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Modelling supply chain sustainability challenges in the food processing sector amid the COVID-19 outbreak

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ABSTRACT

The recent COVID-19 pandemic has significantly impacted most businesses and their supply chains. Due to the negative impacts of COVID-19, businesses have been facing numerous challenges. Among them, sustainability challenges are critical for any supply chain. In the literature, several studies have discussed the impacts of the COVID-19 pandemic on supply chains; however, there is a significant research gap in analysing supply chain sustainability challenges amid the COVID-19 outbreak in a particular context. To fill this research gap, this study aims to develop a systematic approach to identifying and analysing COVID-19 outbreak-related supply chain sustainability challenges in the context of the Australian food processing sector. To achieve the aims, this paper develops a mixed-method approach consisting of both qualitative and quantitative techniques, namely online survey and the Best-Worst method. From the online survey among experts from the Australian food processing sector, 22 sustainability challenges were finalised and categorised into four categories, namely, economic, environmental, social and ethical, and operational challenges. The empirical findings from the exploratory investigation reveal that increased food processing cost, lack of transparency and traceability, increase in price of raw materials, lack of capital and physical resources, and spread of fake information are the top five sustainability challenges to the Australian food processing sector due to the impacts of the COVID-19 outbreak. The findings of this study will help decision-makers, practitioners, and policymakers by developing the policies, guidelines, and strategies to overcome the most impactful sustainability challenges to ensure sustainable recovery from the impacts of the COVID-19 outbreak.

1. Introduction

The recent COVID-19 pandemic disease significantly affected health, economy, social life, and supply chain activities. The disruptions in supply chains are severe due to interruptions in transportation, production facilities, supply, and demand, with unbalance across the supply chain network. On the one hand, research showed the demand for some necessary items, such as dried foods, toilet papers, sanitiser, and face masks, has increased [1]. On the other hand, the demand for other items, such as apparel, car, and electronics, has reduced. Due to the impacts of the COVID-19 outbreak, the food processing industry is one of the most affected sectors. The Australian food processing sector is not an exception and has been significantly impacted by the COVID-19 outbreak. The demand for some food products, such as dried and canned food, has increased due to panic buying [2], while exports of other food products, such as seafood, have decreased due to border closures. By mid-March 2020, it was reported that the COVID-19 outbreak impacted more than 60% of Australian businesses, and among them, the manufacturing sectors have been hit hard [3]. The food processing sector is one of Australia's biggest manufacturing and fastest-growing sectors. The demand for food products increased by 2.4% on average from 1988 to 89 to 2016–17 [4]. According to the report published by the Australian Food and Grocery Council, the food sector in Australia has a turnover of $131.3 billion and more than 324,000 direct employments [5]. Due to the economic importance of the food sector and the devastating impacts of the COVID-19 outbreak, this study takes the Australian food processing sector as the context of the study to analyse its supply chain sustainability challenges. Grey literature indicates that some domestic producers faced a demand decline due to the closure of food services, cafes, and restaurants [6]. The food processing sector has also faced a

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Table 1
Different COVID-19 outbreak-related studies in supply chains.

Reference	Contributions and Findings	Area of supply chain	Methodology Used	Context
[15]	The authors analysed the effect of COVID-19 on the food security of the Canadian food supply chain. They identified several impacts, including food shortages and price increases, limited international exchange, and the lack of farm's financial stability.	Entire supply chain	Researcher's perspective	Food supply chain of Canada
[14]	The authors investigated if short food supply chains are relevant. They concluded that a short supply chain and local production could help the food supply chain.	Entire supply chain	Researcher's perspective	Food supply chain
[13]	The authors investigated the mitigation strategies for the disruptions from the COVID-19 outbreak. They found that the movement of necessary goods and the safety of labour are important to mitigate the impacts.	Entire supply chain	Commentary	Food supply chain of India
[17]	The authors analysed how the COVID-19 outbreak will impact the food supply chain. They found that the entire food supply chain will be affected significantly, including farms and upstream and downstream supplies.	Entire supply chain	Researcher's perspective	Food supply chain of India
[18]	The authors analysed the impacts of COVID-19 on the fruits and vegetable supply chain. They found that there are both short-term and long-term impacts on fruits and vegetable markets, including demand loss, the closure of distribution, and price increases.	Entire supply chain	Secondary data analysis	Food supply chain of Canada
[20]	The authors analysed the impact of the COVID-19 outbreak on the agriculture sector. They found that there will be significant global impacts on the agricultural supply chain, including difficulties in the accessibility of food, issues with food security, price volatility, issues with food safety, and broken supply chains.	Entire supply chain	Secondary data analysis	Food supply chain
[19]	The authors summarised the possible ways of transmission of COVID-19 through the food supply chain, surfaces, and the environment. They found that more safety measures are needed when the supply chain is long as more people are involved in the supply chain process.	Entire supply chain	Review	Food supply chain
[21]	The authors provided solutions for medical equipment needed during the COVID-19 outbreak and recommended that 'low-tech' solutions have a real impact.	Entire supply chain	Researcher's perspective	Healthcare supply chain
[22]	The authors developed a decision support system for demand management during COVID-19 in the healthcare supply chain.	Demand	Fuzzy inference system	Healthcare supply chain
[23]	The authors assessed the role of applied innovative technologies in recovering ventilators' production and supply chain.	Production and distribution	Review	Healthcare supply chain
[26]	The authors analysed the allocation and reallocation of ventilators and estimation of shortfall during the COVID-19 outbreak and observed that there will be a shortfall in the production of ventilators.	Entire supply chain	Stochastic optimisation	Healthcare supply chain
[7]	The author predicted the impacts of the COVID-19 outbreak on the global supply chain and reported several impacts, including ripple effect, supply chain disruption, disturbances in supply, logistics infrastructure and demand, long-term disruption existence, economic impact, and supply chain performance.	Entire supply chain	Simulation modelling	Global supply chain
[43]	The author theorised the viable supply chain in the light of the COVID-19 outbreak and reported that there will be long-term impacts and disruptions in supply chains.	Entire supply chain	Simulation modelling	General context
[34]	The authors introduced a concept of integrity of the intertwined supply network and viability to improve resiliency in the wake of the COVID-19 outbreak. They reported that there are ripple effects and supply chain collapse due to the impacts of the COVID-19 outbreak.	Entire supply chain	Dynamic game-theoretic modelling	General context
[1]	The authors developed a production model to recover from the impacts of COVID-19 for a high-demand item. They found that recovery strategies can play a big role.	Production system	Mathematical model and optimisation	General context
[28]s	The authors reported that the quick ramp-up of COVID-19 drugs can help mitigate the demand surge.	Production and demand	Researcher's perspective	Pharmaceutical supply chain
[44]	The authors provided research directions for moving towards sustainable supply and demand in the post-COVID-19 era.	Entire supply chain	Researcher's perspective	General context
[45]	The authors addressed the prioritisation and focus of supply chain managers to deal with the impacts of the COVID-19 outbreak. They highlighted that building smarter and more resilient supply chains and increasing the sustainable consumption perspective can be useful in managing the impacts.	Entire supply chain	Researcher's perspective	General context
[46]	The authors presented a systematic analysis of the impacts of epidemic outbreaks on supply chains guided by a structured literature review.	Entire supply chain	Review	General context
[33]	The authors investigated strategies to manage disruptions due to the COVID-19 outbreak in toilet paper manufacturing.	Production	Analytical model	Toilet paper's manufacturing supply chain
[47]	The author explored how logistics and technologies together can transform the 'static service operations' to become the 'bring-service-near-your-home' mobile service operations and reported that 'bring-service-near-your-home' can be an effective strategy.	Entire supply chain	Analytical model	Supply chains of Hong Kong
[42]	The authors analysed the implications of the COVID-19 outbreak on modern slavery risks in supply chains and reported that there could be a rise in worker vulnerability and modern slavery risks.	Entire supply chain	Discussion	General context
[29]	The authors investigated the reasons behind the lack of social sustainability in the clothing supply chains operating in South Asian countries and suggested ways to address them. They reported that sharing risk, prohibiting unauthorised subcontracting, and encouraging NGO participation can effectively deal with the impacts.	Sourcing and production	Case study	Apparel supply chain in south Asian countries
[31]	The authors examined the new contemporary challenges of adopting and implementing environmental sustainability policies.	Entire supply chain	Researcher's perspective	Global airline industry

(*continued on next page*)

Table 1 (*continued*)

Reference	Contributions and Findings	Area of supply chain	Methodology Used	Context
[48]	The authors identified and analysed a list of supply chain recovery challenges in the context of the ready-made garment industry.	Entire supply chain	Delphi and grey DEMATEL	Ready-made garment industry
[49]	The authors analysed the impacts of the COVID-19 outbreak and developed a recovery planning model using a simulation approach.	Entire supply chain	Agent-based modelling and simulation	PPE manufacturing supply chain
[50]	The authors analysed risk mitigation strategies during the COVID-19 outbreak.	Entire supply chain	Fuzzy BWM	Perishable food supply chain of India

shortage of labour, longer supply and delivery lead times, stockout of dried food items, increased market complexity, and increased bio-security regulations [6].

Due to the large-scale disruptions of the COVID-19 outbreak, sustainability practices (economic, environmental, and social practices) in supply chains are significantly affected. Also, organisations face numerous challenges in their operations, finances, and supply chains [7]. Many organisations are struggling to survive economically. The environmental and social sustainability practices are significantly affected as organisations are trying to survive the financial shock (A [8]. As sustainability practices are significantly affected, it is important to investigate different sustainability challenges due to the impacts of the COVID-19 outbreak. However, a limited number of studies in the literature have investigated sustainability challenges in the supply chain due to a large-scale and global pandemic such as the COVID-19 outbreak. In particular, Australia is a very large country mostly inhabited by long distances between regions. The impacts of the COVID-19 outbreak on Australian supply chains were severe due to border closures and restricted interstate travels. Therefore, a study investigating identifying and analysing supply chain sustainability challenges in the context of the Australian food processing sector due to the impacts of the COVID-19 outbreak would be particularly interesting given the unique characteristics of Australia, with particular reference to its geography and supply chain network, as well as its growth, economic, and social importance.

This study has a two-phase process. In the first phase, a list of sustainability challenges is finalised in the context of the Australian food processing sector through an online questionnaire survey. Then, the final list of sustainability challenges is analysed using a quantitative method in the second phase. As a number of challenges are involved in the analysis, a multi-criteria decision-making (MCDM) method is applied to analyse the sustainability challenges. The MCDM method can handle multiple criteria to determine the priority ranking by determining the weights of multiple challenges [9]. Further, several review articles on MCDM methods applied in different dimensions of green supply chains are available in the literature [10,11]. Those review papers also confirmed the applicability of MCDM methods in supply chain disciplines.

Though a number of studies analysed the impacts of the COVID-19 outbreak on the supply chain in the literature, there is a research gap in analysing sustainability challenges in a particular context. This study aims at contributing to the academic discussion by addressing the following research questions (RQs).

RQ1: What are the sustainability challenges faced by supply chains of the Australian food processing sector due to the impacts of the COVID-19 outbreak?
RQ2: What are the priority rankings of sustainability challenges?

To answer the above-mentioned RQs, this paper considers the following research objectives.

i. Identify supply chain sustainability challenges (such as economic, environmental, social and ethical, and operational challenges) in the context of the Australian food processing sector due to the impacts of the COVID-19 outbreak.
ii. Analyse sustainability challenges and prioritise the identified sustainability challenges using the best-worst method (BWM).
iii. Provide implications for the practice.

2. Literature background

Recently, a systematic literature review on COVID-19 related supply chain studies was published, and it discussed the impacts of COVID-19, resiliency, sustainability, and the importance of implementing technologies during the COVID-19 outbreak [12]. This section discusses a brief literature review on COVID-19 outbreak studies in supply chains and sustainability areas to make this review more streamlined.

2.1. Studies on COVID-19 outbreak studies in supply chains

There are several COVID-19 outbreak-related studies published in the literature in the supply chain area. Most of them discuss the impacts of the COVID-19 outbreak on the supply chains of different industry sectors [12]. For example, owing to the COVID-19 outbreak, the supply chains of many industry sectors have been impacted, including food [13–20], healthcare [21–27]; D. E. C. [28], apparel [29], retail [30], airlines [31], and other manufacturing sectors [32,33].

Researchers also discussed several impacts of COVID-19 on supply chains, such as the breakdown of transportation and supply chain networks [27,34–36], supply failures and delays [23,37–40], reduction in manufacturing capacities [25], adverse economic impacts [41], and rise of health and safety issues [19,42].

The contributions, findings, methodology, and context of different COVID-19 related studies in supply chains are summarised in Table 1.

2.2. COVID-19 outbreak and sustainability

Several COVID-19 related studies focused on supply chain sustainability.

A recently published article reported the impacts of the COVID-19 outbreak on the decarbonisation of agroecosystems and found that carbon dioxide emissions have reduced in the agri-food sectors in European countries [51]. [52] investigated the criteria for sustainable supplier selection during the COVID-19 outbreak in the context of the Nigerian manufacturing sector and found that the COVID-19 outbreak significantly changed the criteria for selecting sustainable suppliers. Similarly [53], evaluated supplies based on social sustainability innovation criteria and found that the criteria related to health and safety, remote working, and localisation are important during the COVID-19 outbreak [54]. analysed and prioritised the mitigation strategies to improve environmental performance in the clothing supply chain and found that agility, green sourcing and practice, and building trust and coordination are important during the COVID-19 outbreak. Moreover [55], explored the enablers and drivers of a sustainable supply chain to mitigate the impacts of the COVID-19 outbreak and found that an established health protocol and automation in supply chain operations are important to improve supply chain sustainability performance.

Recently [56], investigated the impacts of human behaviours on food shortage and food waste during the COVID-19 outbreak and discussed the implications of sustainability on food supply chains [57]. measured the engagement in sustainability practices of community pharmacies

during the COVID-19 outbreak and found that green procurement practices should be enhanced to improve sustainability practices [58]. discussed the triple bottom line (TBL) dimensions of sustainability and identified research questions focusing on economic, social, and environmental sustainability amid the COVID-19 outbreak [59]. explored the drivers of sustainable global supply chains for frugal innovation and found that government support, leadership, and emerging technologies could help in dealing with the humanitarian crisis of the COVID-19 outbreak [60]. analysed the impacts of the COVID-19 outbreak on sustainability learning and found that social sustainability was the main focus of suppliers during the outbreak.

[61] analysed the impacts of several strategies on supply chain sustainability performance and found that an organisation's capabilities, leadership, and contingency plan positively impacted sustainability performance during the COVID-19 outbreak [62]. investigated the trend of modern slavery in the post-COVID-19 era and found that modern slavery risk could increase and government should explore the governance gaps to fill them. Some other studies on different dimensions of sustainable supply chains and the COVID-19 outbreak are also available in the literature [63–65]; Z [66].

Though researchers discussed the impacts and challenges, mostly economic and operational, on different industry sectors, only a few studies mentioned some challenges in the context of the COVID-19 outbreak. Some examples of the reported sustainability challenges in the literature due to the impacts of the COVID-19 outbreak, are lack of cash flow in the market [41], an increase in price of raw materials [15,67], lack of green manufacturing practices [68], negative environmental impacts of continuous cleaning and disinfecting activities [69], increase in waste [42,70], increased rate of unemployment [41,71], violation of code of conduct in ethical practices [29], rise in modern slavery [42], and reduction in production capacity and longer supply lead-time [25,33].

In summary, academic literature identified a few supply chain sustainability challenges as impacts of the COVID-19 outbreak in different industries' and countries' contexts. There is a significant research gap in analysing supply chain sustainability challenges comprehensively in a particular context using a systematic research methodology. To fill this research gap, this study takes the first step to thoroughly identify, analyse, and prioritise COVID-19 outbreak-related supply chain sustainability challenges in the Australian food processing sector by applying a systematic research methodology. This paper also contributes to the literature by developing a research framework that integrates both qualitative and quantitative methods.

3. Research methodology

This research integrates a qualitative online survey and a quantitative method to identify and analyse the challenges to achieving the objectives. The research methodology is presented in Fig. 1.

3.1. Identifying the initial list of sustainability challenges

The initial list of sustainability challenges is determined through a review of academic literature and from industry literature such as news and magazine articles. The Scopus and Google Scholar databases are used to search academic articles, and the Google search engine is used to find industry articles from reputed newspapers and professional magazines. Several opinions and short articles related to the COVID-19 outbreak and sustainability are published in the academic literature. In addition, there are several industry articles related to sustainability and the COVID-19 outbreak. Both academic and grey literature has been reviewed to prepare an initial list of sustainability challenges due to the impacts of the COVID-19 outbreak.

3.2. Finalising the list of sustainability challenges

The initial list is prepared through a review of academic and industry articles. However, this list should be contextualised for the specific context of the study. In this regard, an expert survey is conducted to finalise the list of sustainability challenges for the context of the food supply chain in Australia. The survey participants are supply chain executives and managers working in the food processing sector in Australia.

3.3. Analysing and prioritising the sustainability challenges

The final list, determined through the online survey, is used for further study to analyse and prioritise them. The BWM is employed to analyse and prioritise the challenges. The advantages of applying the BWM are as follows.

- The data collection of this method is easy as it does not require a pairwise comparison. The data can be collected using a linguistic 1–9 scale [72].
- This method can determine the optimal weight [72].
- The BWM is a data-efficient method and the results from this method are reliable and consistent [72].

The steps of the BWM are as follows [72].

Step 1: Determine the *best* and *worst* sustainability challenges.

The best sustainability challenge is the most critical and the worst sustainability challenge is the least critical. In this step, experts simply mention the best and worst challenges without any comparison.

Step 2: Determine the preference of the *best* sustainability challenge over the other sustainability challenges

In this step, experts undertake a comparison of the best sustainability challenge over the other sustainability challenges using a linguistic scale, as shown in Table 2. The comparison vector can be formatted as follows:

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$$

where a_{Bj} represents the preference of the best sustainability challenge over the sustainability challenge *j*. Hence, $a_{BB} = 1$.

Step 3. Determine the preferences of all the other sustainability challenges over the *worst* sustainability challenge.

In this step, experts again compare the other sustainability challenges to the worst sustainability challenge using the same linguistic scale as shown in Table 2. The formulated comparison vector can be formatted as follows:

$$A_W = (a_{1W}, a_{2W}, \ldots., a_{nW})$$

where a_{jW} indicates the preference of the *j* challenge over the worst challenge and $a_{WW} = 1$.

Step 4: Finding the optimal weights of challenges *(w_1*, w_2*, …, w_n*)*

To determine the optimal weights of sustainability challenges (w_1*, w_2*, …, w_n*), the maximum absolute differences for all *j* challenges can be minimised among the set of $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$, and the problem can be formulated as follows:

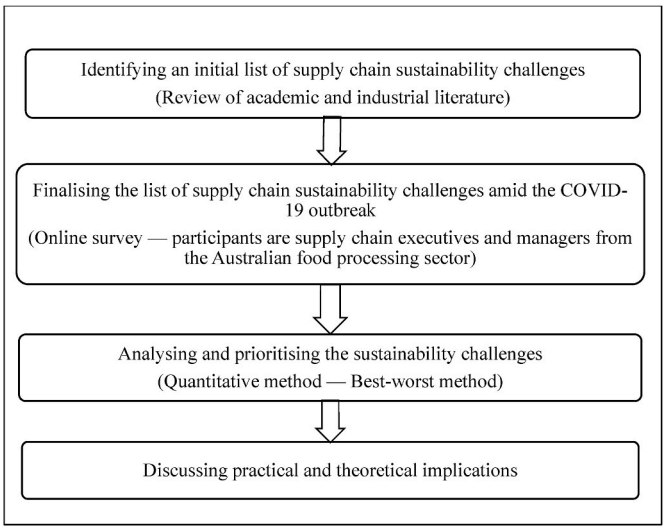

Fig. 1. Research methodology for analysing sustainability challenges.

$$minmaxj\left\{\left|w_B - a_{Bj}w_j\right|, \left|w_j - a_{jW}w_W\right|\right\}$$
$$Subject\ to,$$
$$\sum_j w_j = 1, \qquad \text{(model 1)}$$
$$w_j \geq 0, for\ all\ j$$

The non-linear model (1) can be transferred to a linear model and is given as follows:

$$min\ \xi^L,$$
$$Subject\ to,$$
$$\left|w_B - a_{Bj}w_j\right| \leq \xi^L, for\ all\ j,$$
$$\left|w_j - a_{jW}w_W\right| \leq \xi^L, for\ all\ j, \qquad \text{(model 2)}$$
$$\sum_j w_j = 1,$$
$$w_j \geq 0, for\ all\ j$$

The optimal weights of the sustainability challenges (w_1^*, w_2^*, …, w_n^*) and ξ^L can be established by solving the linear programming (LP) problem shown in model (2). The excel solver can be used to solve model (2).

Table 2
Linguistic scale of the BWM.

Linguistic scale	Meaning
1	Equal preference
2	Equal to moderate preference
3	Moderate preference
4	Moderate to strong preference
5	Strong preference
6	Strong to very strong preference
7	Very strong preference
8	Very strong to extreme preference
9	Extreme preference

Examples.
When determining the preference of the *best* sustainability challenge over the other sustainability challenges, linguistic 3 represents moderately less preference. Similarly, linguistic 9 represents extremely less preference. The other scales should be interpreted similarly.
When determining the preferences of all the other sustainability challenges over the *worst* sustainability challenge, linguistic 3 represents moderately more preference. Similarly, linguistic 9 represents extremely more preference. The other scales should be interpreted similarly.

Table 3
The initial list of sustainability challenges.

Category	Name of the challenge	Sources
Economic challenges	Lack of capital and physical resources	[70]
	Lack of cash flow in the market	[41]
	Increase in price of raw materials	[15,67]
Environmental challenges	Difficulties in implementing environmental sustainability policies	[31]
	Lack of green manufacturing practices	[68]
	Negative environmental impacts of continuous cleaning and disinfecting activities to provide protection from COVID-19	[69]
	Increase in waste	[42,70]
Social and ethical challenges	Loss of jobs/Increase rate of unemployment	[41,71]
	Violation of code of conduct in ethical practices	[29]
	Rise in modern slavery	[42]
	Lack of health and safety equipment	[41,74]
	Lack of collaborations	[40]
Operational challenges	Lack of skilled workforce	[6,24,42]
	Fluctuating market demand	[13,75]
	Shortage of supply/raw material	[1,33,37,76]
	Breakdown of the transportation network	[15,24,75,77]
	Reduction in production capacity	[25,33]
	Long-lasting impacts	[69]
	Longer supply lead-time	[6,76]

3.4. Discussing practical and theoretical implications

In this stage, the results are discussed and the practical and theoretical implications of the results are provided. This discussion helps practitioners from the food processing sector to prepare and formulate strategies to deal with the COVID-19 related supply chain sustainability challenges.

4. Results analysis

This section discusses the results to identify and finalise the list of sustainability challenges and their analyses using the BWM. Sensitivity analysis is also discussed to prove the robustness of the findings.

4.1. Finalising the list of sustainability challenges

A number of articles on the COVID-19 outbreak in supply chain management has been discussed in Section 2. In the specific area of supply chain sustainability, discussion about job loss and issues in health and safety [41], social, economic, and health inequality [73], modern slavery risk [42], damage in code of conduct [29], lack of green practices [68], increase in food waste and resource uses [70], increase in

Table 4
Experts' profiles for finalising sustainability challenges.

Expert Number	Number of years of experience	Position	Size of the organisation
1	20	Manager	0–19
2	15	Head of logistics	20–199
3	11	Supervisor	20–199
4	22	Regional manager	>200
5	18	Manager	>200
6	4	Owner	0–19
7	18	Manager	20–199
8	10	Relationship Manager	0–19
9	8	Owner	0–19
10	16	Manager	20–199

Table 5
Final list of sustainability challenges.

Category and notation	Name of the challenge and notation	Sources LR = Literature review
Economic challenges (SC1)	Lack of capital and physical resources (SC11)	LR + Survey
	Lack of cash flow in the market (SC12)	LR + Survey
	Increase in price of raw materials (SC13)	LR + Survey
	Increased food processing cost (SC14)	Survey
Environmental challenges (SC2)	Lack of green manufacturing practices (SC21)	LR + Survey
	Negative environmental impacts of continuous cleaning and disinfecting activities to provide protection from COVID-19 (SC22)	LR + Survey
	Increase in food waste (SC23)	LR + Survey
Social and ethical challenges (SC3)	Rise in modern slavery (SC31)	LR + Survey
	Breakdown of trust in supply chain (SC32)	Survey
	Lack of transparency and traceability (SC33)	Survey
	Spread of fake information (SC34)	Survey
	Lack of collaborations (SC35)	LR + Survey
	Slow communication among supply chain partners (SC36)	Survey
Operational challenges (SC4)	Lack of skilled workforce (SC41)	LR + Survey
	Fluctuating market demand (SC42)	LR + Survey
	Shortage of supply/raw material (SC43)	LR + Survey
	Breakdown of the transportation network (SC44)	LR + Survey
	Reduction in production capacity (SC45)	LR + Survey
	Long-lasting impacts (SC46)	LR + Survey
	Longer supply lead-time (SC47)	LR + Survey
	Delay in upgrading supply chain technology (SC48)	Survey
	Frequent changes in planning (SC49)	Survey

Table 6
Experts' profiles for BWM analysis.

Expert's code	Number of years of experience	Position	Size of the organisation
E1	14	Regional manager	20–199
E2	11	Operations manager	20–199
E3	8	Logistics specialist	0–19
E4	11	Manager	20–199
E5	5	Supply chain analyst	0–19
E6	7	Inventory analyst	20–199
E7	10	Purchasing manager	0–19
E8	6	Supervisor	20–199
E9	14	Manager	>200
E10	17	Manager	20–199
E11	4	Owner	0–19
E12	8	Purchasing manager	>200

plastic and food waste (H. B. [8], and the challenge in maintaining environmental sustainability practices [31] were found in the literature. The list of sustainability challenges is scattered in the literature on the COVID-19 outbreak in SSCM. No study thoroughly identified and analysed supply chain sustainability challenges using a systematic methodological approach in the context of the food processing sector. An initial list of sustainability challenges is collected through a review of academic and industrial literature. Table 3 presents the initial list of sustainability challenges and their sources.

Table 7
Feedback from experts for BWM.

Category	Name of the challenge	Experts mentioned as the best challenge	Experts mentioned as the worst challenge
Economic challenges (SC1)		E1, E2, E4, E5, E8, E10	
	Lack of capital and physical resources (SC11)	E10	E3, E6, E11
	Lack of cash flow in the market (SC12)	E1	E2, E4, E5, E7, E8, E9, E12
	Increase in price of raw materials (SC13)	E4, E6, E9	E10
	Increased food processing cost (SC14)	E2, E3, E5, E7, E8, E11, E12	E1
Environmental challenges (SC2)			E3, E4, E5, E7, E8, E11, E12
	Lack of green manufacturing practices (SC21)		E1, E3, E4, E5, E6, E8, E9, E10, E12
	Negative environmental impacts of continuous cleaning and disinfecting activities to provide protection from COVID-19 (SC22)	E4, E6, E9	E2, E7, E11,
	Increase in food waste (SC23)	E1, E2, E3, E5, E7,E8,E10, E11,E12	
Social and ethical challenges (SC3)		E3, E6, E7, E9, E11, E12	E1, E2, E10
	Rise in modern slavery (SC31)		E2, E4, E5, E6, E7, E9, E11, E12
	Breakdown of trust in supply chain (SC32)		E10
	Lack of transparency and traceability (SC33)	E1, E3, E4, E5, E6, E7, E8, E9, E10, E12	
	Spread of fake information (SC34)	E2, E11	
	Lack of collaborations (SC35)		E1,E3,E8
	Slow communication among supply chain partners (SC36)		
Operational challenges (SC4)			E6, E9
	Lack of skilled workforce (SC41)		
	Fluctuating market demand (SC42)	E3, E4, E7, E8, E10, E12	
	Shortage of supply/raw material (SC43)	E2, E5, E11	
	Breakdown of the transportation network (SC44)		
	Reduction in production capacity (SC45)		E1, E3, E5, E6, E7, E8, E10, E12
	Long-lasting impacts (SC46)		
	Longer supply lead-time (SC47)	E1, E6, E9	
	Delay in upgrading supply chain technology (SC48)		E2, E4, E9
	Frequent changes in planning (SC49)		E11

Note: Best challenge means most impactful and worst challenge means least impactful.

To finalise and contextualise the list of sustainability challenges, we collected information from Australian food processing industry experts through an online questionnaire survey, as shown in **Appendix A**.

Table 8
Computed weights for the categories of sustainability challenges.

Expert's code		SC1	SC2	SC3	SC4
E1	Best (SC1)	1	3	7	4
	Worst (SC3)	7	4	1	3
	Weights	0.5614	0.2105	0.0702	0.1579
E2	Best (SC1)	1	4	7	3
	Worst (SC3)	7	3	1	4
	Weights	0.5614	0.1579	0.0702	0.2105
E3	Best (SC3)	4	7	1	3
	Worst (SC2)	3	1	7	4
	Weights	0.1579	0.0702	0.5614	0.2105
E4	Best (SC1)	1	8	5	3
	Worst (SC2)	8	1	3	5
	Weights	0.5817	0.0619	0.1337	0.2228
E5	Best (SC1)	1	6	3	4
	Worst (SC2)	6	1	6	2
	Weights	0.5350	0.0637	0.2293	0.1720
E6	Best (SC3)	3	4	1	7
	Worst (SC4)	4	3	7	1
	Weights	0.2105	0.1579	0.5614	0.0702
E7	Best (SC3)	5	7	1	4
	Worst (SC2)	4	1	7	5
	Weights	0.1485	0.0655	0.6004	0.1856
E8	Best (SC1)	1	6	5	4
	Worst (SC2)	7	1	6	5
	Weights	0.5815	0.0617	0.1586	0.1982
E9	Best (SC3)	3	4	1	7
	Worst (SC4)	4	3	7	1
	Weights	0.2105	0.1579	0.5614	0.0702
E10	Best (SC1)	1	5	7	4
	Worst (SC3)	7	6	1	5
	Weights	0.5914	0.1561	0.0575	0.1951
E11	Best (SC3)	3	7	1	4
	Worst (SC2)	4	1	7	5
	Weights	0.2252	0.0596	0.5464	0.1689
E12	Best (SC3)	6	7	1	4
	Worst (SC2)	4	1	7	5
	Weights	0.1269	0.0672	0.6157	0.1903
Average weight (k* = 0.1173)		0.3743	0.1075	0.3472	0.1710
Rank		1	4	2	3

Table 9
Computed weights for the sustainability challenges under the economic challenges category.

Experts code		SC11	SC12	SC13	SC14
E1	Best (SC12)	3	1	4	7
	Worst (SC14)	5	7	3	1
	Weights	0.2186	0.5531	0.1640	0.0643
E2	Best (SC14)	2	7	4	1
	Worst (SC12)	6	1	4	7
	Weights	0.2941	0.0588	0.1471	0.5000
E3	Best (SC14)	7	5	4	1
	Worst (SC11)	1	6	3	7
	Weights	0.0575	0.1561	0.1951	0.5914
E4	Best (SC13)	5	9	1	3
	Worst (SC12)	3	1	9	5
	Weights	0.1319	0.0579	0.5903	0.2199
E5	Best (SC14)	2	9	3	1
	Worst (SC12)	7	1	6	9
	Weights	0.2825	0.0448	0.1883	0.4843
E6	Best (SC13)	7	4	1	2
	Worst (SC11)	1	2	7	4
	Weights	0.0721	0.1351	0.5225	0.2703
E7	Best (SC14)	4	7	5	1
	Worst (SC12)	5	1	4	7
	Weights	0.1856	0.0655	0.1485	0.6004
E8	Best (SC14)	3	9	5	1
	Worst (SC12)	7	1	5	9
	Weights	0.2328	0.0506	0.1397	0.5769
E9	Best (SC13)	3	7	1	4
	Worst (SC12)	4	1	7	5
	Weights	0.2252	0.0596	0.5464	0.1689
E10	Best (SC11)	1	5	7	4
	Worst (SC13)	7	4	1	5
	Weights	0.6004	0.1485	0.0655	0.1856
E11	Best (SC14)	7	4	5	1
	Worst (SC11)	1	3	4	7
	Weights	0.0681	0.1825	0.1460	0.6034
E12	Best (SC14)	3	7	5	1
	Worst (SC12)	5	1	4	7
	Weights	0.2294	0.0642	0.1376	0.5688
Average weight (k* = 0.1107)		0.2165	0.1314	0.2492	0.4029
Rank		3	4	2	1

Taking inspiration from earlier literature [50,78,79], we surveyed ten industry experts, with their profiles presented in Table 4. As shown, experts had managerial experience across organisation of different sizes (from micro enterprises to large ones) to cover a broad range of industry players within the Australian food processing industry. Also, the sampled experts had different roles in their organisation, allowing them to grasp different perspectives related to the sustainability challenges due to the impact of the COVID-19 pandemic.

Interestingly, experts suggested a revision of the initial list based on the literature review, arguing that some sustainability challenges from the initial list were not applicable to the specific Australian food processing industry. Further, they suggested a number of additional sustainability challenges that should be considered for analysis. Upon revision of the list of sustainability challenges, the final list has been finalised and presented in Table 5 for empirical investigation.

4.2. Analysing and prioritising the sustainability challenges

For analysing the sustainability challenges using BWM, we collected data using another survey from **12** experts using the questionnaire (reported in A**ppendix B).** The literature suggested a similar number of experts needed for the BWM [50,78–80]. We distributed a Google form link to participants from the Australian food processing sector to fulfil the values in a Microsoft Excel file. We received responses from 12 experts for analysing and prioritising the sustainability challenges. The profiles of experts for BWM are presented in Table 6. Note that the surveys for finalising sustainability challenges (as presented in Section 4.1) and analysing them were anonymous and conducted separately. It was not possible to check the overlap among experts for both surveys.

Experts were asked to select the best and worst challenges as per the questionnaire shown in Table B1 in Appendix B. The data for the best and worst challenges are summarised and presented in Table 7. For the main categories, it was observed that experts recommended either economic challenges (SC1) or social and ethical challenges (SC3) as the best categories. On the other hand, seven experts recommended environmental challenges (SC2), three experts recommended social and ethical challenges (SC3), and two experts recommended operational challenges (SC4) as the worst categories. Similarly, experts recommended their best and worst challenges under those four categories, as presented in Table 7. It was worth noting that most of the experts recommended increased food processing cost (SC14), increase in food waste (SC23), lack of transparency and traceability (SC33), and fluctuating market demand (SC42) as their best challenges. On the other hand, most of the experts recommended lack of cash flow in the market (SC12), lack of green manufacturing practices (SC21), rise in modern slavery (SC31), and reduction in production capacity (SC45) as the worst challenges.

Then, the experts were also asked to make the comparison matrix for the *b*est challenge preference over the other challenges and for all challenges over the worst challenge using the linguistic 1–9 scale as per the questionnaire shown in Tables B3 and B4 in Appendix B. These data are summarised for four main categories and challenges under those categories. Table 8 presents the data obtained from 12 experts for the best category over the other categories and all other categories over the worst category. Using this comparison data, the weight of each category was also computed by solving model 2 as presented in Section 3.3. The computed weights of each category by using the BWM are also presented

Table 10
Computed weights for the sustainability challenges under the environmental challenges category.

Experts code		SC21	SC22	SC23
E1	Best (SC23)	5	2	1
	Worst (SC21)	1	3	5
	Weights	0.1111	0.3056	0.5833
E2	Best (SC23)	5	3	1
	Worst (SC21)	1	2	5
	Weights	0.1250	0.2250	0.6500
E3	Best (SC23)	7	2	1
	Worst (SC21)	1	4	7
	Weights	0.0833	0.3125	0.6042
E4	Best (SC22)	6	1	2
	Worst (SC21)	1	6	4
	Weights	0.0909	0.5909	0.3182
E5	Best (SC23)	6	2	1
	Worst (SC21)	1	4	6
	Weights	0.0909	0.3182	0.5909
E6	Best (SC22)	9	1	2
	Worst (SC21)	1	9	5
	Weights	0.0667	0.6167	0.3167
E7	Best (SC23)	4	6	1
	Worst (SC22)	5	1	6
	Weights	0.2222	0.0833	0.6944
E8	Best (SC23)	7	2	1
	Worst (SC21)	1	4	7
	Weights	0.0833	0.3125	0.6042
E9	Best (SC22)	6	1	3
	Worst (SC21)	1	6	3
	Weights	0.1000	0.6600	0.2400
E10	Best (SC23)	6	2	1
	Worst (SC21)	1	4	6
	Weights	0.0909	0.3182	0.5909
E11	Best (SC23)	4	7	1
	Worst (SC22)	2	1	7
	Weights	0.1833	0.1000	0.7167
E12	Best (SC23)	7	3	1
	Worst (SC21)	1	4	7
	Weights	0.0833	0.2500	0.6667
Average weight (k* = 0.0502)		0.1109	0.3411	0.5480
Rank		3	2	1

in Table 8 and it was observed that the economic challenges (SC1) obtained the highest average weight of 0.3743, following the social and ethical challenges (SC3), operational challenges (SC4), and environmental challenges (SC2) with the values of average weights 0.3472, 0.1710, and 0.1075, respectively. These results are consistent with the experts' preferences as most of the experts recommended economic challenges (SC1) and social and ethical challenges (SC3) as their best preferences.

Similarly, the best challenge over the other challenges and all other challenges over the worst challenges were summarised as presented in Tables 9–12 for challenges under SC1, SC2, SC3, and SC4, respectively. Then, the weights of the challenges were computed by using the BWM. Using Table 9, it was observed that the increased food processing cost (SC14) obtained the highest average weight of 0.4029, following the increase in price of raw materials (SC13), lack of capital and physical resources (SC11), and lack of cash flow in the market (SC12) with the values of average weights 0.2492, 0.2165, and 0.1314, respectively. These results are consistent with the experts' preferences as most of the experts recommended increased food processing cost (SC14) as their best challenge.

Under the environmental challenges (SC2) category, an increase in food waste (SC23) obtained the highest average weight of 0.5480 as most of the experts recommended this as the best challenge under SC2. The computed weights of challenges under SC2 are presented in Table 10.

Under the social and ethical challenges (SC3) category, lack of transparency and traceability (SC33) obtained the highest average weight of 0.3431. This is consistent with the experts' recommendation, as most experts selected SC33 as their best preference. The computed weights of challenges under SC3 are presented in Table 11.

Under the operational challenges (SC4) category, fluctuating market demand (SC42) obtained the highest average weight of 0.2474. This is consistent with the experts' recommendation, as most experts selected SC42 as their best preference under SC4. The computed weights of challenges under SC4 are presented in Table 12.

The global weights of the challenges were also determined to obtain the overall priority ranking for all the challenges. Table 13 presents the global weights and overall ranking of all the sustainability challenges. The results show that increased food processing cost (SC14), lack of transparency and traceability (SC33), increase in price of raw materials (SC13), lack of capital and physical resources (SC11), spread of fake information (SC34), increase in food waste (SC23), breakdown of trust in the supply chain (SC32), lack of cash flow in the market (SC12), slow communication among supply chain partners (SC36), and fluctuating market demand (SC42) are the top 10 sustainability challenges due to the impacts of the COVID-19 outbreak. It was observed that all four challenges under SC1 were ranked in the top 10. However, four challenges from SC3, and one challenge each from SC2 and SC4 were ranked in the top 10. This means the economic challenges were most significant for the Australian food processing industry during the COVID-19 outbreak. Also, ethical and social challenges became dominant during the COVID-19 outbreak.

4.3. Sensitivity analysis

In this section, a sensitivity analysis is conducted to check the robustness of the proposed approach. In this paper, the value of the highest-ranked category (economic challenges) is changed from 0.1 to 0.9 [78,81] to examine the changes in weights of all the categories and sustainability challenges. Table 14 shows the changes in weights of four categories (SC1, SC2, SC3, and SC4). It was observed that SC3 obtains the highest weight when SC1 has values until 0.3. Further, SC1 obtains the highest weight. This variation is normal as most of the experts rated SC1 and SC3 as the most preferred (best) categories.

Similarly, the changes in weights of all the sustainability challenges are evaluated with the change of values of SC1 from 0.1 to 0.9. These changes in weights are presented in Table 15. It was observed that the lack of transparency and traceability (SC33) obtains the highest weight when SC1 has values until 0.3. Further, increased food processing cost (SC14) obtains the highest weight. This variation is normal as most experts rated SC14 and SC33 as the most preferred (best) sustainability challenges. These variations of weights of sustainability challenges are graphically presented in Fig. 2. Similarly, the changes in the ranking of sustainability challenges are presented numerically in Table 16.

The abovementioned study results and their relevance with respect to the literature are discussed in detail in the next section.

5. Results discussion

From the final list of sustainability challenges (see Table 4), it was observed that the difficulties in implementing environmental sustainability policies, loss of jobs/increased rate of unemployment, violation of code of conduct in ethical practices, and lack of health and safety equipment were removed from the final list as they were not valid in the context of the Australian food processing sector. Though we acknowledge that there were job losses in many countries due to the impacts of COVID-19, however, in Australia, the unemployment rate fell to the pre-COVID level during the COVID-19 recovery period. The unemployment rate was 5.1% in May 2021 compared to 5.3% in March 2020 [82]. Other challenges, such as the difficulties in implementing environmental sustainability policies, violation of code of conduct in ethical practices, and lack of health and safety equipment, were deemed by the sampled experts as not applicable in the Australian manufacturing business context, given the ongoing support provided by the Government on

Table 11
Computed weights for the sustainability challenges under the social and ethical challenges category.

Experts code		SC31	SC32	SC33	SC34	SC35	SC36
E1	Best (SC33)	7	3	1	2	9	1
	Worst (SC35)	3	6	9	5	1	7
	Weights	0.0546	0.1274	0.3262	0.1911	0.0306	0.2701
E2	Best (SC34)	9	3	4	1	7	2
	Worst (SC31)	1	4	2	9	2	7
	Weights	0.0394	0.1512	0.1134	0.4043	0.0648	0.2268
E3	Best (SC33)	7	4	1	2	9	3
	Worst (SC35)	2	7	9	6	1	5
	Weights	0.0685	0.1199	0.3806	0.2398	0.0313	0.1599
E4	Best (SC33)	7	3	1	2	4	6
	Worst (SC31)	1	5	7	6	3	2
	Weights	0.0447	0.1521	0.3848	0.2282	0.1141	0.0761
E5	Best (SC33)	9	3	1	2	4	5
	Worst (SC31)	1	5	9	7	3	2
	Weights	0.0384	0.1474	0.3941	0.2211	0.1105	0.0884
E6	Best (SC33)	9	4	1	3	6	2
	Worst (SC31)	1	5	9	6	2	7
	Weights	0.0361	0.1145	0.3916	0.1526	0.0763	0.2289
E7	Best (SC33)	9	2	1	3	5	6
	Worst (SC31)	1	7	9	5	3	2
	Weights	0.0399	0.2295	0.4092	0.1530	0.0918	0.0765
E8	Best (SC33)	7	2	1	3	9	6
	Worst (SC35)	2	7	9	5	1	4
	Weights	0.0689	0.2411	0.4112	0.1607	0.0378	0.0804
E9	Best (SC33)	7	2	1	3	5	6
	Worst (SC31)	1	7	9	5	3	2
	Weights	0.0447	0.2349	0.3915	0.1566	0.0940	0.0783
E10	Best (SC33)	7	9	1	3	5	6
	Worst (SC32)	2	1	9	5	3	2
	Weights	0.0783	0.0481	0.4902	0.1826	0.1096	0.0913
E11	Best (SC34)	7	3	2	1	5	6
	Worst (SC31)	1	4	6	7	3	2
	Weights	0.0484	0.1533	0.2300	0.3995	0.0920	0.0767
E12	Best (SC33)	7	3	1	2	5	6
	Worst (SC31)	1	4	5	7	3	2
	Weights	0.0556	0.1296	0.1944	0.1944	0.3611	0.0648
Average weight ($k^* = 0.0752$)		0.0515	0.1541	0.3431	0.2237	0.1012	0.1265
Rank		6	3	1	2	5	4

those areas [83]. Furthermore, seven new COVID-19 outbreak-related sustainability challenges such as increased food processing cost, breakdown of trust in the supply chain, lack of transparency and traceability, the spread of fake information, slow communication among supply chain partners, delay in upgrading supply chain technology, and frequent changes in planning, were added to the final list and the sampled experts suggested that importance of these challenges increased due to the impacts of COVID-19 in the Australian food processing industry.

The exploratory analysis of prioritising the sustainability challenges revealed that the category of economic challenges obtained the highest weight among the four different categories (see Table 8). A potential explanation of this can be found in the financial impact of the COVID-19 outbreak on most businesses. In fact, as recent industrial analyses show, the Australian food processing sector also went through an unprecedented financial crisis due to the impacts of the COVID-19 outbreak [6]. Moreover, the social and ethical challenges were also considered important for the Australian food processing sector as this category of challenges obtained the second highest weight. It was observed that social and ethical concerns had increased significantly in many businesses during the COVID-19 outbreak [84]. The operational and environmental challenges categories were the next two important categories. As from this first exploratory study, operational challenges seem to be more common in businesses during the COVID-19 outbreak [85] and the Australian food processing sector also faced many operational challenges, including fluctuating market demand and shortage of supply/raw material. Interestingly, our findings also confirm previous research by highlighting the relevance of several environmental challenges [19]. In particular, the Australian food processing sector faced some environmental challenges, such as an increase in food waste and negative environmental impacts of continuous cleaning and disinfecting activities.

In the final global priority ranking of sustainability challenges (see Table 13), we found that the increased food processing cost (economic challenge) was ranked first. The COVID-19 outbreak disrupted the global supply chain network and resulted in a shortage of raw materials supply and the availability of skilled labour. In this specific case, the Government imposed lockdowns and social distancing rules to contain and control the outbreak. Therefore, this ultimately led to food processing uncertainties and contributed to increasing its processing cost. According to our exploratory investigation, the second-ranked challenge is the lack of transparency and traceability, belonging to the social and ethical challenges. Our findings seem to resonate with previous research, whereby transparency and traceability became increasingly important to enhance the sustainability of the food processing sectors during the pandemic [86]. Interestingly, our investigation revealed the relevance of two economic challenges, such as an increase in price of raw materials and lack of capital and physical resources, both from the category of economic challenges, that were ranked third and fourth positions, respectively. In this case, we can note that long distances and limitations both in interstate and international travels particularly affected Australia, which also impacted the sourcing of physical resources. Further, under the category of social and ethical challenges, the spread of fake information became one of the most important challenges (ranked fifth position). In this case, previous research noted this as a crucial challenge, particularly on social media [87], since COVID-19 posed a clear threat to one of the perceived basic needs, such as food. For this reason, it is expected that the spread of fake or at least

Table 12
Computed weights for the sustainability challenges under the operational challenges category.

Experts code		SC41	SC42	SC43	SC44	SC45	SC46	SC47	SC48	SC49
E1	Best (SC47)	5	2	3	6	9	4	1	8	7
	Worst (SC45)	5	8	7	4	1	6	9	2	3
	Weights	0.0766	0.1915	0.1277	0.0638	0.0274	0.0958	0.3146	0.0479	0.0547
E2	Best (SC43)	8	2	1	4	7	5	3	9	6
	Worst (SC48)	2	8	9	6	3	5	7	1	4
	Weights	0.0479	0.1915	0.3146	0.0958	0.0547	0.0766	0.1277	0.0274	0.0638
E3	Best (SC42)	6	1	2	7	9	5	3	8	4
	Worst (SC45)	4	9	8	3	1	5	7	2	6
	Weights	0.0638	0.3146	0.1915	0.0547	0.0274	0.0766	0.1277	0.0479	0.0958
E4	Best (SC42)	3	1	2	8	5	6	4	9	7
	Worst (SC48)	8	9	7	2	5	4	6	1	3
	Weights	0.1290	0.3095	0.1935	0.0484	0.0774	0.0645	0.0967	0.0258	0.0553
E5	Best (SC43)	3	2	1	5	9	4	8	7	6
	Worst (SC45)	8	7	9	5	1	6	3	2	4
	Weights	0.1290	0.1935	0.3095	0.0774	0.0258	0.0967	0.0484	0.0553	0.0645
E6	Best (SC47)	8	2	3	5	9	4	1	7	6
	Worst (SC45)	2	8	7	5	1	6	9	3	4
	Weights	0.0479	0.1915	0.1277	0.0766	0.0274	0.0958	0.3146	0.0547	0.0638
E7	Best (SC42)	8	1	2	4	9	3	5	7	6
	Worst (SC45)	2	9	8	6	1	7	4	3	5
	Weights	0.0480	0.3133	0.1920	0.0960	0.0270	0.1280	0.0768	0.0549	0.0640
E8	Best (SC42)	8	1	2	4	9	3	5	6	7
	Worst (SC45)	3	9	8	6	1	7	5	4	2
	Weights	0.0479	0.3146	0.1915	0.0958	0.0274	0.1277	0.0766	0.0638	0.0547
E9	Best (SC47)	8	2	3	4	7	6	1	9	5
	Worst (SC48)	2	8	7	6	3	4	9	1	5
	Weights	0.0479	0.1915	0.1277	0.0958	0.0547	0.0638	0.3146	0.0274	0.0766
E10	Best (SC42)	8	1	2	4	9	7	6	5	3
	Worst (SC45)	2	9	8	6	1	3	4	5	7
	Weights	0.0479	0.3146	0.1915	0.0958	0.0274	0.0547	0.0638	0.0766	0.1277
E11	Best (SC43)	7	3	1	4	8	6	2	5	9
	Worst (SC49)	3	7	9	6	2	4	8	5	1
	Weights	0.0547	0.1277	0.3146	0.0958	0.0479	0.0638	0.1915	0.0766	0.0274
E12	Best (SC42)	8	1	2	3	9	5	4	7	6
	Worst (SC45)	2	9	8	7	1	5	6	3	4
	Weights	0.0479	0.3146	0.1915	0.1277	0.0274	0.0766	0.0958	0.0547	0.0638
Average weight (k* = 0.0701)		0.0657	0.2474	0.2061	0.0853	0.0376	0.0851	0.1541	0.0511	0.0677
Rank		7	1	2	4	9	5	3	8	6

misleading information about COVID-19 potential transmission through food represented a major challenge for the Australian food processing sector.

In conclusion, our preliminary study noted that the top five sustainability challenges prioritised by our investigated sample could refer to two main categories: economic and social and ethical challenges. To corroborate these findings, it was observed from the analysis that the increase in food waste, breakdown of trust in the supply chain, lack of cash flow in the market, slow communication among supply chain partners, and fluctuating market demand have become dominant and are placed into the top-10 sustainability challenges for the Australian food processing sector.

6. Managerial and theoretical implications

This section discusses the managerial and theoretical implications based on the findings of the study.

6.1. Managerial implications

Due to the COVID-19 outbreak, most businesses have been impacted. The food processing sector is not an exception, as it has been facing numerous COVID-19-related challenges. Supply chains of the Australian food processing sector consist of both local and international partners and markets. COVID-19 is a global pandemic, and it has impacted the Australian food processing sector both locally and internationally [6]. Hence, this study considered a real-life problem to identify and analyse sustainability challenges faced by the Australian food processing sector amid the COVID-19 outbreak. The findings of this study are important for both practitioners and policymakers. The key points of the managerial implications are explained below.

i. The findings of the study help Australian food processing practitioners obtain a holistic view of all the possible sustainability challenges amid the COVID-19 outbreak. This study found 22 different sustainability challenges related to the COVID-19 outbreak. Among them, nine challenges are operational as COVID-19 has significantly impacted the operational activities within supply chains. A decision-maker should focus on developing resilient strategies to overcome operational challenges. For example, strategies for preparedness, response, and recovery help mitigate the impacts of the COVID-19 outbreak on supply chain operations. Ultimately, this helps to overcome the economic challenges in the long term. In addition, this study identified six ethical and social challenges related to the COVID-19 outbreak. Among them, lack of transparency and traceability and the spread of fake information were most common during the COVID-19 outbreak. Decision-makers should develop and implement corporate social strategies to overcome these challenges. The decision-makers can use the final list of sustainability challenges to compare with their organisations to observe if any sustainability challenges have been overlooked. The present study would then provide a basis to help them identify and address the specific sustainability challenges.
ii. This study applied a quantitative method, namely BWM, to analyse and prioritise the sustainability challenges. The method can be used internally by specific companies to investigate their own sustainability challenges. Also, the final priority ranking will

Table 13
Final weights and priority ranking.

Category	Weight	Name of the challenge	Weight	Global Weight	Overall rank
Economic challenges (SC1)	0.3743	Lack of capital and physical resources (SC11)	0.2165	0.0810	4
		Lack of cash flow in the market (SC12)	0.1314	0.0492	8
		Increase in price of raw materials (SC13)	0.2492	0.0933	3
		Increased food processing cost (SC14)	0.4029	0.1508	1
Environmental challenges (SC2)	0.1075	Lack of green manufacturing practices (SC21)	0.1109	0.0119	18
		Negative environmental impacts of continuous cleaning and disinfecting activities to provide protection from COVID-19 (SC22)	0.3411	0.0367	11
		Increase in food waste (SC23)	0.5480	0.0589	6
Social and ethical challenges (SC3)	0.3472	Rise in modern slavery (SC31)	0.0515	0.0179	15
		Breakdown of trust in supply chain (SC32)	0.1541	0.0535	7
		Lack of transparency and traceability (SC33)	0.3431	0.1191	2
		Spread of fake information (SC34)	0.2237	0.0777	5
		Lack of collaborations (SC35)	0.1012	0.0351	13
		Slow communication among supply chain partners (SC36)	0.1265	0.0439	9
Operational challenges (SC4)	0.1710	Lack of skilled workforce (SC41)	0.0657	0.0112	20
		Fluctuating market demand (SC42)	0.2474	0.0423	10
		Shortage of supply/raw material (SC43)	0.2061	0.0352	12
		Breakdown of the transportation network (SC44)	0.0853	0.0146	16
		Reduction in production capacity (SC45)	0.0376	0.0064	22
		Long lasting impacts (SC46)	0.0851	0.0145	17
		Longer supply lead-time (SC47)	0.1541	0.0263	14
		Delay in upgrading supply chain technology (SC48)	0.0511	0.0087	21
		Frequent changes in planning (SC49)	0.0677	0.0116	19

help practitioners understand which sustainability challenges should gain more focus. Australian food processing practitioners could focus on increased food processing cost (ranked first) and lack of transparency and traceability (ranked second). To overcome economic challenges, decision-makers could consider developing resilience in their supply chains by collaborating with multiple suppliers from different regions of the world and using advanced technologies in manufacturing processes.

iii. The policymakers can consider the findings of this study to formulate appropriate strategies to overcome the prioritised sustainability challenges. Our research has revealed that developing risk management plans and appropriate proactive and reactive strategies related to supply chain resilience could be beneficial in mitigating some of the identified challenges, particularly on the difficulty in accessing physical resources.

6.2. Theoretical implications

Analysing supply chain sustainability challenges due to the impacts of the COVID-19 outbreak is a significant and practical research problem. COVID-19 has brought numerous challenges to businesses and their supply chains. Among them, sustainability challenges are one of the main areas for research. The theoretical implications of this study are highlighted below.

i. The main contribution of this study is to explore a new research problem on supply chain sustainability challenges due to the impacts of the COVID-19 outbreak. In the literature, there was a significant research gap in the quantitative analysis of COVID-19 outbreak-related sustainability challenges in supply chain discipline. This study fills this research gap.
ii. This study considers the supply chains of the Australian food processing sector as the context of the study, which had limited focus in the literature for analysing the impacts of the COVID-19 outbreak.
iii. This study develops a mixed-method approach to identify and analyse COVID-19 outbreak-related supply chain sustainability challenges. The mixed-method includes qualitative and quantitative methods, making the analysis and findings more comprehensive.

7. Conclusions and future research directions

This section discusses the concluding remarks of the study along with the limitations and future research directions.

The main objectives of this paper were to identify and analyse supply chain sustainability challenges in the context of the Australian food processing sector amid the COVID-19 outbreak. A mixed-method approach consisting of an online survey and the BWM was applied to achieve the objectives. The online survey was applied to finalise the list of sustainability challenges in the specific context and the BWM was used to analyse the sustainability challenges to determine their priority ranking. Moreover, a sensitivity analysis was undertaken to check the robustness of the proposed approach.

From the literature review and online survey, 22 sustainability challenges were finalised under four different categories (economic, environmental, social and ethical, and operational challenges). The finalised list was then used to collect data for the BWM analysis. Twelve supply chain experts from the Australian food processing sector provided data for the BWM analysis. The quantitative analysis observed that the COVID-19 outbreak significantly impacted the supply chain of the Australian food processing sector economically. Also, social and ethical challenges were ranked highly. In summary, the top-10 sustainability out of total 22 challenges for the Australian food processing sector due to the impacts of the COVID-19 outbreak were identified under four categories, namely, economic, environmental, social and ethical, and

Table 14
Changes in weights of the categories for the sensitivity analysis.

Selected Challenges		Values of preference weights for listed challenges								
	Normal (0.3743)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
SC1	0.3743	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000
SC2	0.1075	0.1546	0.1374	0.1203	0.1031	0.0859	0.0687	0.0515	0.0344	0.0172
SC3	0.3472	0.4994	0.4439	0.3884	0.3329	0.2774	0.2219	0.1665	0.1110	0.0555
SC4	0.1710	0.2460	0.2187	0.1913	0.1640	0.1367	0.1093	0.0820	0.0547	0.0273
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 15
Changes in weights of the sustainability challenges.

Selected Challenges	Normal (0.3743)	Weights								
		Values of preference weights for listed challenges								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
SC11	0.0810	0.0217	0.0433	0.0650	0.0866	0.1083	0.1299	0.1516	0.1732	0.1949
SC12	0.0492	0.0131	0.0263	0.0394	0.0526	0.0657	0.0788	0.0920	0.1051	0.1183
SC13	0.0933	0.0249	0.0498	0.0748	0.0997	0.1246	0.1495	0.1745	0.1994	0.2243
SC14	0.1508	0.0403	0.0806	0.1209	0.1611	0.2014	0.2417	0.2820	0.3223	0.3626
SC21	0.0119	0.0172	0.0152	0.0133	0.0114	0.0095	0.0076	0.0057	0.0038	0.0019
SC22	0.0367	0.0527	0.0469	0.0410	0.0352	0.0293	0.0234	0.0176	0.0117	0.0059
SC23	0.0589	0.0847	0.0753	0.0659	0.0565	0.0471	0.0377	0.0282	0.0188	0.0094
SC31	0.0179	0.0257	0.0228	0.0200	0.0171	0.0143	0.0114	0.0086	0.0057	0.0029
SC32	0.0535	0.0769	0.0684	0.0598	0.0513	0.0427	0.0342	0.0256	0.0171	0.0085
SC33	0.1191	0.1713	0.1523	0.1333	0.1142	0.0952	0.0762	0.0571	0.0381	0.0190
SC34	0.0777	0.1117	0.0993	0.0869	0.0745	0.0621	0.0496	0.0372	0.0248	0.0124
SC35	0.0351	0.0505	0.0449	0.0393	0.0337	0.0281	0.0225	0.0168	0.0112	0.0056
SC36	0.0439	0.0632	0.0562	0.0491	0.0421	0.0351	0.0281	0.0211	0.0140	0.0070
SC41	0.0112	0.0162	0.0144	0.0126	0.0108	0.0090	0.0072	0.0054	0.0036	0.0018
SC42	0.0423	0.0609	0.0541	0.0473	0.0406	0.0338	0.0270	0.0203	0.0135	0.0068
SC43	0.0352	0.0507	0.0451	0.0394	0.0338	0.0282	0.0225	0.0169	0.0113	0.0056
SC44	0.0146	0.0210	0.0186	0.0163	0.0140	0.0117	0.0093	0.0070	0.0047	0.0023
SC45	0.0064	0.0093	0.0082	0.0072	0.0062	0.0051	0.0041	0.0031	0.0021	0.0010
SC46	0.0145	0.0209	0.0186	0.0163	0.0139	0.0116	0.0093	0.0070	0.0046	0.0023
SC47	0.0263	0.0379	0.0337	0.0295	0.0253	0.0211	0.0168	0.0126	0.0084	0.0042
SC48	0.0087	0.0126	0.0112	0.0098	0.0084	0.0070	0.0056	0.0042	0.0028	0.0014
SC49	0.0116	0.0166	0.0148	0.0129	0.0111	0.0092	0.0074	0.0055	0.0037	0.0018
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

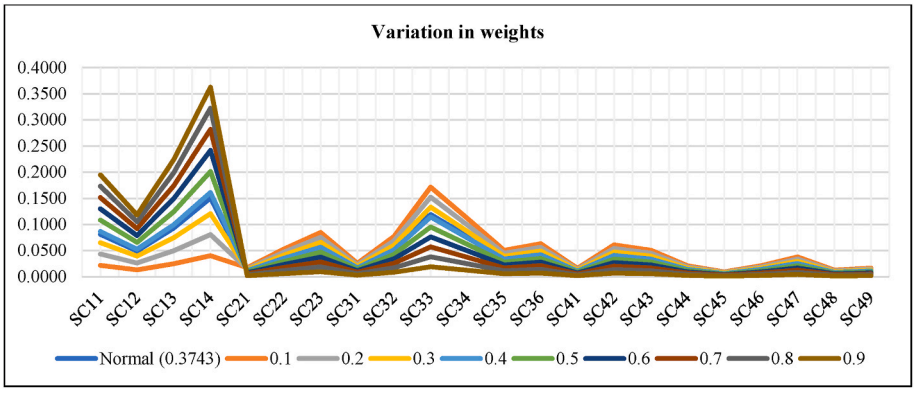

Fig. 2. Variation of weights of challenges while changing the weights of category SC1.

operational challenges. This paper significantly contributes to the food processing sector in the context of the COVID-19 outbreak by analysing sustainability challenges. However, this study also has some limitations. Firstly, this study considered only the Australian food processing sector as the context of the study and identified and analysed sustainability challenges due to the impacts of the COVID-19 outbreak. The analysis was based on the data collected from ten experts for finalising the list of sustainability challenges and twelve experts to analyse them using the BWM. Secondly, strategies to overcome sustainability challenges were not in the scope of the study. Thirdly, the interrelationships and cause and effect analysis among the sustainability challenges were not analysed in this study. Fourthly, our preliminary findings revealed that the delay in upgrading supply chain technology was not deemed as highly important. Further research could more specifically investigate the role of selected technologies, such as artificial intelligence, machine learning, and blockchain, and assess their relevance to addressing sustainability challenges in other contexts.

The above-mentioned limitations can be overcome by conducting further studies in this area. In future, this study can be extended to comprehensively validate the findings of this research by collecting data

Table 16
Changes in the ranking of the sustainability challenges.

Selected Challenges	Normal (0.3743)	Ranking								
		Values of ranking for listed challenges								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
SC11	4	14	12	6	4	3	3	3	3	3
SC12	8	20	14	12	7	5	4	4	4	4
SC13	3	13	8	4	3	2	2	2	2	2
SC14	1	10	3	2	1	1	1	1	1	1
SC21	18	17	18	18	18	18	18	18	18	18
SC22	11	7	9	10	11	11	11	11	11	11
SC23	6	3	4	5	6	7	7	7	7	7
SC31	15	12	15	15	15	15	15	15	15	15
SC32	7	4	5	7	8	8	8	8	8	8
SC33	2	1	1	1	2	4	5	5	5	5
SC34	5	2	2	3	5	6	6	6	6	6
SC35	13	9	11	13	13	13	13	13	13	13
SC36	9	5	6	8	9	9	9	9	9	9
SC41	20	19	20	20	20	20	20	20	20	20
SC42	10	6	7	9	10	10	10	10	10	10
SC43	12	8	10	11	12	12	12	12	12	12
SC44	16	15	16	16	16	16	16	16	16	16
SC45	22	22	22	22	22	22	22	22	22	22
SC46	17	16	17	17	17	17	17	17	17	17
SC47	14	11	13	14	14	14	14	14	14	14
SC48	21	21	21	21	21	21	21	21	21	21
SC49	19	18	19	19	19	19	19	19	19	19

from a large number of participants in the context of different food processing sectors, such as processed, fresh, and frozen food sectors. Also, other industry sectors could be considered for analysing sustainability challenges to compare and discuss the findings of this study. This study can be further extended in the context of supply chains of developing and emerging economies to compare and generalise the findings. This is relevant because there may be considerable differences in how food processing sectors operate and view sustainability challenges in emerging economies during COVID-19 outbreak, which could provide a deeper understanding of sustainability challenges vis-a-viz developed and developing economies. Moreover, supply chain sustainability challenges could influence each other. The relationships and cause and effect analysis among supply chain sustainability challenges and impacts on sustainability performance can be investigated in the future using some other techniques, such as DEMATEL, and structural equation modelling. Moreover, strategies to overcome supply chain sustainability challenges can be further investigated to offer solutions and policymaking guidelines, and the configurations of strategies can be analysed to determine their influence on sustainable performance.

Credit authorship statement

Ananna Paul: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft. **Nagesh Shukla:** Investigation, Supervision, Writing - review and editing. **Andrea Trianni:** Supervision, Writing - review and editing.

Data availability

The data was provided within the manuscript.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.seps.2023.101535.

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