29%	24%
M_5	86%	87%	14%	13%	M_{12}	78%	80%	22%	20%
M_6	72%	72%	28%	28%	M_{13}	77%	80%	23%	20%
M_7	67%	68%	33%	32%	M_{14}	75%	76%	25%	24%
C_2/H_3	75%	76%	25%	24%	H_5	71%	100%	29%	0%

(62%)." At the level of enterprise measures, enterprises are more inclined to adopt low-input methods such as "flexible supply chain," "multi-collaboration mechanism," and "personnel training" to improve their resilience to public safety emergencies. Due to the uncertainty and economic loss caused by sudden public safety incidents, enterprises adopt conservative innovation strategies such as optimizing stock resources. However, by comparing the prior and posterior probabilities of events, the difference between the two is the largest in enterprise digitization, which indicates that enterprises should properly carry out digital transformation, which is more conducive to improving enterprise resilience.

5. Discussion

This paper first uses the grounding theory to construct the resilience process of cold chain logistics of agricultural products under public safety emergencies and clarifies the research object and scope. Then, the knowledge element model is used to contextualize the resilience process. The Bayesian network and fuzzy set theory are used to construct a contextual deduction model of agricultural product cold chain logistics resilience under public safety emergencies. This study finds that the sustainable development of agricultural cold chain logistics under major public safety events requires not only seeking and relying on multifaceted collaboration between the government and enterprises at all stages and in all aspects but also establishing a timely feedback mechanism to solve the problems in the collaboration and ultimately achieve sustainable development. Research contributions are as follows:

Firstly, this paper summarizes the cold chain logistics management of agricultural products from the perspective of "resilience" and verifies that under the emergency public safety incident, digital transformation, flexible supply chain, diversified collaboration, and other measures are effective methods for the cold chain logistics management of agricultural products. In the existing literature, Huang et al. (2020) studied the real-time emergency management mode of agricultural product cold chain logistics under the background of "Internet +" and concluded that through the information upgrade of cold chain logistics, the circulation loss between nodes could be reduced. The emergency management circulation efficiency of the

supply chain can be improved. Wei and Lv (2019) applies the Internet of Things to the cold chain logistics of agricultural products and establishes an IoT-based logistics distribution system for agricultural products. Complete the real-time supervision of the whole process of agricultural product distribution, strengthen the information communication of each distribution link, and improve the efficiency of agricultural product distribution. However, the conclusions of this paper differ from those of Yan et al. (2021), who argue that technological inefficiencies and facility costs are the most severe risks affecting food loss and waste. This may be because, in recent years, due to the impact of sudden public safety incidents, the development of the industry has been affected by many uncertainties in the short term, and the return on equipment investment is unstable. The use of technology has been affected, and the adoption of digital transformation, flexible supply chain, and other measures can effectively reduce the vulnerability and improve the resilience of agricultural products' cold chain logistics under sudden public safety incidents, thereby improving emergency response capabilities, and improving business conditions in the medium and long term, thereby ensuring the long-term stability of enterprises and people's livelihood.

Secondly, this paper uses the knowledge element model, fuzzy set theory, and Bayesian network to construct a situational deduction model of the resilience process of agricultural product cold chain logistics under public safety emergencies. In the existing research, Cao and Zhang (2020) took the cold chain logistics and distribution system of fresh agricultural products as the research object, analyzed the uncertainties affecting the distribution efficiency, constructed a fault tree model, and transformed it into a Bayesian network, and studied the reliability of the cold chain distribution system. At the same time, Cai and Liu (2018) uses fuzzy set theory and Bayesian networks to analyze the reliability of logistics service supply chain systems. Based on the existing literature, this paper constructs and uses a scenario model to extrapolate the resilience process of agricultural product cold chain logistics under public safety emergencies Xicai and Di (2021).

Finally, the results of the study indicate that government-enterprise cooperation in sustainable agricultural cold chain logistics is widespread, but there are certain efficiency issues in some areas. During major public safety events, the government responds by providing emergency supplies of cold-chain agricultural products, organizing agricultural cold-chain logistics enterprises to resume operations in an orderly manner, and guiding them to innovate and improve sustainable development after the crisis is mitigated. This type of cooperation effectively integrates social resources, enhances the enterprises' crisis response capabilities, and establishes a long-term mechanism for the development of agricultural cold-chain logistics. However, despite these benefits, there are still some issues with government-enterprise cooperation. The study discovered that enterprises were not actively investing in innovation despite the government's call to do so. Rather, they tended to favor low-cost improvement measures that did not significantly improve their logistics capacity.

Due to data limitations and other reasons, there are still some limitations in this paper. Firstly, when summarizing the resilience measures of agricultural cold chain logistics using the rooting theory, this paper only evaluates the general evaluation of the regions where agricultural cold chain logistics has been formed or initially built, and refines them to the level of each region. The measures summarized in this paper have a certain guideline, but still need to be further studied with the specific development status. Second, in the actual situation, the logistics development and requirements of different characteristics of agricultural products are different. Due to the limitation of the length of the article, this paper does not divide the agricultural products. Third, this paper is based on the macro-level extrapolation of the resilience of the cold chain logistics of agricultural products under the sudden public safety events, and the macro-level conclusions may not be able to fully meet the needs of micro-decision-making behavior.

6. Policy implications

Many incidents have proved that the cold chain logistics of agricultural products can effectively withstand the impact of unexpected public safety incidents with resilience. However, the existing articles mainly identify and evaluate the vulnerabilities and risks of agricultural product cold chain logistics and do not study the process of coping with shocks. From the perspective of resilience, our research clarifies the role process of resilience based on a large number of text data related to the resilience of agricultural product cold chain logistics, investigates the development status of agricultural product cold chain logistics resilience, finds out the shortcomings of current development, and has a clear guiding role for the introduction and implementation of policies.

First of all, our results show that the resilience process of agricultural product cold chain logistics consists of a resistance period, adaptation period, readjustment period, and innovation period, which effectively resists the impact of public emergencies and further improves resilience through innovative development. The research results provide reference and guidance for industry policies to improve the resilience of agricultural product cold chain logistics and the impact resistance of agricultural product cold chain logistics in the face of unexpected public safety. In the case of sudden public safety incidents, if the supply and demand sides in the chain cannot take an emergency response that effectively reduces losses, the vulnerability will spread the accident to the entire transportation system, resilience is crucial to the development of the agricultural product cold chain logistics industry (Gao, 2018; Xu et al., 2018). Improving the resilience of agricultural product cold chain logistics can reduce the imperfection and instability of the agricultural product cold chain logistics system itself, making it more stable and efficient in the face of internal and external disturbances in the system, thereby overcoming a series of difficulties and obstacles such as high cost of agricultural product cold chain logistics, low circulation rate, and even broken chain under public emergencies, and ensuring the supply of primary agricultural products for the people.

Secondly, the results also show that in a public safety emergency, governments and enterprises can take joint measures to adopt a diversified and collaborative approach, which can not only effectively improve shock resistance but also further improve resilience through innovation. In the face of major emergencies, the coordinated linkage between the government and the public can maximize the efficiency of the emergency logistics system (Song, 2009; Qianru, 2019). Through the comprehensive cooperation between governments and enterprises at all levels, jointly build a modern agricultural product

cold chain logistics facility network, consolidate the cold chain logistics foundation of agricultural product production areas, open up the production and marketing network of agricultural product cold chain logistics, promote the digital, intelligent and green development of agricultural product cold chain logistics, promote the standardization of agricultural product cold chain logistics, strengthen the supervision of the whole chain of agricultural product cold chain logistics, and guide the government and enterprises to carry out matrix emergency response in real-time according to the needs of emergency events, which can not only obtain higher market competitiveness. It can also improve the resilience of cold chain logistics of agricultural products and ensure the stable supply of agricultural materials.

Finally, our study finds that agricultural product cold chain logistics enterprises still have shortcomings in long-term mechanisms such as "building an emergency reserve system (67%)" and "infrastructure construction (62%)." Companies are more inclined to adopt a low-investment approach to improve their resilience to public safety emergencies. Rapid response logistics systems that enable efficient emergency supply and recovery after significant emergencies are essential to mitigate the impact on affected areas (Sheu, 2007). Through digital transformation, adopting information-sharing and inventory control strategies can help agricultural supply chains recover quickly from disruptions (Mingfei and Xin, 2018). Enterprises should expand investment, take the informatization and intelligence of agricultural product cold chain logistics as the path, carry out the digital transformation of the entire logistics network, and ensure that node information is shared in real-time in the logistics network. Decision-makers use big data artificial intelligence technology to make real-time decisions to achieve efficient emergency response and effectively improve the ability to respond to significant public safety incidents in the future.

7. Conclusion

To scientifically improve the resilience of agricultural cold chain logistics, it is first necessary to clarify the mechanism of resilience. Since there are many participating actors in agricultural cold chain logistics and the wide distribution of space and time, it is difficult to study, and the current research results in this field are relatively scarce. In this paper, the resilience process of agricultural cold chain logistics under public safety emergencies is firstly constructed by using the rooting theory, combining previous research results and relevant data collected, and the research object and scope are clarified. Based on the characteristics of the dynamic evolution of the resilience process, a knowledge meta-model is used to contextualize the resilience process using three elements: resilience events, resilience subjects, and resilience measures, and finally a Bayesian network and fuzzy set theory are applied to create a contextualized model of the resilience process of agricultural cold chain logistics under public safety emergencies. This study fills the gap in the research on the dynamic development of resilience of agricultural cold chain logistics, and provides a new perspective for the long-term sustainable development of agricultural cold chain logistics. In the case of the great uncertainty of the impact of sudden public security events on agricultural cold chain logistics enterprises, the use of this extrapolation model can accurately and scientifically portray the process and results of the resilience of agricultural cold chain logistics, which helps scholars to better explore the resilience of agricultural cold chain logistics under sudden public security events and the mechanism of resilience, and then enhance the resilience and prevent the risk of disruption through scientific decision-making.

The Bayesian network constructed in this paper is an exploratory study of the process of resilience in agricultural cold-chain logistics. Although the findings rely on the expertise of experts and scholars, the research results show that the inferred model is in line with the current development reality. The research results show that, given the current level of development of the resilience of agricultural cold chain logistics, the government, and agricultural cold chain logistics enterprises should strengthen communication and cooperation, jointly build a modern agricultural cold chain logistics facility network, consolidate the foundation of agricultural cold chain logistics at the origin, promote the digitalization, intelligence and green development of agricultural cold chain logistics, and strengthen the supervision of the whole chain of agricultural cold chain logistics. To build a high-quality modern agricultural cold chain logistics system with a reasonable layout, optimized structure, efficient operation, and standardized management, and to provide reference and basis for scientific decision-making by the government and enterprises. The Bayesian network constructed in this paper is an exploratory study of the process of resilience in agricultural cold-chain logistics. Although the findings rely on the expertise of experts and scholars, the research results show that the inferred model is in line with the current development reality. The research results show that, given the current level of development of the resilience of agricultural cold chain logistics, the government, and agricultural cold chain logistics enterprises should strengthen communication and cooperation, jointly build a modern agricultural cold chain logistics facility network, consolidate the foundation of agricultural cold chain logistics at the origin, promote the digitalization, intelligence and green development of agricultural cold chain logistics, and strengthen the supervision of the whole chain of agricultural cold chain logistics. To build a high-quality modern agricultural cold chain logistics system with a reasonable layout, optimized structure, efficient operation, and standardized management, and to provide reference and basis for scientific decision-making by the government and enterprises.

At the same time, this study also has some limitations. The research sample only includes agricultural cold chain logistics enterprises in mainland China, and does not consider the differences of other regions in the world, so it may not be applicable to all agricultural cold chain logistics industries in the world. Finally, through this study, it is found that close cooperation between the government and enterprises has a strong positive effect on the sustainable development of agricultural cold chain logistics, but there are still many shortcomings in the government's guidance of enterprise innovation. This paper does not discuss the relationship and mechanism of innovation input mode and sustainable development of agricultural cold chain logistics. As for the related research on enterprise innovation, government incentives and sustainable development of agricultural cold chain logistics, it still needs further discussion by later researchers.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

YH: conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, visualization, and writing—original draft preparation. ML: writing—review and editing and supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Assessment of consumers' knowledge, attitude and perception of the impact of the COVID-19 pandemic on household food security in Caribbean Small Island Developing States

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Introduction: The COVID-19 pandemic and recent international crises including the Russia-Ukraine conflict have resulted in significant disruptions along multiple segments of the Caribbean's agri-food system, thus compromising regional food security. These impacts are still ongoing with the potential to worsen. The aim of this study was to investigate the influence of sociodemographic factors on consumers' knowledge of food security along with their attitude, and perception towards the impact of the COVID-19 pandemic on household food security in the Caribbean Small Island Developing States.

Method: A cross-sectional on-line survey was conducted between January 1 and November 30, 2021. The sampled population included consumers from nine Caribbean countries (Trinidad and Tobago, Barbados, Jamaica, Antigua and Barbuda, Dominica, Grenada, St. Kitts and Nevis, St. Lucia, and St. Vincent and the Grenadines). Survey data were analyzed using Chi-square, one way analysis of variance, and univariate logistic regression.

Results and discussion: A total of 237 consumers participated in the survey. Consumers were generally knowledgeable about food security and had favorable attitudes and perceptions of the impact of the COVID-19 pandemic on household food security. Significant associations ($p<0.05$) and significant differences ($p<0.05$) were obtained for consumers' knowledge, attitude and perception among the sociodemographic variables assessed. The results suggest that there were different levels of vulnerability to food insecurity associated with the COVID-19 pandemic, particularly among economically vulnerable households. Policies that support disadvantaged households and ensure adequate employment opportunities are important to support Caribbean consumers throughout and post the COVID-19 pandemic recovery.

KEYWORDS

Caribbean, consumer, COVID-19, household food security, sociodemographic factors

Introduction

The definition of food security agreed upon at the World Food Summit held in 1996 is that food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life (Pinstrup-Andersen, 2009). Four dimensions have been identified and understood as necessary conditions for food security to exist namely: (1) availability (is the supply of food adequate); (2) access (can people obtain the food they need); (3) utilization (do people have enough intake of nutrients?); and (4) stability (can people always access food?) (Pinstrup-Andersen, 2009; Saint Ville et al., 2019). The COVID-19 pandemic and the compounding effects of other international crises affected all four pillars of food security. Firstly, loss of income as a result of COVID-19 affected people's ability to purchase food especially in developing regions where almost 70% of earnings are spent on food (Laborde et al., 2020). Additionally, availability and stability were also areas of concern since production and distribution of food were affected globally (CARICOM et al., 2020; Luo et al., 2020; Meuwissen et al., 2021). The issues of food security during the COVID-19 pandemic were of greater concern in developing countries such as Caribbean Island Developing States (CSIDs) due to their heavy reliance on manual labor in agricultural production and restriction to movements imposed by most governments which affected local production of and distribution of foods (Laborde et al., 2020). Kent and Haralambides (2022) reported that supply chain crisis was further compounded by the lack of labor, truck drivers, and even warehousing. Considering the vulnerability of food systems in CSIDs to natural hazards and geopolitical conflicts, an understanding of consumer actions and sociodemographic factors that influence behavior can inform approaches to address food security concerns.

Globalization has resulted in significant interconnectivity and interdependence of various countries, regions, and sectors. This is particularly true for the agricultural sector of Caribbean Small Island Developing States (CSIDs), where importation of inputs is significant with some countries importing over 80% of their food (Mohammadi et al., 2022; Rahman, 2022). Ultimately, this level of external dependence renders CSIDs extremely vulnerable to global shocks. For import dependent countries like CSIDs, international crises especially those associated with major trading partners can have deep repercussions on the economies and people's livelihoods are undoubtedly affected. These scenarios unraveled years of achievements under the sustainable development goals (SDGs) by weakening food systems and undermining regional food security (Bignell, 2022). Globally, the COVID-19 pandemic and the Russia-Ukraine conflict has crippled the global supply of grains and a 40 million metric tonne deficit was projected for 2023 (Glauber, 2023; Janzen and Zulauf, 2023). These concerns were further compounded by a decline in fertilizer supply, particularly from Russia and Belarus, which will negatively impact food production (Behnassi and El Haiba, 2022). Higher energy costs are also expected to exert upward pressure on food prices, potentially pushing millions into acute food insecurity (Behnassi and El Haiba, 2022).

The COVID-19 pandemic also led to a worsening of inequality and the food insecurity gender gap, respectively, with food insecurity among women being 10% higher than among men in 2020 (FAO et al., 2022). According to the 2021 State of Food Security and Nutrition (SOFI), the effect of COVID-19 on food security is palpable and detrimental. For example, in Latin America and the Caribbean region the prevalence of undernourishment increased by 2% or 13.8 million people between 2019 and 2020, which was directly and indirectly influenced by the COVID-19 pandemic (FAO et al., 2021). Given the existing challenges before the pandemic, achieving the UN 2030 Agenda of eliminating hunger is poised to become more complicated, threatening millions of people's food security and nutrition worldwide (FAO, 2021). Among the poorest households, where almost 70% of revenue is spent on food, the pandemic has either directly or indirectly compromised their food security. According to WFP et al. (2021), an estimated 2.8 million people or nearly 40% of the population in the English-speaking Caribbean is food insecure, reflecting a 72% increase when compared to April 2020. The combined effect of the COVID-19 pandemic and the escalation in the Russia-Ukraine conflict along with increasing energy prices, poses a serious concern for developing nations as it relates to food security, particularly CSIDs due to their high level of food imports. Agricultural production decreased, supply chains were compromised, and the cost of key agricultural inputs increased (Behnassi and El Haiba, 2022).

Climate Change and the consequent increase in frequency and intensity of natural hazards is yet another factor impacting global and regional food security. Increasing global temperature is expected to expose the world to further climate hazards and food insecurity, leading to higher poverty levels, especially in vulnerable regions (Pörtner et al., 2022). Among low-income countries, the threat is even greater for those that are susceptible to higher temperatures and lack of fresh water (Kogo et al., 2021). CSIDs are considered to be one of the most vulnerable regions in the world to climate change and variability due to their geographical location and inherent geophysical features. They are particularly vulnerable to hydro-climatic hazards, where floods and drought directly impact quality and quantity of agricultural produce (Roopnarine et al., 2021).

Considering the vulnerability of food systems in CSIDs to natural hazards, pandemics and geopolitical conflicts, an understanding of consumer behavior and sociodemographic factors that influence behavior can inform approaches to address food security concerns. Similar studies have been done in other regions but not among CSIDs. Therefore, this study aimed to investigate the influence of sociodemographic factors on knowledge of food security and attitude and perception in relation to the impact of COVID-19 pandemic on household food security. Noting the uniqueness and inherent vulnerability of food systems in CSIDs, an understanding of consumer behavior, factors influencing their choices, attitudes and their perception of impacts will play a crucial role in developing policies and strategies to improve regional food security.

Methods

Study design and participants

A cross-sectional on-line survey was conducted between January 1 and November 30, 2021, to investigate consumers' knowledge of food security along with their attitudes and perception of food security based on the impact of the COVID-19 pandemic in CSIDs. The

sampled population included consumers from nine Caribbean countries (Trinidad and Tobago, Barbados, Jamaica, Antigua and Barbuda, Dominica, Grenada, St. Kitts and Nevis, St. Lucia, and St. Vincent and the Grenadines). However, for analysis purposes, Antigua and Barbuda, Dominica, Grenada, St. Kitts and Nevis, St. Lucia, and St. Vincent and the Grenadines were treated as one block referred to as the Eastern Caribbean (EC).

Data collection

The survey link was distributed online using various crowdsourcing approaches including direct emails and social media. Convenience sampling and snowball sampling methods were also used where participants were asked to complete the questionnaire and share with their contacts to recruit a large majority of the population, and ensure wide distribution of the survey link. The questionnaire was completed anonymously and with prior online informed consent by consumers. The participants were given no reward or incentive.

Measures

Nine socio-demographic variables were collected, including sex, age category; highest education level attained; country of residence, rurality, household size (number of members living in the household), monthly household income (in United States dollars), employment status and breadwinner status. Additional questions asked respondents to indicate their knowledge of food security by responding "yes" or "no" to a series of statements about the various dimensions of food security (Table 1). Similarly, respondents were asked to give responses to statements geared toward depicting their attitude and perception toward household food security based on the impact of the COVID-19 pandemic (Table 2). These responses were based on a five-point Likert scale (1 - strongly disagree, 2 - disagree, 3 - neutral, 4 - agree, and 5 - strongly agree; Table 2).

Coding and data analysis

Data obtained from the online surveys were numerically coded and then subjected to both descriptive and inferential statistical analysis. Overall knowledge, attitude and perception scores for consumers were determined by using total scores obtained by summating the scores of all statements within respective sections. For the section on knowledge, responses to statements ($n = 10$) were scored as follows: Yes = 2 and no = 1, and the scores were combined to give a score range of 10–20. For the section on attitude, responses to statements ($n = 8$) were scored as follows: Strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, and strongly agree = 5 and the scores were combined to give a score range of 8–40. For the section on perception, responses to statements ($n = 10$) were scored as follows: Strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, and strongly agree = 5 and the scores were combined to give a score range of 10–50.

Next, overall scores in each section were tallied for descriptive purposes and to operationalize each variable. For knowledge, low knowledge ranged from 10–13, fair knowledge ranged from 14–17, and high knowledge ranged from 18–20. Knowledge, represents the respondent's awareness of the different dimensions of food security. For attitude level, very unfavorable attitude ranged from 8–16, unfavorable attitude ranged from 17–24, favorable attitude ranged from 24–32, and highly favorable attitude ranged from 33–40. The assessment of attitude captures respondents feeling toward the four dimensions of food security during the COVID-19 pandemic. With respect to perception, statements were reversed (negatively stated) so that agreement with a negative statement showed unfavorable perceptions toward food security. Accordingly, very favorable perception ranged from 10–20, favorable perception ranged from 21–30, unfavorable perception ranged from 31–40 and very unfavorable perception ranged from 41–50. The perception questions sought to capture respondents' thoughts about food security by encouraging logical thinking based on their experience.

Chi-square tests of association were performed using the ordinal values for knowledge (low, fair, and high), attitude and perception (highly favorable, favorable, unfavorable, and very unfavorable) to examine associations between knowledge, attitude, and perception with the socio-demographic factors. One-way analysis of variance (ANOVA) tests and the associated *post-hoc* test (Tukey's b) were performed using the total tallied score for each respondent to examine significant differences among mean score of knowledge attitude, and perception with the socio-demographic factors as independent variables. Spearman's rank order correlation coefficients were calculated to examine the interrelationships among the socio-demographic factors to select factors for further analysis. Univariate ordinal logistic regression analyses using the ordinal values for knowledge (low, fair, and high), attitude and perception (highly favorable, favorable, unfavorable, and very unfavorable) were performed to predict which sociodemographic

TABLE 1 Consumer knowledge of food security during the COVID-19 pandemic.

Statements	Yes (%)	No (%)
I know that having the ability to purchase food is an aspect of food security	81.2	18.8
I know that having the necessary transport and market infrastructure in place is part of food security	72.9	27.1
I know that domestic production of food is an aspect of food security	85.3	14.7
I know that having the ability to import food contributes to food security	74.6	25.4
I know that providing food aid contributes to food security	72.4	27.6
I know that securing food stocks is part of food security	93.5	6.5
I know that having access to safe food is part of food security	94.7	5.3
I know that changes in weather affect food security	92.9	7.1
I know that political factors which affect the stability of a country affect food security	90.5	9.5
I know that factors that contribute to price fluctuations affect food security	90.0	10.0
Knowledge mean	84.8	15.2

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TABLE 2 Consumers attitudes and perception toward the impact of the COVID-19 pandemic on food security in the Caribbean.

Statements	SD[a]	D[b]	N[c]	A[d]	SA[e]
Attitude					
My household has adequate access to safe and nutritious food despite the COVID-19 pandemic	4.1	7.1	21.2	47.6	20.0
My country has adequate access to safe and nutritious food despite the COVID-19 pandemic	7.6	15.9	38.2	32.9	5.3
My household has enough food stock to last more than 1 month	7.6	25.3	24.7	34.1	8.2
Food prices have increased because of the COVID-19 pandemic	5.9	5.9	21.2	43.5	23.5
My ability to carry out livelihood activities was not affected by the COVID-19 pandemic	23.7	26.6	26	18.9	4.7
My household income has increased due to the COVID-19 pandemic	7.6	15.9	34.1	30.6	11.8
Providing food for me and my family is a high priority during the COVID-19 pandemic	5.3	1.2	20.0	49.4	24.1
I expect that my livelihood will continue to be impacted by the COVID-19 pandemic	5.9	6.5	32.4	41.2	14.1
Mean attitude	8.5	13.1	27.2	37.3	14.0
Perception					
I had difficulty eating enough food because of the COVID-19 pandemic	30.0	47.6	14.7	7.1	0.6
I am eating less preferred food because of the COVID-19 pandemic	18.2	42.9	20.0	16.5	2.4
I buy smaller quantities of food because of the COVID-19 pandemic	21.8	40.0	22.9	12.4	2.9
I purchase cheaper and less preferred foods because of the COVID-19 pandemic	20.0	33.5	23.5	19.4	3.5
I accept food aid because of the COVID-19 pandemic	31.8	36.5	21.8	10.0	0.0
Food stocks at home regularly run out during the COVID-19 pandemic	20.0	36.5	25.3	16.5	1.8
I felt that I was not eating balanced meals because of the COVID-19 pandemic	25.3	34.7	25.9	10.6	3.5
I am more concerned about providing food for my family because of the COVID-19 pandemic	13.5	18.8	28.2	30.6	8.8
I am now producing my own food because of the COVID-19 pandemic	18.2	29.4	26.5	21.8	4.1
My household income decreased because of the COVID-19 pandemic	12.4	26.5	24.1	28.2	8.8
Mean perception	21.12	34.64	23.29	17.31	3.64

[a]Strongly disagree.
[b]Disagree.
[c]Neutral.
[d]Agree.
[e]Strongly agree.

characteristics were associated with higher knowledge of food security and favorable attitude and perception to food security based on the impact of the COVID-19 pandemic. All statistical analyses were conducted using the Statistical Package for Social Sciences software (SPSS v. 28).

Results

Socio demographic characteristics of consumers

The socio-demographic characteristics of respondents are presented in Table 3. Most respondents were female (68.8%), in the age category 25–44 (51.8%), achieved tertiary education (81.2%) and from Trinidad and Tobago (68.2%). The majority lived in urban areas (57.6%), while 51.8% reported that their household size was between 4 and 6 members. In terms of respondent's role in the labor force, most (68.8%) were employed in various categories including private sector (28.8%), government employment (20.6%), and self-employment (19.4%). Some 25.3% of respondents were unemployed, 4.1% were students and 1.8% retired. The majority (67.1%) of respondents were not the main breadwinner of their household.

Consumers' knowledge of food security

With respect to consumer's knowledge of food security, mean frequencies suggested that 84.8% of consumers were knowledgeable of the various dimensions of food security, while 15.2% were not (Table 1). Consumers had highest knowledge with respect to the statements "I know that having access to safe food is part of food security," and "I know that securing food stocks is part of food security." Lowest knowledge was reported with respect to the statements "I know that providing food aid contributes to food security," and "I know that having the necessary transport and market infrastructure in place is part of food security."

Consumers' attitude toward the impact of COVID-19 on food security

The mean frequencies of the overall consumer attitude showed that 51.3% had a positive attitude to food security during the COVID-19 pandemic (37.3 and 14.0% agreed and strongly agreed, respectively, to the statements). Some 21.6% of consumers did not have a positive attitude toward the impact of the pandemic (8.5%

TABLE 3 Sociodemographic characteristics of consumers in the survey ($n = 237$).

Socio-demographic categories	Description	Consumer (%) ($n = 237$)
Sex	Male	31.2
	Female	68.8
Age category (years)	<25	21.2
	25–44	51.8
	45–64	25.9
	≥65	1.2
Level of education	Primary school	0.6
	Secondary school	12.4
	Vocational/technical training	5.9
	Tertiary	81.2
	No formal education	0.0
Country or residence	Trinidad and Tobago	68.2
	Barbados	8.2
	Eastern Caribbean	14.1
	Jamaica	9.4
Rurality	Rural	42.4
	Urban	57.6
Household size (members)	1–3	42.9
	4–6	51.8
	≥7	5.3
Combined monthly household income (USD)	<500	8.2
	500–1,999	30.0
	2,000–3,999	32.4
	4,000–5,999	14.1
	6,000–7,999	6.5
	≥8,000	8.8
Employment status	Government employed	20.6
	Privately employed	28.8
	Self employed	19.4
	Unemployed	25.3
	Student	4.1
	Retiree/Pensioner	1.8
Breadwinner status	Breadwinner	32.9
	Non-breadwinner	67.1

strongly disagreed with the statements and 13.1% disagreed with the statements). Consumers agreed most with the statement "Providing food for me and my family is a high priority during the COVID-19 pandemic" with over 73.5% agreeing or strongly agreeing. Also, over 67% of consumers agreed with the statements "My household has adequate access to safe and nutritious food despite the COVID-19 pandemic" and "Food prices have increased because of the COVID-19 pandemic." The highest disagreement was recorded for the statement "My ability to carry out livelihood activities was not affected by the COVID-19 pandemic" with 26.5% disagreeing and 23.5% strongly disagreeing.

Consumers' perception of the impact of COVID-19 on food security

Most consumers (55.7%) had a positive perception toward the impact of the COVID-19 pandemic on food security and either strongly disagreed (21.1%) or disagreed (34.6%) with the negatively worded statements. Some 20.9% of consumers had a negative attitude toward the impact of the COVID-19 pandemic on food security. The highest level of disagreement was recorded for the statement "I had difficulty eating enough food because of the COVID-19 pandemic" with 47.6% and 30% disagreeing and strongly disagreeing, respectively, with the statement. Most consumers (68.3%) also disagreed with the statement "I accept food aid because of the COVID-19 pandemic."

Associations and relationship with consumers' knowledge scores

Chi-square test of association showed that consumer knowledge was significantly associated with sex (χ^2: 12.99, df: 2, p-value: 0.002), level of education (χ^2: 34.22, df: 6, p-value: <0.001), combined monthly household income (χ^2: 20.97, df: 10, p-value: 0.021) and breadwinner status (χ^2: 20.97, df: 10, p-value: 0.021; Table 4). A significantly greater proportion of female consumers had high knowledge of food security (81.4%) compared to male consumers (63.2%; Table 2). A significantly larger proportion of tertiary graduates had high knowledge of food security (81.9%) compared to consumers with vocational/technical training (78.6%) and high school qualification (40.0%; Table 4). A significantly lower proportion of consumers from the combined monthly household income category of <500 USD had high knowledge of food security (52.6%) compared to the other income categories (Table 4). A significantly greater proportion of non-bread winners had low knowledge of food security (6.7%) compared to breadwinners (0.0%).

ANOVA test revealed that consumers' mean knowledge scores were significantly different based on sex ($F = 15.180$, $p \leq 0.001$), age ($F = 5.198$, $p \leq 0.002$), education level ($F = 19.273$, $p \leq 0.001$), rurality ($F = 5.534$, $p \leq 0.019$) and income level ($F = 3.500$, $p \leq 0.005$; Table 5). Tukey's b *post hoc* test indicated that female consumers had higher mean knowledge level (18.665 ± 0.175) of food security compared to male consumers (17.461 ± 0.255). Consumers in the age category <25 years had a significantly lower mean knowledge score ($17.40 \pm 0.0.288$) compared to those in the age category of 65 years or older which showed the highest mean knowledge score (20.00 ± 1.286). In terms of education, consumers that achieved up to secondary school education had the lowest mean knowledge score (16.18 ± 0.365) which was significantly different from other level of education categories. The results indicated that consumers that reside in rural areas tend to have significantly lower knowledge score (17.89 ± 0.220) of food security compared to those that reside in urban areas (18.59 ± 0.199). Furthermore, consumers from households with combined monthly income of <500 USD had the lowest mean knowledge score (16.26 ± 0.512) which was significantly different to all other household income categories. Consumers' mean knowledge

TABLE 4 Consumers knowledge attitude, and perception proportions by socio-demographic characteristics using Chi-square comparisons.

Sociodemographic categories and descriptions	Knowledge *n* (%)			Attitude *n* (%)				Perception *n* (%)			
	Low	Fair	High	VF	F	UF	VU	VF	F	UF	VU
Sex	χ^2: 12.99, df: 2, *p*-value: 0.002			χ^2: 19.10, df: 3, *p*-value: <0.001				χ^2: 5.83, df: 3, *p*-value: 0.120			
Male	8 (10.5*)	20 (26.3)	48 (63.2)	11 (14.5)	35 (46.1)	24 (31.6)	6 (7.9)	13 (17.1)	44 (57.9)	19 (25.0)	0 (0.0)
Female	3 (1.9)	27 (16.8)	131 (81.4)	8 (5.0)	114 (70.8)	37 (23.0)	2 (1.2)	43 (26.7)	94 (58.4)	23 (14.3)	1 (0.6)
Age category (years)	χ^2: 12.00, df: 6, *p*-value: 0.062			χ^2: 9.09, df: 9, *p*-value: 0.429				χ^2: 17.50, df: 9, *p*-value: 0.014			
<25	5 (8.3)	19 (31.7)	36 (60.0)	2 (3.3)	36 (60.0)	20 (33.3)	2 (3.3)	5 (8.3)	47 (78.3)	8 (13.3)	0 (0.0)
25–44	5 (4.1)	21 (17.2)	96 (78.7)	11 (9.0)	78 (63.9)	27 (22.1)	6 (4.9)	36 (29.5)	59 (48.4)	26 (21.3)	1 (0.8)
45–64	1 (1.9)	7 (13.5)	44 (84.6)	6 (11.5)	32 (61.5)	14 (26.9)	0 (0.0)	14 (26.9)	30 (57.7)	8 (15.4)	0 (0.0)
≥65	0 (0.0)	0 (0.0)	3 (100)	0 (0.0)	3 (100.0)	0 (0.0)	0 (0.0)	1 (33.3)	2 (66.7)	0 (0.0)	0 (0.0)
Level of education	χ^2: 34.22, df: 6, *p*-value: <0.001			χ^2: 10.69, df: 9, *p*-value: 0.298				χ^2: 4.49, df: 9, *p*-value: 0.876			
Secondary School	6 (17.1)	15 (42.9)	14 (40.0)	0 (0)	22 (62.9)	13 (37.1)	0 (0.0)	6 (17.1)	22 (62.9)	7 (20.0)	0 (0.0)
Vocational training	0 (0.0)	3 (21.4)	11 (78.6)	1 (7.1)	8 (57.1)	5 (35.7)	0 (0.0)	1 (7.1)	10 (71.4)	3 (21.4)	0 (0.0)
Tertiary	5 (2.7)	29 (15.4)	154 (81.9)	18 (9.6)	119 (63.3)	43 (22.9)	8 (4.3)	49 (26.1)	106 (56.4)	32 (17.0)	1 (0.5)
Country of residence	χ^2: 9.21, df: 6, *p*-value: 0.162			χ^2: 8.11, df: 9, *p*-value: 0.523				χ^2: 9.08, df: 9, *p*-value: 0.430			
Trinidad and Tobago	6 (3.8)	32 (20.5)	118 (75.6)	9 (5.8)	102 (65.4)	38 (24.4)	7 (4.5)	32 (20.5)	95 (60.9)	28 (17.9)	1 (0.6)
Barbados	2 (10.0)	1 (5.0)	17 (85)	3 (15.0)	11 (55.0)	6 (30.0)	0 (0.0)	6 (30.0)	10 (50.0)	4 (20.0)	0 (0.0)
Eastern Caribbean	2 (4.7)	13 (30.2)	28 (65.1)	4 (9.3)	27 (62.8)	12 (27.9)	0 (0.0)	9 (20.9)	26 (60.5)	8 (18.6)	0 (0.0)
Jamaica	1 (5.6)	1 (5.6)	16 (88.9)	3 (16.7)	9 (50.0)	5 (27.8)	1 (5.6)	9 (50.0)	7 (38.9)	2 (11.1)	0 (0.0)
Rurality	χ^2: 3.63, df: 2, *p*-value: 0.163			χ^2: 5.36, df: 3, *p*-value: 0.147				χ^2: 2.36, df: 3, *p*-value: 0.501			
Rural	5 (4.7)	27 (25.2)	75 (70.1)	5 (4.7)	68 (63.6)	32 (29.9)	2 (1.9)	23 (21.5)	66 (61.7)	17 (15.9)	1 (0.9)
Urban	6 (4.6)	20 (15.4)	104 (80.0)	14 (10.8)	81 (62.3)	29 (22.3)	6 (4.6)	33 (25.4)	72 (55.4)	25 (19.2)	0 (0.0)
Household size (members)	χ^2: 6.63, df: 4, *p*-value: 0.156			χ^2: 14.46, df: 6, *p*-value: 0.025				χ^2: 11.73, df: 6, *p*-value: 0.068			
1–3	7 (6.8)	15 (14.6)	81 (78.6)	12 (11.7)	56 (54.4)	30 (29.1)	5 (4.9)	24 (23.3)	65 (63.1)	13 (12.6)	1 (1.0)
4–6	4 (3.4)	30 (25.4)	84 (71.2)	7 (5.9)	77 (65.3)	31 (26.3)	3 (2.5)	24 (20.3)	67 (56.8)	27 (22.9)	0 (0.0)
≥7	0 (0.0)	2 (12.5)	14 (87.5)	0 (0.0)	16 (100.0)	0 (0.0)	0 (0.0)	8 (50.0)	6 (37.5)	2 (12.5)	0 (0.0)
Combine monthly household income (USD)	χ^2: 20.97, df: 10, *p*-value: 0.021			χ^2: 17.58, df: 15, *p*-value: 0.285				χ^2: 29.19, df: 15, *p*-value: 0.015			
<500	4 (21.1)	5 (26.3)	10 (52.6)	2 (10.5)	8 (42.1)	8 (42.1)	1 (5.3)	2 (10.5)	10 (52.6)	7 (36.8)	0 (0.0)
500–1,999	2 (2.7)	16 (21.3)	57 (76.0)	4 (5.3)	50 (66.7)	15 (20.0)	6 (8.0)	16 (21.3)	40 (53.3)	18 (24.0)	1 (1.3)
2,000–3,999	2 (2.7)	15 (20.5)	56 (76.7)	5 (6.8)	50 (68.5)	17 (23.3)	1 (1.4)	20 (27.4)	49 (67.1)	4 (5.5)	0 (0.0)
4,000–5,999	1 (2.9)	8 (22.9)	26 (74.3)	3 (8.6)	20 (57.1)	12 (34.3)	0 (0.0)	11 (31.4)	15 (42.9)	9 (25.7)	0 (0.0)
6,000–7,999	0 (0.0)	3 (20.0)	12 (80.0)	2 (13.3)	10 (66.7)	3 (20.0)	0 (0.0)	1 (6.7)	14 (93.3)	0 (0.0)	0 (0.0)
≥8,000	2 (10.0)	0 (0.0)	18 (90.0)	3 (15.0)	11 (55.0)	6 (30.0)	0 (0.0)	6 (30.0)	10 (50.0)	4 (20.0)	0 (0.0)
Employment status	χ^2: 10.91, df: 10, *p*-value: 0.364			χ^2: 27.57, df: 15, *p*-value: 0.024				χ^2: 22.08, df: 15, *p*-value: 0.106			
Government employed	0 (0.0)	6 (13.3)	39 (86.7)	3 (6.7)	36 (80.0)	6 (13.3)	0 (0.0)	13 (28.9)	27 (60.0)	4 (8.9)	1 (2.2)
Privately employed	4 (6.0)	13 (19.4)	50 (74.6)	3 (4.5)	46 (68.7)	13 (19.4)	5 (7.5)	12 (17.9)	38 (56.7)	17 (25.4)	0 (0.0)
Self employed	1 (2.3)	11 (25.6)	31 (72.1)	6 (14.0)	20 (46.5)	17 (39.5)	0 (0.0)	17 (39.5)	21 (48.8)	5 (11.6)	0 (0.0)
Unemployed	6 (9.1)	15 (22.7)	45 (68.3)	5 (7.6)	38 (57.6)	20 (30.3)	3 (4.5)	10 (15.2)	44 (66.7)	12 (18.2)	0 (0.0)
Student	0 (0.0)	2 (16.7)	10 (83.3)	2 (16.7)	5 (41.7)	5 (41.7)	0 (0.0)	3 (25.0)	7 (58.3)	2 (16.7)	0 (0.0)
Retiree/ Pensioner	0 (0.0)	0 (0.0)	4 (100)	0 (0.0)	4 (100.0)	0 (0.0)	0 (0.0)	1 (25.0)	1 (25.0)	2 (50)	0 (0.0)
Breadwinner status	χ^2: 6.09, df: 2, *p*-value: 0.048			χ^2: 1.98, df: 3, *p*-value: 0.576				χ^2: 9.03, df: 3, *p*-value: 0.029			
Breadwinner	0 (0.0)	18 (24.3)	56 (75.7)	6 (8.1)	42 (56.8)	23 (31.1)	3 (4.1)	14 (18.9)	39 (52.7)	20 (27.0)	1 (1.4)
Non-breadwinner	11 (6.7)	29 (17.8)	123 (75.5)	13 (8.0)	107 (65.6)	38 (23.3)	5 (3.1)	42 (25.8)	99 (60.7)	22 (13.5)	0 (0.0)

TABLE 5 ANOVA model on the socio-demographic variables on consumers' knowledge of food security and attitude, and perception of the impact of the COVID-19 pandemic on household food security in CSIDs.

Demographic categories and descriptions	Knowledge level (Mean ± SEM*)	Attitude levels (Mean ± SEM)	Perception levels (Mean ± SEM)
Sex			
Male	17.461 ± 0.255b[#]	26.26 ± 0.662	25.28 ± 0.956
Female	18.67 ± 0.1175a	27.05 ± 0.445	24.54 ± 0.644
F	15.180	0.974	0.417
p-value	<0.001	0.325	0.519
Age			
<25	17.40 ± 0.288b	25.69 ± 0.798	26.22 ± 1.159
25–44	18.40 ± 0.202ab	26.85 ± 0.511	24.13 ± 0.741
45–64	18.90 ± 0.309ab	27.39 ± 0.722	25.02 ± 1.048
≥65	20.00 ± 1.248a	32.00 ± 3.387	21.50 ± 4.917
F	5.198	1.648	0.942
p-value	0.002	0.180	0.422
Level of education			
Secondary school	16.18 ± 0.365b	26.05 ± 1.052	26.95 ± 1.518
Vocational training	18.79 ± 0.569a	27.20 ± 1.525	25.70 ± 2.200
Tertiary	18.61 ± 0.155a	26.94 ± 0.410	24.38 ± 0.592
F	19.273	0.342	1.335
p-value	<0.001	0.711	0.266
Country of residence			
Trinidad and Tobago	18.34 ± 0.184	26.82 ± 0.448	25.17 ± 0.642
Barbados	18.25 ± 0.513	28.14 ± 1.291	25.29 ± 1.848
Eastern Caribbean	17.88 ± 0.354	26.79 ± 0.986	24.92 ± 1.411
Jamaica	18.61 ± 0.541	25.56 ± 1.208	21.19 ± 1.729
F	0.584	0.711	1.592
p-value	0.626	0.547	0.193
Rurality			
Rural	17.89 ± 0.220b	26.26 ± 0.567	25.57 ± 0.818
Urban	18.59 ± 0.199a	27.20 ± 0.486	24.18 ± 0.701
F	5.534	1.586	1.656
p-value	0.019	0.210	0.200
Household size (members)			
1–3	18.29 ± 0.226	26.55 ± 0.565	24.58 ± 0.809
4–6	18.21 ± 0.212	26.84 ± 0.514	25.36 ± 0.736
≥7	18.63 ± 0.574	28.56 ± 1.609	20.56 ± 2.303
F	0.242	0.698	2.029
p-value	0.785	0.499	0.135
Combined monthly household income (USD)			
<500	16.26 ± 0.512b	23.93 ± 1.272	28.00 ± 1.840
500–1,999	18.54 ± 0.259a	26.08 ± 0.667	25.86 ± 0.964
2,000–3,999	18.34 ± 0.261a	27.60 ± 0.642	22.98 ± 0.928
4,000–5,999	18.37 ± 0.377a	27.17 ± 0.972	25.12 ± 1.405
6,000–7,999	18.80 ± 0.576a	27.64 ± 1.435	24.27 ± 20.76
≥8,000	18.35 ± 0.499a	27.87 ± 1.229	24.40 ± 1.778

(Continued)

TABLE 5 (Continued)

Demographic categories and descriptions	Knowledge level (Mean ± SEM*)	Attitude levels (Mean ± SEM)	Perception levels (Mean ± SEM)
F	3.500	1.810	1.648
p-value	0.005	0.114	0.150
Employment status			
Government employed	18.84 ± 0.340	27.86 ± 0.812	23.63 ± 1.166
Privately employed	18.18 ± 0.281	26.10 ± 0.686	26.08 ± 0.985
Self employed	18.30 ± 0.342	27.30 ± 0.836	23.27 ± 1.201
Unemployed	17.83 ± 0.281	25.98 ± 0.732	25.93 ± 1.052
Student	18.50 ± 0.658	27.86 ± 1.815	21.00 ± 2.607
Retiree/Pensioner	19.50 ± 1.140	30.00 ± 2.773	25.33 ± 3.982
F	1.334	1.205	1.523
p-value	0.251	0.309	0.185
Breadwinner status			
Breadwinner	18.42 ± 0.266	26.46 ± 0.645	25.93 ± 0.929
Non-breadwinner	18.20 ± 0.180	26.97 ± 0.452	24.20 ± 0.648
F	0.448	0.418	2.336
p-value	0.504	0.519	0.128

*SEM, Standard error of the mean.
[#]Values within sociodemographic category that share the same letters along the column are not significantly different.

TABLE 6 Correlation matrix of socio-demographic variables.

		A	B	C	D	E	F	G	H	I
A	Age	1.00								
B	Sex	0.08	1.00							
C	Country of Residence	−0.08	−0.18	1.00						
D	Rurality	0.06	0.10	−0.17	1.00					
E	Education	−0.08	0.15	−0.06	0.14	1.00				
F	Employment status	−0.27	0.04	−0.08	0.04	−0.03	1.00			
G	Household size (members)	−0.05	0.23	−0.28	−0.03	−0.01	−0.04	1.00		
H	Breadwinner status	−0.30	0.24	0.00	−0.04	0.11	0.38	0.21	1.00	
I	Monthly household income (USD)	0.09	0.00	−0.16	0.13	0.07	0.00	−0.07	0.15	1.00

scores did not significantly differ with country of residence, household size, employment status and breadwinner status.

Sociodemographic variables were not strongly correlated and attempts to include all in the univariate ordinal logistic analysis were unsuccessful (Table 6). However, seven of the nine variables were successfully included and three of those variables including sex, level of education, and combined household income were found to be significantly associated with knowledge levels of consumers (Table 7). The odds of a consumers having higher knowledge level of food security were 2.5 times lower for male consumers compared to female consumers. The odds of having higher knowledge level were 0.9 time lower for consumers with secondary school education when compared to tertiary graduates (Table 7). Consumers from households with a combined monthly income of <500 USD were 0.2 times less likely to have a higher knowledge score of food security compared to consumers from the category >8,000 USD (Table 7).

Associations and relationship with consumers' attitude and perception

Chi-square test of association showed that consumers' attitude was significantly associated with sex (χ^2: 19.10, df: 3, *p*-value: <0.001), household size (χ^2: 14.46, df: 6, *p*-value: 0.025), and employment status (χ^2: 27.57, df: 15, *p*-value: 0.024; Table 4). Higher proportion of females had favorable attitude toward food security (70.8%) compared to male consumers (46.1%). A greater proportion of consumers from households with 1–3 members have an unfavorable and very unfavorable attitude toward food security (29.9 and 4.9%, respectively) compared to those from household seven or more members (0%; Table 4). A higher proportion of government employees had favorable attitude toward food security (80%) compared to self-employed consumers (46.5%; Table 4).

TABLE 7 Results of univariate ordinal logistic model for consumers' knowledge, attitude, and perception of the impact of COVID-19 on food security in the Caribbean.

Sociodemographic categories and descriptions	Knowledge			Attitude			Perception		
	β	OR	95% CI	β	OR	95% CI	β	OR	95% CI
Sex									
Male	−1.38	0.25	−2.20 to −0.565 *	0.10	1.11	−0.64 to 0.84	0.34	1.41	−0.37 to 1.06
Female	Ref			Ref			Ref		
Age category (years)									
<25				0.56	1.74	−3.00 to 4.11	1.35	3.87	−1.95 to 4.65
25–44				0.20	1.22	−3.26 to 3.66	0.85	2.35	−2.35 to 4.06
45–64				0.05	1.05	−3.42 to 3.51	0.46	1.58	−2.74 to 3.65
≥65				Ref			Ref		
Level of education									
Secondary School	−2.45	0.09	−3.40 to −1.50 *	0.38	1.47	−0.63 to 1.39	0.26	1.29	−0.74 to 1.25
Vocational training	0.20	1.22	−1.58 to 1.98	0.05	1.05	−1.40 to 1.49	0.56	1.76	−0.82 to 1.95
Tertiary	Ref.			Ref			Ref		
Country of residence									
Trinidad and Tobago	−1.70	0.18	−3.50 to 0.10	0.08	1.08	−1.16 to 1.32	1.63	5.11	0.37–2.89*
Barbados	−2.10	0.12	−4.36 to 0.16	−0.48	0.62	−2.16 to 1.20	1.65	5.18	0.002–3.29*
Eastern Caribbean	−1.93	0.15	−3.97 to 0.11	−0.54	0.58	−2.09 to 1.02	1.30	3.67	−0.24 to 2.84
Jamaica	Ref			Ref			Ref		
Rurality									
Rural	0.73	2.06	−0.32 to 1.78	0.44	1.55	−0.26 to 1.14	−0.14	0.87	−0.81 to 0.54
Urban	Ref			Ref			Ref		
Household size (members)									
1–3	−1.86	0.16	−3.77 to 0.06*	0.89	2.43	−0.75 to 2.53	1.36	3.89	−0.22 to 2.93
4–6	−2.52	0.08	−4.41 to −0.64*	0.76	2.13	−0.86 to 2.38	1.90	6.71	0.34–3.47*
≥7	Ref			Ref			Ref		
Combine monthly household income (USD)									
<500	−3.98	0.02	−6.01 to −1.95 *	0.76	2.14	−0.94 to 2.47	1.46	4.30	−0.22 to 3.13
500–1,999	−1.06	0.35	−2.76 to 0.63	0.34	1.40	−0.98 to 1.65	0.67	1.96	−0.59 to 1.93
2,000–3,999	−0.81	0.45	−2.52 to 0.90	0.02	1.02	−1.27 to 1.31	−0.45	0.64	−1.68 to 0.78
4,000–5,999	−1.55	0.21	−3.31 to 0.21	0.34	1.41	−1.09 to 1.77	0.42	1.53	−0.95 to 1.79
6,000–7,999	−1.00	0.37	−3.15 to 1.16	−0.13	0.88	−1.84 to 1.58	0.31	1.36	−1.30 to 1.91
≥8,000	Ref			Ref			Ref		
Employment status									
Government employed				0.37	1.45	−2.52 to 3.26	−0.58	0.56	−3.22 to 2.07
Privately employed				0.72	2.06	−2.15 to 3.59	−0.53	0.59	−3.16 to 2.09
Self employed				1.06	2.89	−1.78 to 3.90	−0.77	0.46	−3.37 to 1.82
Unemployed				0.86	2.35	−2.06 to 3.77	−0.54	0.59	−3.21 to 2.14
Student				1.36	3.90	−1.94 to 4.67	−0.56	0.57	−3.64 to 2.51
Retiree/Pensioner				Ref			Ref		
Breadwinner status									
Breadwinner	0.74	2.09	−0.28 to 1.75	0.40	1.49	−0.44 to 1.23	0.81	2.24	−0.01 to 1.62*
Non-breadwinner	Ref			Ref			Ref		

β - Estimate. *Significant at the 5% level ($p < 0.05$). Ref, Reference category.

In terms of perception, Chi-square test of association showed that consumers' perception was significantly associated with age (χ^2: 17.50, df: 9, *p*-value: 0.014), combined monthly household income (χ^2: 29.19, df: 15, *p*-value: 0.015) and breadwinner status (χ^2: 9.03, df: 3, *p*-value: 0.029) (Table 4). A significantly higher proportion of consumers in the age category <25 years old had a favorable perception of food security (78.3%) compared to those consumers who were between 45–65 years old (57.7%). Additionally, a significantly higher proportion of consumers in the 25–44 age category had a highly favorable perception compared to those in the age category <25 years old. (8.3%). A significantly lower proportion of consumers from households with combined monthly income of 2,000–3,999 USD had an unfavorable perception (5.5%) compared to those in the income categories <500 USD (36.8%), 500–1,999 USD (24.0%) and 4,000–5,999 USD (25.7%) (Table 4). A significantly higher proportion of breadwinners had an unfavorable perception of the COVID-19 pandemic impact on food security (27%) compared to non-breadwinners (13.5%) (Table 4).

ANOVA tests indicated that consumers' mean attitude and mean perception scores were not significantly different for any of the socio-demographic variables evaluated (Table 4). All nine socio-demographic variables were successfully included in the univariate ordinal logistic regression model for both attitude and perception (Table 7). None of the socio-demographic variables were found to be significantly associated with attitude. However, three sociodemographic variables including country of residence, household size and breadwinner status were all significantly associated with perception. The odds of consumers having a more favorable perception of food security was 5.11 times higher for consumers from Trinidad and Tobago, 5.18 times higher for consumers in Barbados and 3.67 times higher for consumers in the Eastern Caribbean compared to the reference category Jamaica (Table 7). With respect to household size (members) the odds of consumers having a favorable perception was 3.89 times higher for consumers from households with 1–3 members and 6.71 time higher for consumers from households with 4–6 members compared to the reference category of households with 7 or more members (Table 7). Based on breadwinner status, the odds of a consumer having a favorable perception was 2.24 times higher for those consumers who were the breadwinner of their families (Table 7).

Discussion

The COVID-19 pandemic presented unprecedented challenges to food systems and food security across the globe. Many feared that there would be an increase in food insecurity which would be expected to affect the most vulnerable consumers in society. These factors were also likely to affect consumers food purchasing behavior, meal preparation and eating habits. Several reports and commentaries suggested that the pandemic impacted food dynamics in the Caribbean region and an understanding of this among consumers is critical to developing approaches toward achieving food and nutrition security (Blazy et al., 2021; CARICOM et al., 2021; Marshall et al., 2021; Daley et al., 2022). The Caribbean COVID-19 Food Security and Livelihoods Impact Survey reported that food insecurity remains a concern, with many consumers having to reduce their food consumption and average household food stocks continued to decrease (CARICOM et al., 2021). However, the extent of these impacts and the dynamics among Caribbean consumers have not been investigated. This study investigated how various sociodemographic factors influenced consumers knowledge of food security along with their attitude, and perception of the impact of the COVID-19 pandemic on household food security in the CSIDs.

The results of this study indicated that overall, Caribbean consumers were very knowledgeable of the dimensions of food security. However, it was clear that the COVID-19 pandemic impacted food access, availability, utilization, and stability. The majority of respondents had favorable attitude and perception in relation to the impact of COVID-19 on food security. This could be due to the fact that although measures were put in place to protect public health which resulted in reduced economic activity with negative impacts on production, distribution and consumption, there was a surge in e-commerce and accelerated digital transformation (Deconinck et al., 2020; Sneader and Singhal, 2021). Although it is true that negative effects were not felt equally across all sociodemographic categories and some persons were more vulnerable than others, the overall pictures point to a region were consumers responded to the COVID-19 pandemic in various ways to maintain their household food security (Daley et al., 2022). Recent studies showed that panic buying, food hoarding, and home gardening were some of the activities that increased because of the COVID-19 pandemic and may have increased consumer knowledge of the dimensions of food security (Blazy et al., 2021; Daley et al., 2022).

In term of sex or gender, female consumers generally had higher knowledge of food security than their male counterparts. However, it is also noteworthy that this study had a higher proportion of females, which coupled with the relatively small sample size of the study could introduce some bias in the analysis. Nevertheless, the odds ratio indicated that male consumers were 0.25 times more likely to fall into a lower knowledge category than female consumers although there were no significant differences in attitudes and perceptions between males and females based on odds ratio. Other studies also reported sex or gender differences relating to knowledge and other aspects of food security. A previous study done in Latin America and the Caribbean reported that female and non-binary genders were found to have higher food insecurity compared to males (Benites-Zapata et al., 2021). This higher risk of experiencing food insecurity was likely a major factor that caused female consumers to become more aware of issues of food security. In Caribbean societies, females tend to have a greater commitment to unpaid family and household work (Pastore et al., 2021). This commitment and desire to improve the wellbeing of their family or household, as well as lower aversion to risk, likely translate into having more concern and awareness of food security issues. These qualities may also cause female consumers to take greater precaution when it comes to securing household food security. Similar sex and gender discordance have been reported in studies looking at household food security. Wang et al. (2020) reported that because females were more risk averse, they were more likely to reserve larger scale food reserves than males when it comes to food security in China. A study that looked at the role of cash transfers in enhancing food security in South Africa reported that food insecurity decreases in households headed by males compared to households headed by females, which also consume less food (Mncube et al., 2023). Similarly, Ganpule et al. (2023) reported that female headed households, especially among rural areas in north and south India experienced significantly higher food insecurity than their male counterparts,

which could be linked to inequities such as access to lower amount of food and lower consumption of nutrient rich food.

The results of this study showed that consumers that were in the age category <25 years old had significantly lower knowledge of food security than consumers ≥65 years old. These were the youngest and the oldest age categories used in the survey. Although the association between age and knowledge level was not significant, there was a low proportion of consumers with high knowledge in the <25 years old category. It was hypothesized that older consumers, because of more experience and increased responsibilities were likely to be more knowledgeable and have more favorable attitudes and perceptions to food security. However, analyzing the knowledge, attitude and perception levels among age categories can be very complicated because many other socio-economic factors could influence individuals. Nevertheless, the results of this study showed similar inferences to a previous study conducted in the Caribbean where an increasing age was associated with a lower prevalence of food insecurity (Benites-Zapata et al., 2021). In northern Italy, a study investigating the effects of the imposed lockdown on food insecurity and other factors reported that parents' of higher age (over 50) was protective against food insecurity (Dondi et al., 2021). Similarly, an online survey performed between May and June on adults living in Tasmania, Australia also found that increasing age was protective against food insecurity (Kent et al., 2020).

Several studies found that education positively contributed to food security or was a protective factor against food insecurity of households (Abu and Soom, 2016; Kent et al., 2020; Getaneh et al., 2022). This is based on the premise that with higher education, individuals will be able to improve their productivity or have access to better employment opportunities in the labor market (Maharjan and Khatri-Chhetri, 2006; Abu and Soom, 2016). Education is also considered to be a means for food security improvement because educated individuals are more likely to practice family planning programs resulting in smaller family size with more manageable food demands (Getaneh et al., 2022). The results of this study showed that consumers with secondary school education had significantly lower knowledge of food security compared to consumers with vocational or tertiary training and respondents from smaller households had a more favorable perception of the impact of COVID-19 on food security. Furthermore, there were significantly higher proportions of tertiary and vocational training graduates with higher knowledge of food security compared to high school graduates. There were no significant associations between education and attitude or perception, nor was there any correlation between education level and any of the other sociodemographic variables. Nevertheless, from the assessment of consumer knowledge, the findings of this study shows agreement with those reported by Kent et al. (2020) where it was reported that respondents with a diploma or high-school qualification showed a two-fold increase in the odds of experiencing food insecurity compared to those with a university-level education (Bachelor's degree or higher). From the current study, secondary school graduates had a 9% odds of falling into a lower knowledge category compared to tertiary trained graduates (Table 7). Lack of education has also been recognized as a barrier to healthy food choices that prevent some consumers from purchasing foods according to their values (Kneafsey et al., 2013).

Other studies have reported differences in response to food security based on rurality and the present study contributes to this area. In this study, consumers from urban areas had a significantly higher knowledge of food security compared to consumers from rural areas, although there were no significant differences in attitudes and perception and there were no significant associations. The results of this study suggest that urban consumers may have greater awareness of issues regarding the availability and access to food, especially during the COVID-19 pandemic. This may be as a consequence of stronger enforcement of restrictions on movement in urban areas compared to rural areas where there is generally less pressure or concern for food security, since most agricultural activities are conducted in rural areas (Connors et al., 2021; Huang et al., 2021). A study in France suggested that living in rural areas was a protective factor against the COVID-19 pandemic as those persons generally had better social support, greater family presence, less frequent feeling of imprisonment, had a garden, fewer depressive symptoms and lower anxiety scores (Pérès et al., 2021). Our results may also be interpreted in the context of a study done by Roy-Macauley (2002) which found that rural people strive to feed themselves while the urban population spends more than 70% of its earnings on food, leaving only 30% for other minimum basic needs such as housing, education, healthcare, water and livelihoods, which in a pandemic may cause greater concern over food security. Abu and Soom (2016) also reported that the high cost of food items was not significant in the rural areas with low loading, implying that rural people spent less on food items. On the other hand, other studies have reported higher levels of food insecurity among rural populations. Kent et al. (2020) reported that during the COVID-19 pandemic in Tasmania, Australia, reduced access to food and fewer shops in rural areas coupled with media reports of price gouging of foods in response to increased demand, may have infringed upon the ability of rural residents to buy enough healthy food to meet their needs. Furthermore, in Latin America and the Caribbean, Benites-Zapata et al. (2021) reported that higher food insecurity in rural areas may be related to the predominance of informal businesses and situations of extreme poverty in these areas, despite having easier access to self-produced food during the COVID-19 pandemic.

Household income is one of the most consistent and often the strongest predictor of food insecurity reported in published literature (Abu and Soom, 2016; Kent et al., 2020; Benites-Zapata et al., 2021). In this study, consumers in the lowest income category having a combined monthly household income of <500 USD showed the lowest knowledge of food security. This group was also significantly underrepresented in terms of high knowledge of food security, and they also had a significantly higher proportion of highly unfavorable perception of the impact of the COVID-19 pandemic on household food security. Our results also showed that there was a significant 2% odds of this group falling into a lower knowledge category when compared to consumers from households with combined monthly income of ≥8,000 USD. Closely related to household incomes are employment and breadwinner status. In the present study, government employed consumers had favorable attitudes to the impact of the COVID-19 pandemic on household food security compared to self-employed consumers. This may be a direct relation to the fact that while many self-employed consumers lost some or all of their income stream due to the lockdown restriction measures imposed, government employees in the sampled countries continued to receive their salaries although in many cases they had to work from home (Mulder, 2020). Breadwinners have the responsibility of ensuring that their family has sufficient food. This responsibility may have contributed to their higher level of unfavorable perceptions of the COVID-19 impact on household

food security. These results combined may be indicative of higher vulnerability to food security among lower income households as well as higher income as a protective factor against food insecurity during the COVID-19 pandemic.

Loss of income was also very widespread during the pandemic because of the restriction imposed in many countries that prevented people from going out to their jobs (Eriksson et al., 2020; Huang, 2020; Sharma et al., 2020). Loss of income not only reduces the amount of money available for food, but it forces people to change their lifestyle including eating less preferred food which is an important part of food security. A recent study in the Caribbean showed over 25.5% of consumers in the study experienced loss of income which was significantly more associated with poorer families and smaller businesses (Daley et al., 2022). The findings of our study is congruent with other studies from other countries and regions. Kent et al. (2020) reported that in Tasmania, Australia, household income was independently associated with food insecurity, with incomes above AU$80,000/year seemingly protective against food insecurity, and incomes below AU$40,000 per year associated with a two-fold increase in the odds of food insecurity during the COVID-19 pandemic. In the same study, food insecurity was not limited to only those on low incomes, but loss of income at any level above 25% contributed to substantially higher odds of experiencing food insecurity (Adesiyun et al., 2014). In another study which sought to estimate the prevalence of moderate to severe food insecurity (MSFI) in Peru, the authors reported that people with low income (<255 US$/month) before the COVID-19 pandemic as well as those whose income was significantly reduced during the pandemic period were more likely to experience MSFI (Cañari-Casaño et al., 2021). Dondi et al. (2021) from their study in Italy, concluded that household food insecurity was increasing in the early months of the COVID-19 pandemic even among wealthier areas but persons with lower income and disposable means were especially at risk. They further reported that weight gain and pediatric obesity are strictly linked to food insecurity among low-income groups (Dondi et al., 2021). This may be indicative of unhealthier food choices which are likely associated with loss of income. Being able to access healthy preferred food is an important part of food security and the inability to do so may contribute to higher incidences of non-communicable diet related diseases. This is usually a problem among lower income households because healthier diets are generally more costly. A study conducted in Trinidad and Tobago in 2017 before the COVID-19 pandemic reported that the cost of improving diets to ensure compliance with the Institute of Medicine (IOM) standards was approximately 45 US dollars per month or 540 US dollars per year which represents a substantial cost especially for larger families (Rocke et al., 2017). Considering the rise in inflation and socioeconomic issues associated with COVID-19, this situation may worsen and could cause increases in chronic non-communicable diseases which are already major contributors to illnesses and death throughout the Caribbean (Alcaraz et al., 2023; Alleyne et al., 2023; Cunningham-Myrie et al., 2023).

Conclusions and recommendations

Assessment of the sociodemographic factors that influence consumer knowledge of food security and their attitude and perception to the impact of the COVID-19 on household food security in CSIDs is important to help develop effective data driven decision making and interventions for pandemics and other international crises. Given the current global geopolitical and economic conditions, these crises are likely to occur more frequently and will have significant impacts on countries or regions with high import dependency. Continued monitoring of those factors that affect food security is also needed to support complete recovery from the COVID-19 pandemic especially given the compounding effects of other current international crises including the ongoing Russia-Ukraine conflicts.

The results of this study indicate that overall, Caribbean consumers were knowledgeable about food security and its various dimensions. Despite most consumers having favorable attitudes and perceptions toward the impact of the COVID-19 pandemic on household food security, there were significant associations with sociodemographic variables and differences in the odds of experiencing food insecurity which suggest different levels of vulnerability among consumers in the CSIDs. Male consumers were more likely to have lower knowledge of food security than female consumers. As expected, tertiary graduates were more likely to have higher knowledge of food security than respondents of lower education background. Consumers of low economic status were more likely to have lower knowledge of food security than consumers of high economic status. Furthermore, the results of this study showed that consumers residing in Jamaica were likely to have a lower perception of the impacts of COVID-19 compared to respondents from other countries covered in the survey. Additionally, smaller households were more likely to have a more favorable perception of the impact of the COVID-19 pandemic. The response measures instituted by governments, non-governmental and private sector organizations should consider these differences and variations among respondents to improve the efficiency and effectiveness of the measures implemented. Therefore, this study contributes to a better understanding of the nature of food security and consumer demographics in CSIDs. It also highlights some of the major factors to be considered for crises intervention.

Limitations

The results must be understood within the context of some limitations. Firstly, this was a cross-sectional study, and the outputs were descriptive, and inferences were limited by study design, sample size and statistical methods used. The use of online recruitment tools has inherent limitations such as the need for participants to be literate and have internet access. Because of this, the use of online surveys may have excluded some groups or limited the number of respondents from some sociodemographic categories. There was a notably higher proportion of female to male respondents and a relatively small number of respondents. These are not reflective of the proportion in the general population and could have introduced biases which may impact the interpretation of the results obtained. Furthermore, the timing of the survey may have had an impact on respondents' views and their views may be different if they had a longer time to reflect on their responses or had face-to-face interactions with surveyors. This likely impacted respondents' attitudes and perceptions to the stated issues. Therefore, the findings presented should not

be generalized, but rather taken in the context of consumers in the sampled countries and sociodemographic categories who had access to the various online resources used to collect data. It is recommended that future studies should use a combination of methods for data collection. Furthermore, these studies should also explore the effectiveness of intervention strategies and ways to reorganize and build resilience in the food systems of CSIDs.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by The University of the West Indies. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

OD and W-AI conceived and developed the questionnaire. OD, W-AI, AJ, and RR conducted the surveys. OD and DP performed quantitative analysis. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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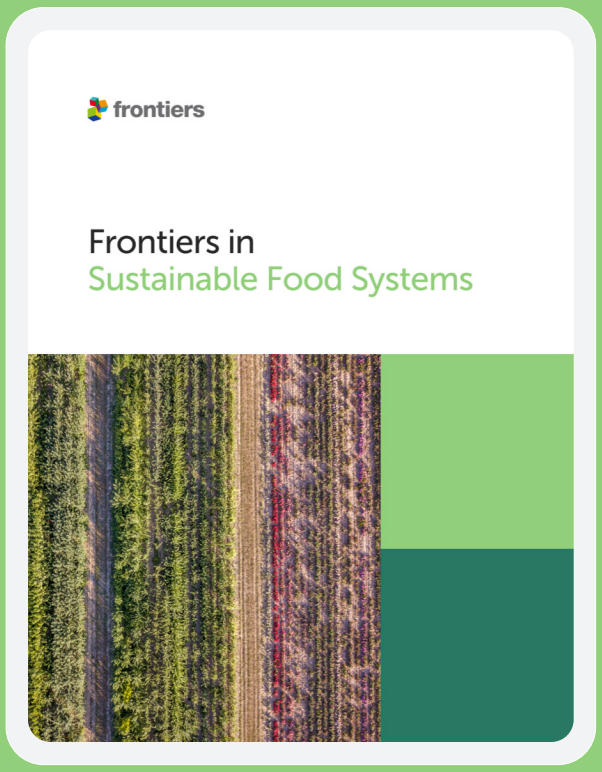

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