International Journal of Food Science +Technology

Institute of Food Science +Technology ifst

Check for updates

International Journal of Food Science and Technology 2024

Original article

Surviving the storm: navigating the quadruple whammy impact on Europe's food supply chain

Sandeep Jagtap,[1,2]* Hana Trollman,[3] Frank Trollman,[4] Guillermo Garcia-Garcia[5] & Wayne Martindale[6]

1 Division of Engineering Logistics, Department of Mechanical Engineering Sciences, Faculty of Engineering, Lund University, Lund 22363, Sweden
2 Sustainable Manufacturing Systems Centre, School of Aerospace, Transport and Manufacturing, Cranfield University, Cranfield MK43 0AL, UK
3 School of Business, University of Leicester, Leicester LE1 7RH, UK
4 Royal Derby Hospital, Uttoxeter Rd, Derby DE22 3NE, UK
5 Department of Chemical Engineering, Faculty of Sciences, University of Granada, 18071 Granada, Spain
6 Food Insights and Sustainability, National Centre for Food Manufacturing, University of Lincoln, 2 Peppermint Way, Holbeach PE12 7FJ, UK

(Received 6 February 2024; Accepted in revised form 18 March 2024)

Summary This article explores the impact of the 'Quadruple Whammy' consisting of Brexit, COVID-19, Conflicts (Russia-Ukraine and Israel-Palestine) and Natural disasters on the food supply chain in Europe. This research adopted a two-phase methodology comprised of the e-Delphi technique followed by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach within the context of these four identified challenges. The objective of this article is to analyse the challenges faced by the European food supply chain due to these four factors. The article examines the impact of political isolationism such as Brexit on trade, cost and border controls, while also discussing the effects of COVID-19 on labour, supply chains and the rise of e-commerce. In addition, the article examines the impact of conflicts on food access and availability and the role of international aid and assistance. The effects of natural disasters, such as the Turkish and Moroccan earthquakes, floods in Spain and Portugal and the Moroccan drought, on food security are also analysed. The article offers several strategies for taming the quadruple whammy, such as investing in local food production and supply chains, diversifying supply chains and trade partnerships and strengthening food safety regulations and standards. The importance of building resilience and preparedness in the face of these challenges is emphasised and the article concludes with final thoughts and recommendations.

Keywords Brexit, conflicts, COVID-19, food security, food supply chain, Israel-Palestine, natural disasters, political isolationism, Russia-Ukraine.

Introduction

In recent times, Europe has faced an unprecedented challenge that can be described as a 'Quadruple Whammy'. This extraordinary set of events includes the aftermath of political isolationism such as Brexit (Mahfouz *et al.*, 2019), the global COVID-19 pandemic (Aday & Aday, 2020), a series of natural disasters (e.g. earthquakes, floods, droughts) (Reddy *et al.*, 2016) and the ongoing Russia–Ukraine and Israel–Palestine conflicts (Jagtap *et al.*, 2022; Pache, 2024). Apart from conflicts, terrorism, migration, protectionism and social and economic inequalities, these challenges have created significant issues for the stability, resilience and security of European food supply chains (Lund *et al.*, 2020). Furthermore, when combined, they create a complex and multifaceted crisis which demands a thorough analysis.

The decision of the UK to leave the EU in 2016, commonly referred to as Brexit, initiated a series of economic and political repercussions (Khan, 2023). The trade disruptions, regulatory adjustments and changes in supply chains resulting from Brexit have posed a considerable challenge to Europe's ability to maintain a seamless flow of goods, especially food, across its member states (Moradlou *et al.*, 2021). It has given rise to food fraud and raised doubts about food authenticity

*Correspondent: E-mail: sandeep.jagtap@tlog.lth.se

doi:10.1111/ijfs.17106

(Brooks *et al.*, 2021). While the UK and European partners reached a trade agreement, the full implications of this monumental shift are still unfolding (Diamond & Richardson, 2023).

The outbreak of the COVID-19 pandemic in late 2019 had profound effects on global food supply chains (Naja & Hamadeh, 2020). Lockdowns, travel restrictions and disruptions to labour forces created bottlenecks in the production and distribution of goods (Ijaz *et al.*, 2021). The food supply chain, in particular, faced disruptions as the pandemic strained logistics, labour availability and demand patterns (Chari *et al.*, 2022). Although the fight against COVID-19 has brought some relief, the pandemic's long-term effects linger, including shifts in consumer behaviour and the need for ongoing health and safety precautions (Antwi *et al.*, 2021).

The ongoing conflicts between Russia and Ukraine and Israel and Palestine have escalated into full-scale confrontations (European Parliament, 2022; ACLED, 2023). These crises have geopolitical implications that extend far beyond the immediate regions. For Europe, these conflicts have disrupted energy (natural gas) and food supplies and have raised concerns about the security of supply routes that traverse the affected areas (Jagtap *et al.*, 2022; Amicarelli *et al.*, 2023; Hamulczuk *et al.*, 2023). Additionally, the EU has imposed sanctions on Russia, further complicating trade relations.

Europe has experienced a rising frequency and severity of natural disasters, including wildfires, floods, droughts and extreme weather conditions, together with damaging earthquakes in neighbouring countries such as Turkey and Morocco (Chaudhary & Piracha, 2021; Diaconu & Grecu, 2023). These events disrupt agriculture, damage infrastructure and consequently strain food systems. Climate change exacerbates these challenges, making it increasingly important for Europe to adapt to more frequent and severe environmental disruptions (Mirón *et al.*, 2023; European Environment Agency, 2024).

This article addresses the combined impact of four major challenges, termed a 'Quadruple Whammy', on European food supply chains: political isolationism (events such as Brexit), the COVID-19 pandemic, international conflicts (Russia–Ukraine and Israel–Palestine) and natural disasters. Understanding these challenges' effects is critical as they jeopardise food security, jobs and the economic well-being of millions of Europeans. This study aims to assess vulnerabilities, analyse policy responses, forecast future scenarios and provide recommendations for enhancing the resilience of the European food supply chain. We define the scope of our study within the context of these four challenges and acknowledge potential limitations in data availability and the evolving nature of the issues. We drew on economic and policy theories to analyse the impact of external shocks on supply chains. We employed e-Delphi and PRISMA methods to identify, review and then discuss these four challenges. The article is organised as follows: after this introduction, we delve into the methodology, followed by an examination of the vulnerabilities in the food supply chain. Subsequently, we analyse policy responses, forecast future scenarios and conclude with recommendations.

Methodology

The methodology adopted for this research comprised two distinct phases:

Phase 1 – The utilisation of the e-Delphi technique (Chou, 2002) to identify and rank the most important four challenges. The e-Delphi method engages 'experts' as its panel members (Kernan *et al.*, 2023). The selection of experts for this study followed a purposive sampling approach, which aimed to deliberately choose individuals with specialised knowledge in the field. However, it is noteworthy that only six experts granted written informed consent to participate in the online discussions. To ensure compliance with the university's policies, a formal written request was sent to provide these experts with the necessary online access. The panel of experts included not only professionals from the food industry but also individuals affiliated with academic institutions. All of them possessed substantial expertise in the domain of food supply chains, with some having additional experience within food organisations. For a detailed overview of the experts' respective occupations, experience levels and qualifications, please refer to Table 1. Among the six experts, three held doctoral degrees, two possessed master's degrees, and one had earned a bachelor's degree. Their collective experience spanned an impressive range of 15–31 years within the food sector and food supply chains.

The e-Delphi technique employed in this study comprised two iterative rounds aimed at achieving consensus. In the initial e-round, the panel of experts assessed the state of food supply chains in Europe, with the objective of identifying challenges that could exert substantial influences on food security, resilience and the overall stability of these supply chains. Subsequently, in the second e-round, the experts conducted a comprehensive evaluation of all the challenges confronted by the European food supply chain and distilled the top four most critical challenges.

Phase 2 – Subsequently, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher *et al.*, 2009) approach was implemented within the context of these four identified challenges. Large-scale review syntheses, particularly when addressing contemporary and dynamic subjects, rely significantly on grey literature as a vital source of information. An effective grey literature search plan

Table 1 Experts occupation, experience and qualification

Expert	Occupation	Years of experience	Food supply chain qualification and experience
1	Managing Director (Strategy), Food Supply Chain (Food Logistics Company)	21 years	PhD, Procurement & Supply Chain resilience
2	Commercial Manager, Food Industry (Meat Industry)	29 years	BSc, Agribusiness & Management
3	Manufacturing Manager, Food Industry (Convenience Foods)	27 years	PG Diploma, Food Science
4	Factory Director, Food Industry (Dairy Industry)	15 years	MSc, Bio-Food Technology
5	Professor in Logistics & Supply Chain Management	31 years	PhD, Retail Logistics
6	Professor of Operations & Supply Chain Management	30 years	PhD, Supply Chain

must delineate the specific resources, search terms, websites and imposed limitations. In accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, the report should encompass a comprehensive account of all information sources used in the search, specifying the individual responsible for conducting the search, the date of the search and a complete search strategy applied to at least one database, inclusive of all search terms and their combinations. A grey literature search plan was developed incorporating three different searching strategies: (1) customised Google search, (2) targeted websites and (3) news reports. The grey literature search was supplemented with relevant peer-reviewed articles from the SCOPUS and Google Scholar databases using the same search terms: 'Brexit', 'Earthquake', 'COVID-19' and the keywords of each of the identified challenges. Each impact area was searched in this way by one of the co-authors based on their area of expertise, supported and corroborated by the other co-authors. Searches were performed from 13 March 2023 to 17 July 2023. We did a further search from 21 February 2024 to 12 March 2024 to include the impact of the Israel-Palestine conflict on the food supply chain. This research employed a PRISMA approach (Page *et al.*, 2021) with the eligibility criteria shown in Table 2.

Table 2 Inclusion and exclusions criteria for the literature review

Inclusion criteria	Exclusion criteria
Available in English	Unavailable in English
Published by Government, NGO, or broadsheet	Published by a tabloid
Published by an expert in the field	Published as a generic blog
Related to identified impact categories	Unrelated to identified impact categories

Political isolationism and the food supply chain

No doctrine of international relations has suffered as severe a rebuff and loss of prestige over the last decade as realism (Antunes & Camisão, 2018; Arlen & Rossi, 2021; Jørgensen & Ergul Jorgensen, 2021). The entire model of states acting in their rational self-interest is essentially falsified by states making unambiguous errors that are identified as such prospectively rather than retrospectively. Events such as the United Kingdom's Brexit (Mitchell, 2017), Sri Lanka's fertiliser ban (Jayasinghe & Ghoshal, 2022), Donald Trump's Trade War (Rosalsky, 2022) and the apparent destruction of the Nord Stream 2 Pipeline (Vakulenko, 2022) were considered impossible by prominent Realists. Importantly, that these events factually occurred does not represent errors in understanding the context of those decisions, but a far more devastating failure of the underlying theory.

The negative effects of these actions were correctly identified prior to their enaction, both in academic publications and in the popular press (Dhingra *et al.*, 2017; Swanson, 2019; Nordhaus & Shah, 2022). Thus, it cannot reasonably be concluded that any of these choices were made in the absence of an understanding of the likely outcomes. The vivid images of soybean mountains rotting away (Burroughs, 2019) and empty shelves waiting in vain for shipments of tomatoes were in no sense surprising (BBC, 2023). Any theory that depends on rational use of state power must at the very least be modified to include revealed preferences that allow financial ruin, food insecurity and the discarding of national resources in the pursuit of utterly intangible goals such as pride and malice.

'Famines are not natural phenomena, they are catastrophic political failures.' This conclusion by the Oxfam director for Somalia was contentious at the time (Teofilo, 2013). Indeed, it is true that in ancient times there was much less available shipping and many local crop failures led to food shortfalls that had no obvious political solution. However, when we look at famines over the last two centuries such as the Bengal Famine of 1943, the Ukrainian Holodomor of 1932, or the Irish Great Famine of 1845, while historians quibble about how many millions of people died,

the political aspect of these calamities has become part of the consensus. While it would be comforting to think that such callous misrule belonged firmly in the past, it is both anecdotally and statistically obvious that this is not the case.

While the global pandemic put substantial strain on supply chains, it nonetheless remained the case that there was factually sufficient food to feed every man woman and child in 2022 (Strzyżyńska, 2022). Despite this, hunger-related deaths rose to over seven million in that year (Hartnett, 2022). This is roughly the magnitude of the Bengal Famine and the Holodomor happening at the same time, representing a current global failure of political organisation on par with world-historical atrocities.

International trade is a major stabilising force and guarantee of food security. Every year over three hundred million tons of wheat, rice and corn cross national borders (USDA, 2023). This can be justly called a triumph of the modern era, putting food into the mouths of literally billions of people. It is therefore deeply unfortunate that every one of those tons is subject to veto by political actors that may be utterly indifferent to the suffering and deaths of millions of people. Donald Trump's American government prevented millions of tons of soybeans from ever reaching consumers in any form (Adjemian *et al.*, 2021). Gotabaya Rajapaksa's Sri Lankan government stopped the imports of tens of thousands of tons of fertiliser (CEIC, 2018), resulting in the predictable and predicted collapse of the country's agricultural sector. The global food trade is over $1.9 trillion (News Agencies, 2022) and while it would be financially ruinous and a humanitarian disaster to disrupt it, there exist many political agents in the world who have the power to do so. They may use that power and they do not need a good reason to do so.

Political failures of this sort can be considered as failures of hubris, credulity, or callousness. Britain's Brexit and Trump's Trade War were acts of colossal hubris. The governments unilaterally and voluntarily enacted quite significant barriers to trade under the Icarian belief that other countries would somehow accommodate them. Sri Lanka's fertiliser ban and the Soviet Union's Holodomor in Ukraine were justified at the time by their respective governments with the credulous acceptance of pseudoscience from Vandana Shiva (Stuttaford, 2022) and Trofim Lysenko (Dunn, 2021), respectively. Motivated reasoning compelling people in positions of power to ignore the views of the vast majority of biologists in favour of contrarian viewpoints that the leadership would prefer to be true (Kolchinsky *et al.*, 2017; Reznik & Fet, 2019). This credulous acceptance of pseudoscientific beliefs creates a permission structure for decision-making that is irrational. But with more than two hundred million people in the world today lacking access to sufficient food (Rayment, 2022), it is apparent that most of them are accounted for by countries where the leadership appears callously indifferent to their suffering, making no particular effort to secure adequate food supplies.

COVID-19 and the food supply chain

The COVID-19 pandemic, with its far-reaching effects, has significantly reshaped European food supply chains (Trollman *et al.*, 2021). The pandemic disrupted European food supply chains in multiple ways. One of the most pronounced effects was the disruption of labour (Clapp & Moseley, 2020). With lockdowns, quarantine measures and illness outbreaks among workers, the availability of labour in the agriculture, food processing and distribution sectors faced severe challenges (Aday & Aday, 2020).

In many European countries, migrant workers, often from Eastern Europe, play a crucial role in seasonal agriculture (Paul, 2020). Travel restrictions and border closures impeded their movement, leading to labour shortages during planting and harvesting seasons (Hossain, 2018). Additionally, social distancing requirements in food processing facilities slowed down production lines, affecting the timely delivery of goods to consumers (Hobbs, 2020). Food supply chains also faced disruptions due to the pandemic. Panic buying and hoarding early in the crisis led to temporary shortages of certain products on store shelves (Trollman *et al.*, 2021; Rejeb *et al.*, 2022). Moreover, the reliance on '-just-in-time' supply chain models meant that even minor disruptions in production or transportation could lead to significant delays in restocking (Raj *et al.*, 2022). For instance, farming activities are season and climate-dependent, requiring a strict schedule that can be accelerated when necessary. Any delays can adversely affect yield and production throughout the supply chain, including the supply of agricultural products, storage, packaging, inventory management and distribution (Barman *et al.*, 2021). The COVID-19 pandemic also exacerbated transportation delays, as it limited the availability of truck drivers and some routes presented challenges for efficient truck service (Gray, 2020).

In this context, the meat processing industry experienced significant disruptions, primarily stemming from the high number of COVID-19 cases among workers (Aday & Aday, 2020). Consequently, meat processing plants had to cease operations, triggering a domino effect throughout the meat supply chain. This cascade effect included the culling of animals because there were no available facilities to process and sell them, resulting in empty shelves due to heightened consumer demand and escalating meat prices due to reduced supply. Retailers responded by imposing purchase

limits on meat products for individual consumers, restaurants suspended beef service and some markets enforced restrictions on purchases (Aday & Aday, 2020). To alleviate panic buying, grocery stores introduced free delivery services, implemented crowd control measures in-store and established designated shopping hours for vulnerable customers (Nicola *et al*., 2020).

The pandemic accelerated the adoption of e-commerce and online grocery shopping in Europe. As lockdowns and social distancing measures limited in-person shopping, consumers turned to online platforms to meet their food needs. This shift had several notable consequences (Nanda *et al*., 2021). Firstly, it increased the demand for last-mile delivery services. Online grocery retailers and traditional supermarkets alike had to ramp up their delivery infrastructure to cope with the surge in orders. This included hiring more drivers, expanding delivery zones and optimising logistics (Shapiro, 2023). Secondly, it forced traditional brick-and-mortar grocery stores to adapt quickly. Many established supermarket chains launched or expanded their online ordering and delivery services to remain competitive. This transformation allowed them to retain customers who preferred the convenience and safety of online shopping (Marusak *et al*., 2021).

COVID-19 concerns, encompassing both financial and health aspects, prompted shifts in consumer food choices. Customers began seeking healthier options that fit within their budgets, with a focus on items rich in nutrients like fruits, vegetables, legumes and olive oil (Barman *et al*., 2021). Considerations for mental health also influenced product choices. In Italy, during the pandemic, there were significant increases in consumption of fruit by 24.4%, vegetables by 28.5%, legumes by 22.1%, nuts by 12% and fish or shellfish by 14%; however, at the same time, excessive consumption of sweets and pastries by 36.9% and comfort foods by 22.7% was observed (Grant *et al*., 2021).

In France, e-commerce platforms specialising in groceries, such as Auchan Direct and Leclerc Chez Moi, saw a significant increase in orders during the pandemic. Consumers, particularly in urban areas, turned to these services for convenience and reduced exposure to crowded stores (McLoughlin, 2021; ecommerceDB, 2022). The UK's agricultural sector faced labour shortages due to COVID-19 restrictions. The soft-fruit (e.g., strawberry) industry, heavily reliant on seasonal labour, struggled to find workers. This led to some farms experimenting with automation and robotics to mitigate the impact (Rose & Bhattacharya, 2023). Germany, Europe's largest economy, experienced a surge in online grocery shopping during COVID times. Retail giants like Edeka and REWE expanded their online presence, offering a wider range of products for home delivery. This trend has continued even as restrictions eased, suggesting a lasting shift in consumer behaviour (McKinsey, 2021). Italy, at the pandemic's epicentre early on, faced significant disruptions in its food supply chain (Arndt *et al*., 2023). Delays in transporting goods from the south, where much of the agriculture is concentrated, to the north, where consumption is higher, highlighted vulnerabilities in the supply chains' geographical distribution (Coluccia *et al*., 2021). These case studies and examples highlight the diverse ways in which European countries responded to the challenges posed by the COVID-19 pandemic. From embracing e-commerce to finding innovative solutions to labour shortages, the European food supply chain adapted and evolved in response to the crisis.

Conflicts and the food supply chain

The Russia–Ukraine and Israel–Palestine conflicts have had a significant impact on global food supply chains. Both Russia and Ukraine are major producers of food, particularly grain. Reduced food production and exports from both countries are already affecting food availability and prices, particularly in countries that were heavily dependent on their imports (Hamulczuk *et al*., 2023). Also, the Israel–Palestine conflict is significantly impacting the global food supply chain, exacerbated by ongoing attacks on container ships in the Red Sea. The impact of these ongoing conflicts on global food supply chains in the coming months and years is still uncertain.

There is already some data to show the impact of such a conflict on the food sector. In 2022, Ukrainian farmers sowed an area 22% smaller than in 2021, leading to a decline in grain production. It is projected that Ukraine will produce 47.1 million tonnes of grain in the 2023/2024 season, significantly less than the 86.7 million tonnes produced in 2021/2022 (Council of the European Union, 2023). The situation is particularly serious for some countries that were heavily dependent on Russian and Ukrainian grain exports before the conflict. Countries such as Armenia, Azerbaijan, Eritrea, Georgia, Mongolia and Somalia imported more than 90% of their wheat from Russia and Ukraine (FAO, 2022a). The role of international aid and assistance to these affected countries, as well as to Ukraine itself, is paramount in ensuring their food security.

Some of the impacts already felt in the food system include rising agricultural prices, declining trade volumes and severe food insecurity (Feng *et al*., 2023). The vegetable oil price index more than doubled, the cereal price index increased by more than 60% and the sugar price index by more than 50% (FAO, 2023). However, although still high, food prices have already started to fall (United Nations, 2022). High food prices are putting more people at risk of hunger and

poverty and are affecting the state of global food security. FAO predicted that a prolonged conflict that reduces food exports from Ukraine and Russia could increase the number of undernourished people worldwide by between 8 and 13 million in 2022/2023, mostly in Asia-Pacific, sub-Saharan Africa, the Near East and North Africa (FAO, 2022a). Other sources increased this figure to 27.2 and 22.3 million more people pushed into poverty and hunger, respectively, in just 19 developing countries (Arndt *et al*., 2023).

Lin *et al*. (2023) analysed the potential impact of the conflict on the global wheat market and concluded that, in the most severe scenario, the conflict could lead to a trade drop (60%), soaring wheat prices (50%) and severe food insecurity with decreased purchasing power for wheat (above 30%) (Lin *et al*., 2023). It should be remembered that Ukraine was the world's fifth largest wheat exporter in 2020, with more than 18 million tonnes or 9% of global wheat exports (FAOSTAT, 2023). However, high food prices are not the only factor affecting the economic performance of food systems. The prices of key commodities and inputs, such as energy and fertiliser, are more damaging to food prices, as well as for health and the environment, than restrictions on food exports from Ukraine and Russia (Alexander *et al*., 2023). In modern global supply chains, the price and availability of a product from one region can cause disruptions in a very distant sector.

Activities that require human labour and/or livestock are seriously affected by the conflict (Jagtap *et al*., 2022). Concerns about the safety of farmers to carry out their work, as well as some of the population fighting in the conflict, result in labour shortages that lead to reduced food production. Similarly, lack of livestock safety and reduced access to animal feed, fodder and veterinary medicine is leading to stock reduction and reduced availability of animal products.

Other important conflict-related problems include reduced availability of agricultural inputs, damage to crops due to military activity and destruction of food system assets and infrastructure (FAO, 2022b). This not only poses a challenge to food security but also has negative economic consequences, particularly for Ukraine. It should be noted that cereals account for about one-fifth of total exports, valued at more than $9.4 billion in 2020 and Ukraine was the second largest cereal exporter in the world (Barklie, 2022). Winter wheat, spring barley and maize were the main small-grain crops grown in Ukraine (World Data Center, 2020; Amicarelli *et al*., 2023).

The aforementioned problems caused by the conflict are disrupting food supply chains between Ukraine and European countries. In 2020, the main EU destinations for Ukrainian wheat, maize, sunflower seeds and oil were Bulgaria, Cyprus, Estonia, Greece, Hungary, Italy, Lithuania, the Netherlands, Portugal and Spain, where Ukraine was also the first country of origin for these products (Jagtap *et al*., 2022). These countries, therefore, had to look for alternative suppliers to cover their demand.

Houthi's have targeted shipping vessels since mid-November 2023 after the outbreak of the Israel–Palestine conflict, prompting nations such as the U.S., UK and China to deploy naval forces for protection (Campbell, 2024). This has led to a re-evaluation of trade routes and merchandising plans, affecting the delicate balance between supply and demand that characterised COVID-19's impact. Container ship capacities are now constrained, causing shifts in market dynamics for food importers. Prominent shipping companies have opted to avoid the Red Sea, with seven out of the ten largest shipping companies suspending operations in the region, as reported by the Atlantic Council. Ships are now being rerouted around the Cape of Good Hope, increasing journey times by up to 2 weeks (Tran, 2023). It has also led to rising insurance risk premiums for high-risk areas, which have surged from 0.07% to approximately 0.5–0.7%, further contributing to the complexities (Yerushalmy, 2023). The uncertainty surrounding the reopening of the Bab-el-Mandeb Strait for commercial shipping adds another layer of challenges. While there are no immediate indications of specific food items being impacted, concerns are rising as present delays are estimated to last 2–3 weeks, potentially affecting trans-Atlantic and trans-Pacific passages. Analysts also predict that the pause in BP's Red Sea shipments may contribute to rising oil and fossil gas prices, leading to further increases in energy costs if vessel attacks persist. Shipping companies now face a binary choice: navigate the Red Sea with increased insurance costs or divert vessels around Africa, both options carrying the risk of higher expenses and potential delays, further highlighting the intricate challenges posed by geopolitical tensions on the global food supply chain and broader economic dynamics.

It is clear, therefore, that the conflict is causing major disruptions in global food supply chains, particularly affecting certain countries that rely on exports from Ukraine and Russia and use the Red Sea routes (Israel–Palestine conflict). The obvious and ideal solution to this crisis is to stop the conflicts and resume food production and distribution activities, but it is uncertain when this will happen. Therefore, alternative short-term solutions need to be explored. Abay *et al*. (2023) proposed the following recommendations to address the food crisis caused by the conflict: exempt food and fertiliser from trade sanctions, refrain from implementing export bans and restrictions, avoid hoarding and panic buying, target social protection and food subsidies to the most vulnerable households,

provide humanitarian aid, suspend biofuel mandates and subsidies and help global markets to become more diversified and inclusive (Abay *et al.*, 2023). Lin *et al.* (2023) estimated that, if major wheat producers such as China, India, the US, Canada, France and Germany increased their production by 2–3% in 2022–2023, the global wheat crisis would be significantly alleviated.

Natural disasters and the food supply chain

'All Terrestrial life ultimately depends on soil and water', is the opening line of Daniel Hillel's Out of the Earth book first published in 1992 and it has guided agronomists ever since who need to cut through detail in defining how natural resource crises can occur (Hillel, 1992). The study developed an understanding of the growth and decline of civilizations through the limitations placed on them by the supply and demand functions of natural resource conversions. Limitations to these are the root cause of crisis and Hillel's analysis makes it clear that systems will have a time when they can be considered prosperous and the ability to be resilient in response to crises will determine their survival. Crises are detailed since agriculture became the settled practice for humankind some 10–12 thousand years ago and projecting the future of food production has largely taken on a negative outlook since. Scientific methods have been used to do this since the Reverend Thomas Malthus in the 18th Century through to Professor Paul Ehrlich in the 20th Century (Bradshaw *et al.*, 2021). They have all proposed that population growth will outstrip the capacity for economic growth if the demand for natural resources continues to increase (Ehrlich, 1978). They were not wrong; they were selective in their view of which sectors of society should be controlled and their approach has been developed further by the 'peak' models of natural resource use. An alternative view that does enable an explanation for the 'dirty growth' scenario is Kuznet's Curve where crises of increased pollution and even climate change are a necessary outcome of growth and as wealth develops it is the emergence of new societal values and innovation that effectively stop natural systems becoming degraded or crisis-ridden (Ansari, 2022). The two approaches rarely meet on any kind of centre-ground and this creates many problems manifested in trying to agree on or reach sustainable solutions.

Ever since the vision of sustainable development was raised by the 1960's boomer generation activists, in a major part in response to Ehrlich's study of population, have formed a framework of what resilience should be and one chief policy maker stands out in sustainable development among many others, Gro Harlem Bruntland (Brundtland *et al.*, 1987). They established the World Commission on Environment and Development which concluded in its 1987 report, 'Our Common Future,' that sustained economic growth, which is a precondition for the elimination of mass poverty, is possible only within a more equitable international economic regime. The commission called for a new era of economic growth and without this, crises will continue to occur. An outcome of this sustainable outlook was that there are no absolute limits to growth other than those imposed by technologies or social organisation on the biosphere and ingenuity is an agent of change that can provide increased global equity. Integrating peak models with this understanding is critical to averting future crises and geopolitical boundaries are often a major barrier as we see in conflicts and international responses to disasters.

A major barrier to enabling this understanding of how innovation can avert crises in agricultural and food production that scientists have a turn-key role is the ability to project what the limits are because every peak model has been foiled by new technologies or exploitation (Tilton, 2018). The equitable distribution of resources has not worked in the way the Brundtland report put forward and of course, we may be entering a Kuznets transition as is evident with the plateauing of meat consumption in high-income countries where increased consumption of livestock products has a recognised environmental and nutritional cost (Cole & McCoskey, 2013). The scientific community is well-practised in using ecological models and theoretical ecology calculations to project future limits to natural resource growth, utilisation and transformation. It is some 40 years since Sir Robert May developed the principle that simple mathematical operators could be used to model biological resources and population structure and project future conditions no matter how chaotic (May, 2001). The ability to provide a biological inventory of global resources has been a long-term goal started with the International Biological Program sought to define the global inventory of biological resources and limits of natural capital (Worthington, 1965). The integration of projection and inventories has brought new assessment methods for natural systems including ecosystem services that were described by Constanza and colleagues in 1997, this was transformative because it gave a platform for assessing the cost and risks associated with natural resource crises (Costanza *et al.*, 2017).

These platforms of theoretical and applied modelling of natural resources have enabled the analysis of the current food system to be more incisive in determining where it is most critical to act in order to reduce risk. Digitalization and data access has transformed what we can do, the research community has the ability to utilise Earth Observation data sets in close to real time across the globe. This is a transformative example of

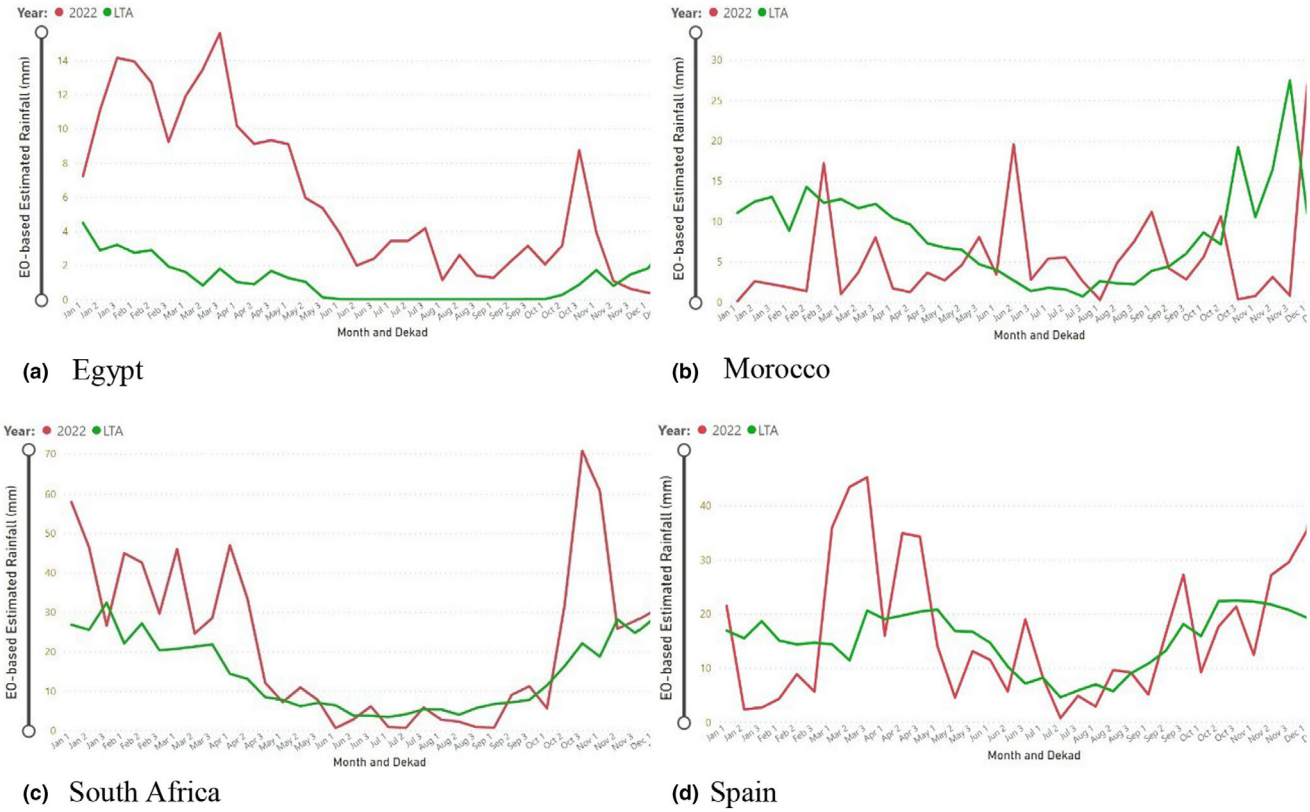

Figure 1 Estimated rainfall trends for important fresh produce exporting nations that the UK is dependent on, 2022 rainfall per dekad (10 days) is benchmarked with Long Term Average data sets. The graphs were developed using the FAO Global Information and Early Warning System on Food and Agriculture (GIEWS) tools and the data shown has been sourced from NOAA/FEWSNet for African countries (except Cabo Verde and Mauritius) and ECMWF for others. Long-Term Average (1989–2015 for FEWSNet countries, 1969–2015 for ECMWF countries).

the impact of using digital data to improve sourcing foods in a rapidly changing world (Venter *et al.*, 2022). The natural resource inventories are no longer a static data set that is released on an annual basis, the ability to analyse and respond to real-time events in our food system is apparent (Bhandari *et al.*, 2021). Figure 1 demonstrates an example of this for Morocco, South Africa and Spain, which are nations that are crucial producers of fresh fruit and vegetables imported by the UK to maintain out-of-season supply. Seasonal weather changes are disrupting these supplies because of increasing frequencies of drought and flooding which are disrupting the production and distribution of produce. Figure 1 shows precipitation in 2022 benchmarked against mean long-term precipitation and each nation exporting fresh produce to the UK has specific concerns that are associated with variable weather conditions and continued climate change. Each profile for 2022 provides examples of how our food system needs to be ready for change, Fig. 1 shows precipitation has increased at critical points in the growing season concerning the long-term mean. This will mean flooding and wet conditions at harvest will impact production and distribution in areas that also experience drought and increased temperatures. These figures demonstrate an urgent requirement for water catchment management planning that can divert and conserve water that would otherwise flood production.

Table 3 develops the assessment of weather variation and climate criticality by demonstrating the importance of Egypt, Morocco, South Africa and Spain as exporters of fresh produce for the UK where the percentage of imported fruit into the UK from each nation is above 25% of the total for that food item. The combination of precipitation variance, agricultural stress and demand for fresh produce across these subtropical crop production systems is likely to result in the initial and most visible impacts of climate change in the UK food system. Resilience in global trading partners is also demonstrated in Table 3, where most tomato imports are sourced from three

Table 3 Mass of fresh produce imported by the UK in 2021, the food items are ranked by mass imported for the top ten food items and the partner or source country of origin is shown

Nation exported from	Food item	Tonnes exported in 2021	% of total food item imported into UK
Spain	Lettuce	178 255.8	83
Netherlands	Tomatoes	127 430.8	38
Morocco	Tomatoes	110 845.7	33
South Africa	Apples	83 996	26
Spain	Oranges	79 938.24	33
France	Apples	68 602.59	21
Spain	Tomatoes	68 432.8	20
South Africa	Grapes	67 706.14	25
South Africa	Oranges	65 738.29	27
Egypt	Oranges	64 117.58	26

The data has been developed from the FAOStat database.

countries – Italy, the Netherlands and Spain – the importance of these countries has changed concerning indoor-grown and outdoor-grown or protected crops. The impact of fuel prices will change how indoor production crops are sourced in future because the current switch to indoor heated cropping is experiencing specific price pressures and the market may see an increase in demand for outdoor-grown crops if weather conditions and climate support this. Figure 1 and Table 3 do demonstrate the increased importance of water catchment and water conservation measures that are going to be increasingly important with extremely variable rainfall that results in droughting and flooding.

In this short analysis, the data shows the importance of managing water and soil resources in a just way so that resilience to crisis is built into food system design and the benefits of a sustainable system need to be recognised globally. The requirement for achieving this is a scientific measurement of natural resource inventories that reflect responses and changes to environmental change, geopolitical conflict and international disasters. The custodianship of the ecosystem services associated with natural resources must increasingly be governed internationally so that constructive responses to crises can be delivered.

Strategies for taming the quadruple whammy

Taming the quadruple whammy will be no mean feat given the interrelationships among the four factors identified in this research that represent significant challenges for European food supply chains. Furthermore, political isolationism, COVID-19, conflict and natural disasters lend themselves to complexity theory and necessitate resilience in response (Birkie & Trucco, 2020). In Table 4, a systematic summary of each of the four factors is presented as they relate to complexity theory and resilience, respectively. The implications are then critically discussed.

Table 4 The four factors of the quadruple whammy are compared in terms of complexity theory and resilience response

Quadruple whammy factor	Source of complexity	Basis for resilience
Political isolationism	Irrational use of state power	International trade capability
COVID-19	Labour disruptions	Technological innovation
Conflict	Reduced food production and availability	Alternative suppliers and logistics
Natural disasters	Growth (population and economic)	Resource management

Although international trade capability may mitigate a state's irrational use of power (which may be present in any of the four factors), the economic growth resulting from trade expansion may impact on the environment by increasing pollution or degrading natural resources. Furthermore, reliance on foreign countries may hinder national defence and complicate national planning for growth and development.

Technological innovation may alleviate issues of labour availability, but it is also associated with possible significant environmental impact, job losses over the longer term and the fact that reliance on technological solutions carries inherent risk.

Alternative suppliers of food and logistics capabilities may temporarily buffer the impacts of reduced food availability due to any of the four factors, however, the ability to access alternative resources largely depends on financial criteria which may lead to inequalities of food access on a global scale.

Advanced resource management depends on technological and financial resources and appropriate expertise. Technological disadvantage may exacerbate existing inequalities, including the need for educating qualified decision-makers who can create emergent knowledge strategies (Bratianu & Bejinaru, 2021) based on climate vulnerability assessments (Naylor, 2020) that reflect complex global processes.

The Quadruple Whammy has highlighted the vulnerability of the European food supply chain, demonstrating the importance of restructuring the food system to improve resilience to future shocks and stresses. The following are some strategies identified by the experts (see Table 5) that may help to address these challenges in the future which are divided into two main categories based on whether they are proactive or reactive and then further based on their area of focus: policy, infrastructure, technology.

Table 5 Selected strategies for addressing future shocks and stresses to the European food system (based on expert's views)

	Proactive strategy	**Reactive strategy**
Policy	Promote trade openness	Temporary suspension of tariffs
	Resilient food systems contingency plan	Financial assistance for SMEs
	Enhancing supply diversification	Strengthen risk management frameworks
Infrastructure	Harmonised and flexible food labelling and control	Addressing logistical challenges
	Establish a centralised nerve center for coordinated organisational responses	Securing energy accessibility
		Inventory strategy adjustment
		Adapt product portfolio
		Build capabilities and talent
Technology	Harness technology for comprehensive risk assessment	
	Engage in comprehensive global scenario planning	

Addressing logistical challenges (reactive, infrastructure): To ensure the smooth flow of essential food products, it is imperative to eliminate transportation bottlenecks in Europe by implementing dedicated 'green lanes' for their protection and efficient movement.

Securing energy accessibility (reactive, infrastructure): In the event of energy supply shortages, it is crucial to provide European food and beverage companies with affordable access to ample energy resources, recognising the critical role of the 'food and beverage' sector in our systems.

Practical short-term measures for sourcing challenges (proactive, infrastructure): Implementing a harmonised and flexible approach to food labelling and official controls within the EU, with the caveat that it does not compromise food safety or human health, could assist companies in navigating volatile ingredient availability.

Temporary suspension of tariffs on essential food products (reactive, policy): Exploring the possibility of temporarily suspending tariffs on select products that are in short supply, such as sunflower oil, to facilitate imports from third countries.

Promote trade openness (proactive, policy): It is essential to resist protectionist tendencies, including national export restrictions and other measures, as they contribute to heightened price volatility, diminish the global market's buffering capacity and fragment the integrity of the European Market.

Assisting small and medium-sized enterprises (SMEs) (reactive, policy): In light of rising input and energy costs, coupled with disrupted market access and sourcing challenges, it is crucial to recognise the heightened vulnerability of certain SMEs to bankruptcy and job losses. To provide necessary relief, the Temporary Crisis Framework for State Aid should be leveraged to support these businesses.

Establishing a resilient food systems contingency plan (proactive, policy): Europe's supply chains, despite their past resilience, require proactive European-level contingency preparedness mechanisms. Instead of a reactive approach, we should prioritise comprehensive preparedness to avoid crisis management. The COVID-19 pandemic exposed the inadequacy of traditional supply chain inventory reductions. Maintaining a 'strategic stock' of critical food raw materials is essential for companies. While some mitigated conflict (Russia–Ukraine and Israel–Palestine) risks with increased stockpiles, others were caught unprepared, risking disruptions in food production. Backup inventories are vital during crises, such as the pandemic. Supply shortages often emerge in sub-tier suppliers with limited visibility. To improve transparency, companies can use spending data and N-tier mapping, prioritising strategic suppliers and assessing vulnerability. Mitigation includes finding alternatives, optimising networks, adjusting inventory targets, maintaining safety stocks and exploring local or regional sourcing.

Enhancing supply diversification (proactive, policy): Through a proactive European trade agenda, we can diversify raw material sources, foster regulatory cooperation and find new export markets, enhancing long-term resilience. It is vital to engage in substantive European-level discussions about strategic autonomy, moving beyond simplistic protectionism. Organisations should act swiftly to activate secondary suppliers for essential inputs, but with caution to avoid further concentration. The pandemic and Ukraine conflict have accelerated the shift towards regional or local supply chains. Repatriation offers control but isn't always feasible. 'Friend-shoring,' replacing risky foreign suppliers with trusted allies, is a pragmatic solution.

Strengthening risk management frameworks (reactive, policy): The COVID-19 pandemic exposed a significant gap in preparedness for many organisations. While it is true that there was no specific playbook for COVID-19, the reality is that most organisations lacked comprehensive risk management tools

altogether. In light of the ongoing crisis arising from the conflict in Ukraine, it is imperative to ensure the establishment of robust risk management systems. This entails a concentrated effort to identify and mitigate risks within the extended supplier network, as well as addressing supply and inflationary pressures related to critical commodities.

Harnessing technology for comprehensive risk assessment (proactive, technology): While Russia may not appear as critical to complex global supply chains as other nations like China on the surface, the situation changes when we examine the supply network beyond direct suppliers. To build resilience, visibility must extend across the entire supply network. According to a Deloitte survey of chief procurement officers, only a minority of companies (26%) felt confident in predicting risks within their Tier 1 supplier base, let alone those in their upstream supply chain. To gain a better understanding of these risks, consider the implementation of 'control towers' empowered by artificial intelligence/machine learning and advanced analytics. These control towers offer real-time data visibility, proactive alerts, prescriptive insights and autonomous execution (Appolloni *et al.*, 2024). They are capable of identifying suppliers or commodities with elevated risk levels within both your primary supplier base and the broader extended supply network, including your supplier's suppliers.

Engage in comprehensive global scenario planning (proactive, technology): While we all hope for a swift and satisfactory resolution to this conflict, the duration and scale of the crisis remain uncertain. Equally unclear are the potential repercussions on commodity costs, supply availability and the implications of further sanctions and government interventions. To navigate these uncertainties, companies must undertake thorough scenario planning based on the nature of their exposure to this conflict. This will enable them to chart the most prudent medium to long-term course of action.

Establish a centralised nerve center for coordinated organisational responses (proactive, infrastructure): Within this central hub, a cross-functional team should proactively manage a wide range of issues, focusing on supporting colleagues, assessing financial resilience and early detection. Organise the nerve centre into four main categories: people, operations, decision resources and an early warning system. This system plays a critical role in flagging political developments, cyber threats, compliance issues and other concerns, enhancing overall responsiveness and resilience. Companies can adopt several strategies, like procuring components in advance, allowing extra delivery time and adjusting production plans based on material inventories. Secure alternative transportation routes for anticipated logistics disruptions and simulate regional demand shifts' impact on production to prevent excessive inventory buildup. Identify vulnerabilities within supplier networks, labour, manufacturing and delivery and implement control measures. Consider creating a 'digital twin' or two models to map material flows and uncover hidden suppliers and dependencies. Evaluate various scenarios and prioritise mitigation efforts for the weakest links in the supply chain to prepare for different contingencies.

Inventory strategy adjustment (reactive, infrastructure): Many companies must adapt their inventory tactics in the short term to ensure business continuity and maintain service levels in various Brexit scenarios. In the medium term, reassessing safety-stock levels in light of new operating conditions is essential.

Adapt product portfolio (reactive, infrastructure): Companies should be prepared to adjust their R&D strategies to accommodate changes in product specifications. These changes may result from Brexit-related regulatory shifts or evolving consumer preferences.

Build capabilities and talent (reactive, infrastructure): To support a more agile and flexible organisation, invest in new capabilities such as forecasting and analytics. Implement digitally powered control towers for real-time data visibility, enabling quick responses to market shifts. Attracting and retaining talent will be crucial in building and sustaining these capabilities.

Strategic management includes corporate, business and functional strategies. Functional strategies tend to be reactive. From the strategies above, 'Addressing Logistical Challenges' and 'Inventory Strategy Adjustment' are examples of reactive functional-level strategies. Business strategies, on the contrary, address how a specific company competes in the market. Such strategies may be formulated as either reactive or proactive. 'Promoting trade openness' will lead to reconsideration of business strategies in light of increased competition. Finally, at the corporate level which identifies what business a corporation should be in, Porter (1987) identified four relevant concepts: portfolio management, restructuring, transferring skills and sharing activities. The latter two exploit the interrelationships between businesses and are hence relevant to, for example, the strategy to 'Establish a Centralized Nerve Center for Coordinated Organizational Responses' and 'Enhancing Supply Diversification'.

In terms of supporting decision-making, the adoption of digital technologies will be invaluable. The strategies above that support decision-making via novel technologies include 'Harnessing Technology for Comprehensive Risk Assessment' and 'Engage in Comprehensive Global Scenario Planning'.

Finally, from a theoretical perspective, given the quadruple whammy effect, it is important to consider cascading risk (Zuccaro *et al.*, 2018). Appropriate modelling of cascading risk will be critical to 'Strengthening Risk

Management Frameworks' and 'Establishing a Resilient Food Systems Contingency Plan'.

Conclusion

This article has examined the profound impact of the 'Quadruple Whammy' consisting of political isolationism (e.g., Brexit), COVID-19, international conflicts (Russia-Ukraine and Israel-Palestine) and natural disasters (e.g., earthquakes, droughts, floods, etc.) on the European food supply chains. We have analysed the multifaceted challenges posed by these four factors, including labour disruptions, supply chain complexities and food security concerns. To address these challenges and build resilience in the face of future crises, we have proposed a series of proactive and reactive strategies. These strategies encompass measures to enhance supply diversification, secure energy accessibility and address logistical challenges. They also emphasise the importance of strengthening risk management frameworks, harnessing technology for comprehensive risk assessment and engaging in comprehensive global scenario planning. Furthermore, we have advocated for establishing a centralised nerve centre for coordinated organisational responses. In a world marked by increasing uncertainty and disruptions, the imperative for preparedness and adaptability in the European food supply chain cannot be overstated. The lessons learned from the 'Quadruple Whammy' underscore the need for a holistic approach to risk mitigation and proactive strategic planning. By implementing these strategies, companies and policymakers can work together to ensure the resilience and sustainability of the European food supply chain in the face of unprecedented challenges.

Author contributions

Sandeep Jagtap: Conceptualization; investigation; validation; methodology; formal analysis; data curation; supervision; resources; project administration; visualization; funding acquisition; writing – original draft; writing – review and editing. **Hana Trollman:** Investigation; writing – original draft; methodology; validation; visualization; writing – review and editing; formal analysis; data curation. **Frank Trollman:** Methodology; investigation; validation; writing – original draft; visualization; writing – review and editing; project administration; formal analysis; data curation. **Guillermo Garcia-Garcia:** Conceptualization; investigation; methodology; validation; visualization; writing – review and editing; writing – original draft; formal analysis; data curation. **Wayne Martindale:** Conceptualization; investigation; writing – original draft; writing – review and editing; visualization; validation; methodology; formal analysis; supervision; software; data curation.

Peer review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ijfs.17106.

Data availability statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

References

Abay, K.A., Breisinger, C., Glauber, J., Kurdi, S., Laborde, D. & Siddig, K. (2023). The Russia-Ukraine war: implications for global and regional food security and potential policy responses. *Global Food Security*, **36**, 100675.

ACLED. (2023). *Fact sheet: Israel and Palestine conflict (19 October 2023)*. Reliefweb. https://reliefweb.int/report/occupied-palestinian-territory/fact-sheet-israel-and-palestine-conflict-19-october-2023

Aday, S. & Aday, M.S. (2020). Impact of COVID-19 on the food supply chain. *Food Quality and Safety*, **4**, 167–180.

Adjemian, M.K., Smith, A. & He, W. (2021). Estimating the market effect of a trade war: the case of soybean tariffs. *Food Policy*, **105**, 102152.

Alexander, P.A., Rabin, S. & Rounsevell, M.D. (2023). High energy and fertilizer prices are more damaging than food export curtailment from Ukraine and Russia for food prices, health and the environment. *Nature Food*, **4**, 84–95.

Amicarelli, V., Lombardi, M., Varese, E. & Bux, C. (2023). Material flow and economic cost analysis of the Italian artisan bread production before and during the Russia-Ukraine conflict. *Environmental Impact Assessment Review*, **101**, 107101.

Ansari, M.A. (2022). Re-visiting the environmental Kuznets curve for ASEAN: a comparison between ecological footprint and carbon dioxide emissions. *Renewable and Sustainable Energy Reviews*, **168**, 112867.

Antunes, S. & Camisão, I. (2018). *Introducing Realism in International Relations Theory*. Boston: International Relations Theory. https://www.e-ir.info/pdf/72860

Antwi, J., Appiah, B., Oluwakuse, B. & Abu, B. (2021). The nutrition-COVID-19 interplay: a review. *Current Nutrition Reports*, **10**, 364–374.

Appolloni, A., Cheng, W., Masili, G., Binci, D. & Stein, M. (2024). Sustainable public food procurement in Italy. In: *Sustainable Food Procurement: legal, Social and Organisational Challenges* (edited by M. Stein, M. Mariani, R. Caranta & Y. Polychronakis). Pp. 161. London: Routledge.

Arlen, G. & Rossi, E. (2021). Must realists be pessimists about democracy? Responding to epistemic and oligarchic challenges. *Moral Philosophy and Politics*, **8**, 27–49.

Arndt, C., Diao, X., Dorosh, P., Pauw, K. & Thurlow, J. (2023). The Ukraine war and rising commodity prices: implications for developing countries. *Global Food Security*, **36**, 100680.

The article employs national economywide models to quantify the immediate repercussions of the Russia-Ukraine war on agrifood systems, poverty, and food insecurity in 19 countries, revealing a collective increase of 27.2 million people in poverty and 22.3 million in hunger, emphasizing the vulnerability of agrifood systems and poverty to escalating fuel and fertilizer prices, and the pronounced impact of higher food prices on hunger and diet quality.

Barklie, G. (2022). *The impact of the Russia-Ukraine conflict on trade*. Investment Monitor. https://www.investmentmonitor.ai/special-focus/ukraine-crisis/ukraine-russia-conflict-impact-trade/

Barman, A., Das, R. & De, P. (2021). Impact of COVID-19 in food supply chain: disruptions and recovery strategy. *Current Research in Behavioral Sciences*, **2**, 100017.

BBC. (2023). Tomato shortage: how far is Brexit to blame? *BBC News*. https://www.bbc.com/news/64762429
Bhandari, M., Baker, S., Rudd, J.C. *et al.* (2021). Assessing the effect of drought on winter wheat growth using unmanned aerial system (UAS)-based phenotyping. *Remote Sensing*, **13**, 1144. https://doi.org/10.3390/rs13061144
Birkie, S.E. & Trucco, P. (2020). Do not expect others do what you should! Supply chain complexity and mitigation of the ripple effect of disruptions. *International Journal of Logistics Management*, **31**, 123–144.
Bradshaw, C.J., Ehrlich, P.R., Beattie, A. *et al.* (2021). Underestimating the challenges of avoiding a ghastly future. *Frontiers in Conservation Science*, **1**. https://doi.org/10.3389/fcosc.2020.615419
Bratianu, C. & Bejinaru, R. (2021). COVID-19 induced emergent knowledge strategies. *Knowledge and Process Management*, **28**, 11–17.
Brooks, C., Parr, L., Smith, J., Buchanan, D., Snioch, D. & Hebishy, E. (2021). A review of food fraud and food authenticity across the food supply chain, with an examination of the impact of the COVID-19 pandemic and Brexit on food industry. *Food Control*, **130**, 108171.
Brundtland, G., Khalid, M., Agnelli, S., Al-Athel, S. & Chidzero, B. (1987). *Our common future*.
Burroughs, C. (2019). 27.5 million tons of US soybeans expected to go unsold this year as a direct consequence of the trade war with China. *Business Insider*. https://www.businessinsider.com/trump-china-trade-war-25-million-tonnes-of-us-soybeans-to-go-unsold-2019-2?r=US&IR=T
Campbell, C. (2024). *How Will the Red Sea Attacks Affect the Food Industry?* Upper Saddle River: The Food Institute. https://foodinstitute.com/focus/how-will-the-red-sea-attacks-affect-the-food-industry/
CEIC. (2018). *Sri Lanka Imports: by End Use: intermediate Goods: fertilizer*. London: CEIC. https://www.ceicdata.com/en/sri-lanka/imports-by-end-use-annual/imports-by-end-use-intermediate-goods-fertilizer
Chari, F., Muzinda, O., Novukela, C. & Ngcamu, B. (2022). Pandemic outbreaks and food supply chains in developing countries: a case of COVID-19 in Zimbabwe. *Cogent Business & Management*, **9**, 2026188.
Chaudhary, M. & Piracha, A. (2021). Natural disasters—origins, impacts, management. *Encyclopedia*, **1**, 1101–1131.
Chou, C. (2002). Developing the e-Delphi system: a web-based forecasting tool for educational research. *British Journal of Educational Technology*, **33**, 233–236.
Clapp, J. & Moseley, W. (2020). This food crisis is different: COVID-19 and the fragility of the neoliberal food security order. *The Journal of Peasant Studies*, **47**, 1393–1417.
Cole, J.R. & McCoskey, S. (2013). Does global meat consumption follow an environmental Kuznets curve? *Sustainability: Science, Practice and Policy*, **9**, 26–36.
Coluccia, B., Agnusdei, G., Miglietta, P. & De Leo, F. (2021). Effects of COVID-19 on the Italian agri-food supply and value chains. *Food Control*, **123**, 107839.
Costanza, R., de Groot, R., Braat, L. *et al.* (2017). Twenty years of ecosystem services: how far have we come and how far do we still need to go? *Ecosystem Services*, **28**, 1–16.
Council of the European Union. (2023). *How the Russian Invasion of Ukraine Has Further Aggravated the Global Food Crisis*. Brussels: Council of the European Union. https://www.consilium.europa.eu/en/infographics/how-the-russian-invasion-of-ukraine-has-further-aggravated-the-global-food-crisis/
Dhingra, S., Machin, S. & Overman, H. (2017). Local economic effects of Brexit. *National Institute Economic Review*, **242**, 24–36.
Diaconu, D. & Grecu, A. (2023). Conflicts and natural disasters, sources of migration in the twenty-first century. In: *The Handbook of Environmental Chemistry* (edited by R.D. Deshpande & R.D. Deshpande). Pp. 1–26. Berlin, Heidelberg: Springer.
Diamond, P. & Richardson, J. (2023). The Brexit omnishambles and the law of large solutions. *Journal of European Public Policy*, **30**, 1–16.
Dunn, M. (2021). *Meet Trofim Lysenko, The Russian Agronomist Whose Pseudoscience Doomed Millions*. New York: ATI. https://allthatsinteresting.com/trofim-lysenko#:~:text=Stalin's%20policies%20resulted%20in%20what,soon%20spread%20across%20the%20country
ecommerceDB. (2022). *The race for France's top online supermarket*. ecommerceDB. https://ecommercedb.com/insights/the-race-for-frances-top-online-supermarket/3439
Ehrlich, P. (1978). *The Population Bomb*. New York: Ballantine Books.
European Environment Agency. (2024). *Climate Change Impacts, Risks and Adaptation*. Copenhagen, Denmark: European Environment Agency. https://www.eea.europa.eu/en/topics/in-depth/climate-change-impacts-risks-and-adaptation?activeAccordion=4268d9b2-6e3b-409b-8b2a-b624c120090d
European Parliament. (2022). *Russia's War on Ukraine: background*. Brussels: European Parliament. https://www.europarl.europa.eu/EPRS/TD_Russia_war_Ukraine.pdf
FAO. (2022a). *Information Note – the Importance of Ukraine and The Russian Federation for Global Agricultural Markets and the Risks Associated with the War in Ukraine*. Rome: FAO. https://www.fao.org/3/cb9013en/cb9013en.pdf
FAO. (2022b). *Ukraine: note on the Impact of the War on Food Security in Ukraine*. Rome: FAO. https://doi.org/10.4060/cc1025en
FAO. (2023). *FAO Food Price Index – World Food Situation*. Rome: FAO. https://www.fao.org/worldfoodsituation/foodpricesindex/en/
FAOSTAT. (2023). *Crops and Livestock Products*. Rome: FAO. https://www.fao.org/faostat/en/#data/QCL
Feng, F., Jia, N. & Lin, F. (2023). Quantifying the impact of Russia–Ukraine crisis on food security and trade pattern: evidence from a structural general equilibrium trade model. *China Agricultural Economic Review*, **15**, 241–258.
Grant, F., Scalvedi, M., Scognamiglio, U., Turrini, A. & Rossi, L. (2021). Eating habits during the COVID-19 lockdown in Italy: the nutritional and lifestyle side effects of the pandemic. *Nutrients*, **13**, 2279.
Gray, R. (2020). Agriculture, transportation, and the COVID-19 crisis. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, **68**, 239–243.
Hamulczuk, M., Pawlak, K., Stefańczyk, J. & Gołębiewski, J. (2023). Agri-food supply and retail food prices during the Russia–Ukraine conflict's early stage: implications for food security. *Agriculture*, **13**, 2154.
Hartnett, L. (2022). *Humanitarian organizations estimate one person dying of hunger every four seconds*. https://www.oxfam.org/en/press-releases/humanitarian-organizations-estimate-one-person-dying-hunger-every-four-seconds#:~:text=This%20would%20equal%20between%207%2C745.7,dying%20every%204.25%20%E2%80%93%2012%20seconds
Hillel, D. (1992). *Out of the Earth: civilization and the Life of the Soil*. Berkeley, CA: University of California Press.
Hobbs, J. (2020). Food supply chains during the COVID-19 pandemic. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, **68**, 171–176.
Hossain, S. (2018). *Impacts of COVID-19 on the Agri-Food Sector: food Security Policies of Asian Productivity Organization Members*. Belihuloya, Sri Lanka: Sabaragamuwa University of Sri Lanka. http://repo.lib.sab.ac.lk:8080/xmlui/handle/123456789/1077
Ijaz, M., Yar, M., Badar, I. *et al.* (2021). Meat production and supply chain under COVID-19 scenario: current trends and future prospects. *Frontiers in Veterinary Science*, **8**, 432.
Jagtap, S., Trollman, H., Trollman, F. *et al.* (2022). The Russia-Ukraine conflict: its implications for the global food supply chains. *Foods*, **11**(9), 2098.

Examining the repercussions of the Russia-Ukraine conflict on global food supply chains reveals disruptions in production, sourcing, manufacturing, processing, logistics, and shifts in demand, necessitating strategic solutions and technological innovations for

maintaining food safety and quality amidst ongoing geopolitical challenges.

Jayasinghe, U. & Ghoshal, D. (2022). *Fertiliser Ban Decimates Sri Lankan Crops as Government Popularity Ebbs*. Mumbai: Reuters. https://www.reuters.com/markets/commodities/fertiliser-ban-decimates-sri-lankan-crops-government-popularity-ebbs-2022-03-03/

Jørgensen, K. & Ergul Jorgensen, F.A. (2021). Realist theories in search of realists: the failure in Europe to advance realist theory. *International Relations*, **35**, 3–22.

Kernan, L., Dryden, E., Nearing, K. *et al.* (2023). Integrating CFIR-ERIC and e-Delphi methods to increase telegeriatrics uptake. *The Gerontologist*, **63**, 545–557.

Khan, E. (2023). The post-Brexit paradigm: investigating the effects of foreign direct investment on economic growth in the United Kingdom. *Archives of the Social Sciences: A Journal of Collaborative Memory*, **2**, 94–110.

Kolchinsky, E.I., Kutschera, U., Hossfeld, U. & Levit, G.S. (2017). Russia's new lysenkoism. *Current Biology*, **27**, R1042–R1047.

Lin, F., Li, X., Jia, N. *et al.* (2023). The impact of Russia-Ukraine conflict on global food security. *Global Food Security*, **36**, 100661.

Lund, S., Manyika, J., Woetzel, J. *et al.* (2020). *Risk, Resilience, and Rebalancing in Global Value Chains*. New York: McKinsey Global Institute. http://dln.jaipuria.ac.in:8080/jspui/bitstream/123456789/10865/1/Risk-resilience-and-rebalancing-in-global-value-chains-full-report.pdf

Mahfouz, A., Allen, D., Arisha, A., Elbert, R. & Gleser, M. (2019). A post-Brexit transportation scenario analysis for an agri-fresh produce supply chain. In: *2019 Winter Simulation Conference (WSC)*, National Harbor, MD, USA. Pp. 1789–1800. Piscataway, NJ: IEEE. https://doi.org/10.1109/WSC40007.2019.9004790

Marusak, A., Sadeghiamirshahidi, N., Krejci, C. *et al.* (2021). Resilient regional food supply chains and rethinking the way forward: key takeaways from the COVID-19 pandemic. *Agricultural Systems*, **190**, 103101.

May, R.M. (2001). *Stability and Complexity in Model Ecosystems*. Princeton, NJ: Princeton University Press. https://doi.org/10.1515/9780691206912

McKinsey. (2021). *Disruption & Uncertainty – the State of Grocery Retail 2021*. London, UK: McKinsey. https://www.mckinsey.com/~/media/mckinsey/industries/retail/our%20insights/the%20path%20forward%20for%20european%20grocery%20retailers/disruption-and-uncertainty-the-state-of-grocery-retail-2021-europe-final.pdf

McLoughlin, B. (2021). *This start-up helped one of France's biggest retailers get deliveries out*. https://www.here.com/learn/blog/delivery-routing-solutions-france

Mirón, I.J., Linares, C. & Díaz, J. (2023). The influence of climate change on food production and food safety. *Environmental Research*, **216**, 114674.

Mitchell, R. (2017). Sovereignty and normative conflict: international legal realism as a theory of uncertainty. *Harvard International Law Journal*, **58**, 421–483. https://ssrn.com/abstract=2996089

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. & PRISMA-Group*. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of Internal Medicine*, **151**, 264–269.

Moradlou, H., Reefke, H., Skipworth, H. & Roscoe, S. (2021). Geopolitical disruptions and the manufacturing location decision in multinational company supply chains: a Delphi study on Brexit. *International Journal of Operations & Production Management*, **41**, 102–130.

Naja, F. & Hamadeh, R. (2020). Nutrition amid the COVID-19 pandemic: a multi-level framework for action. *European Journal of Clinical Nutrition*, **74**, 1117–1121.

Nanda, A., Xu, Y. & Zhang, F. (2021). How would the COVID-19 pandemic reshape retail real estate and high streets through acceleration of E-commerce and digitalization? *Journal of Urban Management*, **10**, 110–124.

Naylor, A.F. (2020). Conceptualizing climate vulnerability in complex adaptive systems. *One Earth*, **2**, 444–454.

News Agencies. (2022). *Global food import bill to jump to record $1.9 trillion: FAO*. AlJazeera. https://www.aljazeera.com/news/2022/11/11/global-food-import-bill-to-jump-to-record-1-9-trillion-fao

Nicola, M., Alsafi, Z., Sohrabi, C. *et al.* (2020). The socio-economic implications of the coronavirus pandemic (COVID-19): a review. *International Journal of Surgery*, **78**, 185–193.

Nordhaus, T. & Shah, S. (2022). How Sri Lanka's shift to organic farming left it in the manure. *The Sunday Times*. https://www.thetimes.co.uk/article/how-sri-lankas-shift-to-organic-farming-left-it-in-the-manure-0td92r6fp

Pache, G. (2024). Israeli-Palestinian conflict: towards a major logistical and environmental crisis? *Technium Social Sciences Journal*, **53**, 252–258.

Page, M., McKenzie, J., Bossuyt, P. *et al.* (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *British Medical Journal*, **372**, n71.

The PRISMA 2020 statement, an updated guideline for systematic reviews and meta-analyses, introduces new reporting guidance and an expanded 27-item checklist to transparently communicate the purpose, methodology, and findings, reflecting advances in review methods and terminology.

Paul, R. (2020). Europe's essential workers: migration and pandemic politics in central and Eastern Europe during COVID-19. *European Policy Analysis*, **6**, 238–263.

Porter, M.E. (1987). *From Competitive Advantage to Corporate Strategy*. Boston: Harvard Business Review. https://hbr.org/1987/05/from-competitive-advantage-to-corporate-strategy

Raj, A., Mukherjee, A., de Sousa Jabbour, A. & Srivastava, S. (2022). Supply chain management during and post-COVID-19 pandemic: mitigation strategies and practical lessons learned. *Journal of Business Research*, **142**, 1125–1139.

This article explores the unprecedented impact of the COVID-19 pandemic on global supply chains, focusing on manufacturing organizations in emerging economies, utilizing a dynamic capability theory-based conceptual framework to identify and analyze ten major challenges, with the Grey-DEMATEL method revealing the significance of Scarcity of Labor and Scarcity of Material, and offering guidelines and strategies for addressing post-COVID-19 supply chain challenges.

Rayment, L. (2022). 200 Million Face Life-Threatening Hunger, Says New UN Report. Charity Today. https://www.charitytoday.co.uk/200-million-face-life-threatening-hunger-says-new-un-report/

Reddy, V.R., Singh, S.K. & Anbumozhi, V. (2016). *Food Supply Chain Disruption Due to Natural Disasters: entities, Risks, and Strategies for Resilience*. Pp. 18. *ERIA Discussion Paper*. Jakarta, Indonesia: Economic Research Institute for ASEAN and East Asia (ERIA). https://api.semanticscholar.org/CorpusID:198925322

Rejeb, A., Rejeb, K., Appolloni, A., Iranmanesh, M., Treiblmaier, H. & Jagtap, S. (2022). Exploring food supply chain trends in the COVID-19 era: a bibliometric review. *Sustainability*, **14**, 12437.

Reznik, S. & Fet, V. (2019). The destructive role of Trofim Lysenko in Russian science. *European Journal of Human Genetics*, **27**, 1324–1325.

Rosalsky, G. (2022). *China Promised Trump a Better Deal for America; It Didn't Actually Deliver*. Washington, D.C.: NPR. https://www.npr.org/sections/money/2022/02/15/1079761270/china-promised-trump-a-better-deal-for-america-it-didnt-actually-deliver

Rose, D. & Bhattacharya, M. (2023). Adoption of autonomous robots in the soft fruit sector: grower perspectives in the UK. *Smart Agricultural Technology*, **3**, 100118.

Shapiro, A. (2023). Platform urbanism in a pandemic: dark stores, ghost kitchens, and the logistical-urban frontier. *Journal of Consumer Culture*, **23**, 168–187.

Strzyżyńska, W. (2022). *Can the world feed 8bn people sustainably?* https://www.theguardian.com/global-development/2022/nov/15/can-the-world-feed-8bn-people-sustainably

Stuttaford, A. (2022). *Sri Lanka: an 'organic' catastrophe*. National Review. https://www.nationalreview.com/corner/sri-lanka-an-organic-catastrophe/

Swanson, A. (2019). As trump escalates trade war, U.S. and China move further apart with No end in sight. *The New York Times*. https://www.nytimes.com/2019/09/01/world/asia/trump-trade-war-china.html

Teofilo, G. (2013). *260,000 people died in the Somalia famine*. FEWSNET report. https://www.oxfam.org/en/press-releases/fewsnet-report-260000-people-died-somalia-famine

Tilton, J.E. (2018). The Hubbert peak model and assessing the threat of mineral depletion. *Resources, Conservation and Recycling*, **139**, 280–286.

Tran, H. (2023). *What Attacks in the Red Sea Could Mean for the Global Economy*. Washington, DC: Atlantic Council. https://www.atlanticcouncil.org/blogs/econographics/shipping-disrupted-by-attacks-in-the-red-sea/

Trollman, H., Jagtap, S., Garcia-Garcia, G., Harastani, R., Colwill, J. & Trollman, F. (2021). COVID-19 demand-induced scarcity effects on nutrition and environment: investigating mitigation strategies for eggs and wheat flour in the United Kingdom. *Sustainable Production and Consumption*, **27**, 1255–1272.

United Nations. (2022). *Global Impact of War in Ukraine: energy Crisis*. Geneva, Switzerland: UNCTAD. https://unctad.org/system/files/official-document/un-gcrg-ukraine-brief-no-3_en.pdf

USDA. (2023). *Grain: world markets and trade*. https://apps.fas.usda.gov/psdonline/circulars/grain.pdf

Vakulenko, S. (2022). *Shock and awe: who attacked the nord stream pipelines?* Carnegie politika. https://carnegieendowment.org/politika/88062

Venter, Z.S., Barton, D.N., Chakraborty, T., Simensen, T. & Singh, G. (2022). Global 10 m land use land cover datasets: a comparison of dynamic world, world cover and Esri land cover. *Remote Sensing*, **14**, 4101.

World Data Center. (2020). *Ukraine: agricultural Overview*. Kyiv: NTUU 'Igor Sikorsky Kyiv Polytechnic Institute. http://wdc.org.ua/en/node/29

Worthington, E.B. (1965). The international biological programme. *Nature*, **208**, 223–226.

Yerushalmy, J. (2023). *Red sea crisis explained: what is happening and what does it mean for global trade?* The Guardian. https://www.theguardian.com/business/2023/dec/19/red-sea-shipping-crisis-bp-oil-explained-what-is-happening-and-what-does-it-mean-for-global-trade

Zuccaro, G., De Gregorio, D. & Leone, M.F. (2018). Theoretical model for cascading effects analyses. *International Journal of Disaster Risk Reduction*, **30**, 199–215.

2024-04-11

Surviving the storm: navigating the þÿ q u a d r u p l e w h a m m y i m p a c t o n food supply chain

Jagtap, Sandeep

Wiley

Jagtap S, Trollman H, Trollman F, et al., (2024) Surviving the storm: navigating the quadruple whammy impact on Europe's food supply chain. International Journal of Food Science & Technology. Available online 11 April 2024

https://doi.org/10.1111/ijfs.17106