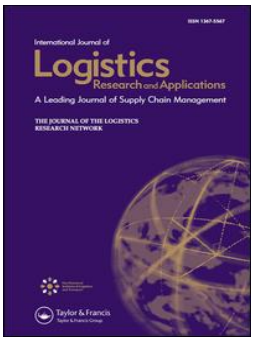

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Agriculture supply chain risks and COVID-19: mitigation strategies and implications for the practitioners

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ABSTRACT
The agricultural supply chains (ASCs) are exposed to unprecedented risks following COVID-19. It is necessary to investigate the impact of risks and to create resilient ASC organisations. In this study, we have identified and assessed the ASC risks caused by disruptions. These threats were assessed using Fuzzy Linguistic Quantifier Order Weighted Aggregation (FLQ-OWA). The findings reveal that supply risks, demand risks, financial risks, logistics and infrastructure risks, management and operational, policy and regulation, and biological and environmental risks have a significant impact in ASC depending upon the organisations scope and scale. Various strategies such as adoption of industry 4.0 technologies, supply chain collaboration and shared responsibility is identified for sustainable future. Theoretical and managerial implications are provided based on the outcomes of the study.

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KEYWORDS
Agriculture supply chain; supply chain risk; supply chain disruption; COVID-19; risk assessment

1. Introduction

COVID-19 has severely impacted all countries in the world[1] and has caused several supply chain disruptions globally (Ivanov 2020; Choi 2020; Govindan, Mina, and Alavi 2020). The current pandemic COVID-19 has inflicted an economic shock across so drastic that it has been compared with the Great Depression of the 1930s as more than 170 countries will experience a negative per capita GDP growth (IMF 2020).[2] In the recent past, the world has already witnessed many such epidemics such as Spanish Flu, SARS (Severe Acute Respiratory Syndrome), MERS (Middle East Respiratory Syndrome), and Ebola outbreak in 2013. All these outbreaks separately have been severe episodes. However, the COVID-19 pandemic, which originated in Wuhan, China, in December 2019, is turning out to be the fatal health crisis in our history. Amid this pandemic, while writing this piece, there have been 17,660,523 confirmed cases of COVID-19, including 680,894 deaths, reported to WHO (WHO 2020). Many experts have already termed this pandemic as a notified disaster, which will have severe negative impacts on the global economy.

As most of the developing and third world countries are heavily dependent on agriculture and agricultural imports, the agricultural supply chains (ASCs) in all these countries are exposed to unprecedented risks following COVID-19. Food and Agriculture Organization (FAO 2020) reports that COVID-19 is affecting ASCs on two critical aspects viz. the demand and supply for food. Food supply and demand are directly related to the food security aspect; therefore, global food security is at risk (Siche 2020). In the absence of vaccine or effective medicine to contain the spread of the

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disease, the governments worldwide are turning to non-pharmaceutical measures such as social distancing policies and civic lockdowns to stop the spread of the virus. The impact of keeping people from being able to work, meet, and socialise has severely damaged economic activities, especially in the services and the agricultural sector (Barichello 2020). Countries have imposed travel bans, border controls, and export restrictions on food commodities. At this point, there is no definite end date of these lockdowns and the ensuing economic damage, and no region of the globe is being spared as COVID-19 tests the resilience of global health systems.

As ASCs are labour-intensive for fisheries, meat products, and high-value crops, the effects of lockdown are taking a toll on the labour markets. The labour market shocks that arise from the movement restrictions on migrant labourers are affecting their ability to harvest, process, and the agricultural market produces. COVID-19 has had a significant impact on global food imports and exports. Along with the labour market issues, horticultural produce, which makes up a substantial part of the fresh food supply chains have suffered heavily. Major ports worldwide are congested with reefer containers that cannot be shipped due to trade restrictions. Therefore, the shipments are being diverted to minor ports resulting in substantial revenue losses for the logistics providers (Hey 2020). Despite having the latest technological tools at their expense, supply chain organisations worldwide are facing a crisis in tackling COVID-19 as they have never experienced such an event in the near past. In this uncertain situation, there is a need to acquire in-depth insights into quantifying the current impact of the COVID-19 outbreak on the ASCs for the supply-chain researchers and practitioners. Very few studies (see Ker 2020; Hobbs 2020) have explored this aspect in the literature and have focused the COIVD-19 induced risks on ASCs and have focused on the qualitative aspects of managing the risks and not quantified the current impacts on the firms operating in the ASC. The present study aims to quantify the effect of the COVID-19 and offer strategies for different companies depending on their sizes, such as micro, small, medium, and MNC enterprises. In this study, we identify the risk factors from the pertinent literature and compute the scores using the Fuzzy Linguistic Quantifier Order Weighted Aggregation (FLQ-OWA) technique.

The outcome of this study will help the practitioners in the ASC to assess the risk exposure and determine short-term and long-term strategic plans. The current study is an effort towards providing useful insights into the global ASC practitioners to mitigate the risks in the ASCs following this outbreak by addressing the following research questions (RQs):

RQ1: What are the various risks that COVID-19 has induced in the ASCs?

RQ2: What implications can be drawn for the ASCs based on the risk mitigation strategies observed in the industry to overcome the pandemic impact?

RQ3: How emerging disruptive technologies can be used effectively deployed to overcome such risk events?

In doing so, we identified ASC risks from the existing literature of review. We sought empirical validation of COVID-19 pandemic risks impacting the different phases of ASC's from the practitioners using a questionnaire survey. The remainder of the paper is organised as follows. The next section highlights the literature about ASCs, prominent risks in the ASCs, and impacts of COVID-19 related risks on the ASC. Section 3 presents the FLQ-OWA methodology outlining the motivation and fuzziness related to evaluating ASC risks. The algorithm of this approach, accompanied by the results and discussions, is presented in Section 4. Theoretical insights and implications for practitioners are highlighted in Section 5. The study concludes by providing limitations and scope for future work in Section 6.

2. Literature review

This section focuses on the relevant literature on agricultural supply chain management, including definitions, ASC risks, and their impact on ASC phases.

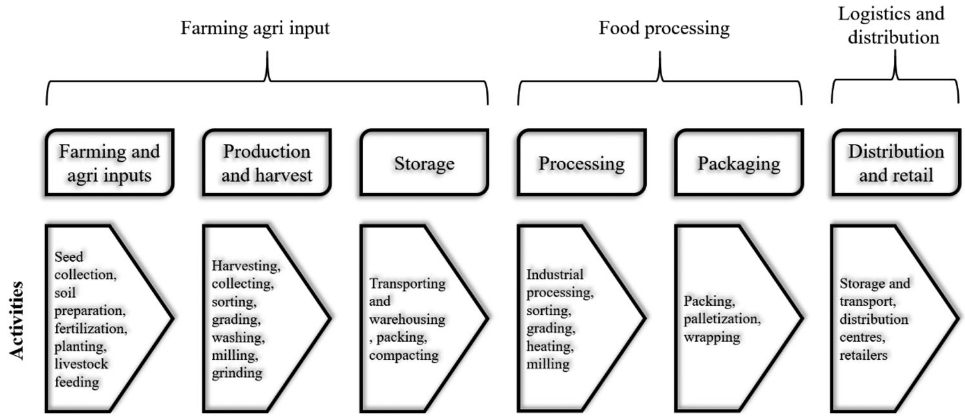

Figure 1. Phases in ASCs.

2.1. Agricultural supply chains (ASCs)

ASCs are defined as 'the set of activities included in a "farm to fork" progression, including activities such as farming (i.e. cultivation of land for crop production), processing/ production, testing, packaging, warehousing, transportation, distribution and marketing' (Tsolakis et al. 2014). ASCs encompass the activities of supply management, production and process management, and demand management through a competitive distribution channel for satisfying the end consumers (Chandrasekaran and Raghuram 2014). ASCs comprise of stakeholders such as food procurement, processing, and manufacturing organisations, distribution and commercial organisations, agents, food-service firms and hotels and restaurants, and grocers, and retail organisations (Sgarbossa and Russo 2017). Different studies have utilised the term ASC according to the study context, such as food supply chain (Zirham and Palomba 2016), agriculture value chain (Brewin 2016), post-harvest supply chain (Mvumi, Matsikira, and Mutambara 2016), fruit supply chain (Glowacz and Rees 2016), agri-business supply chain (Bhagat and Dhar 2011), perishable produce supply chain (Yared, Kitaw, and Gatew 2014), fresh produce supply chain (Glowacz and Rees 2016) and horticulture supply chain (Mahajan et al. 2014). The ASC comprises of three main aspects viz. farming and agriculture inputs, processing and storage, and transportation and distribution. Further, these are segregated into six phases based on the nature of operations, i.e. commodity types, and stakeholders involved. Figure 1 highlights the stages in ASCs. ASCs are exposed to severe disruptions that arise due to complex operations due to produce seasonality, varied production lead times, low standardisation of product quantity and product quality, trade and inventory storage restrictions, and lack of traceability. These shortcomings expose the ASCs to severe disruptions (van der Vorst, Beulens, and van Beek 2000; Dong 2006), Therefore, investigating the complex nature of agri-food supply chain risk will aid agri-food firms/managers managing risks effectively to improve the performance of the chain.

Similar to any other supply chain, the risks in the ASC adversely affect the service levels, responsiveness, and cost (Tummala and Schoenherr 2011). The prominent ASC risks have been extensively documented in the literature, which is presented in Table 1. Managing risks requires a thorough understanding of the different types of threats and their sources, risk interactions and interdependence, risk propagations, and their ripple effects, which severely impact the operational performance of the ASCs. The ASC practitioner's overall objective is to reduce economic losses and enhance the performance of the supply chain by choosing and implementing the most appropriate set of strategies through the development and deployment of suitable risk mitigation strategies and tactics.

2.2. ASC risks classification

Based on the current literature review of the pertinent literature on ASCs, the prominent ASC risks, and their sub-factors are documented in this section.

It can be inferred from Table 1, that the ASC risks vary differently across the ASC phases. These identified risks not only hamper the productivity of the ASC but also deteriorate the ASC performance. The ongoing pandemic has had a severe impact on food security and has adversely affected community health and incomes (Deaton and Deaton 2020). Apart from a few risks (such as weather-related risks, biological and environmental risks), all other risk factors can be optimised for enhancing the ASC performance. The new pandemic situation has created significant supply and demand issues for the supply chain management and distribution systems (Gray 2020). Other noteworthy risks instead of the pandemic are brought about by transportation challenges during nation-wide lockdowns, international border closures, farm-financial instability, and migrant labour-management issues (Ker 2020). Stakeholders on processing, retail, and distribution side of the ASCs have suffered tremendously due to demand-side shocks (panic buying, stocking), supply shortages, and transportation issues (Hailu 2020; Goddard 2020). As the pandemic unfolds, the ASCs must look for alternative strategies for enhancing their resilience capabilities (Hobbs, 2020; Ker and Cardwell 2020).

2.3. Impact of COVID-19 pandemic risks on ASCs

The COVID-19 pandemic has disrupted all business operations worldwide (Choi 2020). Ivanov (2020) describes this catastrophe as one of the most severe since the last decade as it has disrupted and dismantled supply chains globally. In the agricultural sector, the impact of COVID-19 has led to stringent measures such as the imposition of trade barriers and export restrictions that have affected the global farm trade and negatively impacted the credit market. The COVID-19 crisis has sharply depreciated the exchange rates and commodity and energy prices of the developing economies. With the rising costs of capital, the impacts are felt in the capital-intensive agricultural operations. The latest reports by the WTO (2020) suggest that global merchandise trade will likely fall between 13 and 32% in 2020. Figure 2 highlights the agricultural trade projections during and post COVID-19. Different recovery scenarios, i.e. optimistic (V shape, represented in solid blue coloured line), less optimistic (U shape, represented in dotted blue coloured line), and pessimistic (L shape, represented in dotted orange coloured line), are highlighted. As the global food supply chains are becoming increasingly complex, the risk mitigation measures have to be proactive for effective ASC operations management.

Risks in the supply chain occur either due to supply chain coordination or supply chain disruptions (Kleindorfer and Saad 2005). de Paulo Farias and dos Santos Gomes (2020) highlight that COVID-19 has put the health of people involved in the ASCs at risk, and therefore, the final links in the ASCs should be careful in handling and food processing to prevent ASC contamination and transmission of the disease. Hobbs (2020) investigated the various supply-side (labour shortages, transport disruptions) and demand-side (consumer panic buying behaviour, changes in consumption patterns) risks in the food supply chains during the COVID-19 pandemic. Glanakis (2020) highlights various risks hampering the sustainable production and consumption of food during COVID-19. Torero (2020) highlights the ASC disruptions and their impact on food security. Stephens et al. (2020) report on the suddenness of the virus spread and severity of the contamination measures such as lockdowns and community social distancing have left minuscule scope for identifying ideal domestic substitutes in the short term but may spur less reliance on global agri-food value chains in the future due to trust and transparency issues. Hailu (2020) reports on the supply and demand-side shocks in the food manufacturing sector emanating from a sharp decline in the demand for processed foods due to the border closures and trade restrictions. Brewin (2020) investigates the risks faced by the oilseed processors due to potential labour

Table 1. Risks and their impact on different ASC phases.

Major risk dimensions	Sources of risks	Impact of Risk on ASC Phase	Relevant Studies
Supply-side (S)	Supplier quality problems (S1)	Farming and Agri inputs	Meyer-Aurich and Karatay (2019); Joffre, Poortvliet, and Klerkx (2019)
	Payment default by supplier for the availed services (transportation, wages etc.) (S2)	Storage, Packaging, Distribution	Ker (2020)
	The underperformance of logistics providers (S3)	Storage, Distribution	Behzadi et al. (2017); Bloemhof et al. (2015)
	Supply shortages (S4)	Production and Harvest, Processing	Boyabatlı, Nguyen, and Wang (2017); Shukla and Naim (2018)
Demand-side (D)	Uncertain & unanticipated demand (D1)	Distribution and Retail	Liu et al. (2018)
	Inadequate information on demand (D2)	Production and Harvest, Storage, Distribution and Retail	de Janvry and Sadoulet (2020)
	Changes in food safety requirements (D3)	Processing and Packaging	Ortega and Tschirley (2017)
	Transportation issues (D4)	Storage, Distribution	Gray (2020); Badraoui, Van der Vorst, and Boulaksil (2020);
Logistics and infrastructural (L&I)	Inadequate road infrastructure (L1)	Storage, Distribution	Gray (2020); Badraoui, Van der Vorst, and Boulaksil (2020);
	Increase in fuel costs (L2)	Processing, Production, and Harvest	Li et al. (2019)
	Lack of transportation infrastructure (L3)	Storage	Wesana et al. (2019)
	Conflicts, labour disputes, labour shortages (L4)	Production and Harvest, Processing, Packaging	Adelaja and George (2019)
	Lack of infrastructure and service units (L5)	Storage, Processing	Lemaire and Limbourg (2019)
Policy and regulatory (*P*&R)	Uncertain monetary, fiscal, tax policies (P1)	Farming and Agri inputs	Yazdani, Gonzalez, and Chatterjee (2019)
	Uncertain legal policies and enforcements (P2)	Farming and Agri inputs	Verdonk (2019)
	Uncertain trade and market policies (P3)	Storage	Mittenzwei et al. (2017)
	Uncertain land policies and tenurial systems (P4)	Farming and Agri inputs	Bellemare et al. (2020)
Financial (F)	Lack of financial support (F1)	Farming and Agri inputs, storage	Long, Blok, and Coninx (2016)
	Delays in accessing financial support (F2)	Farming and Agri inputs	Nyamah et al. (2017)
	Uncertain credit support (F3)	Farming and Agri inputs, processing	Makate et al. (2019)
	Uncertain interest and exchange rate policies (F4)	Farming and Agri inputs, packaging	Kamble, Gunasekaran, and Gawankar (2020)
Biological and environmental (B&E)	Pests, diseases, yield losses (B1)	Farming and Agri inputs	Savary et al. (2019)
	Contamination related to inadequate sanitisation and illnesses (B2)	Farming and Agri inputs, Processing, Packaging	Bozkurt et al. (2020)
	Contamination affecting food safety (B3)	Processing, Packaging	Hou et al. (2020); Gray (2020); Dani and Deep (2010)
	Degradation of processed food products (B4)	Processing, Packaging	Deng et al. (2020)
Management and operational (M&O)	Poor management decisions (M1)	Farming and Agri inputs, Production and Harvest, Storage, Processing, Packaging, Distribution, and Retail	Zhao et al. (2020); Xu and Long (2020)
	Poor quality control (M2)	Production and Harvest, Processing, Packaging, Storage	Ali et al. (2019)
	Planning and forecast errors (M3)	Distribution and Retail	Golmohammadi and Hassini (2019)
	Use of outdated inputs (M4)	Farming and Agri inputs, Processing, Packaging	Mangla et al. (2018b)
Weather-related (W)	Periodic deficit/ excess rainfall (W1)	Farming and Agri inputs	Michler et al. (2019)
	Extreme drought (W2)	Farming and Agri inputs	Dai et al. (2020)
	Flooding (W3)	Farming and Agri inputs, storage	Li et al. (2019)
	Extreme winds/ cyclone (W4)	Farming and Agri inputs	Roy et al. (2019)
Political (PO)	Political instability/ crisis (PO1)	Farming and Agri inputs	Komarek, De Pinto, and Smith (2020)
	Trade interruptions/ restrictions (PO2)	Storage, Distribution	Gray (2020); Ker (2020)
	Changes in the political environment (PO3)	Farming and Agri inputs	Thomson (2019)
	Legislation risks (PO4)	Farming and Agri inputs	Verdonk (2019)

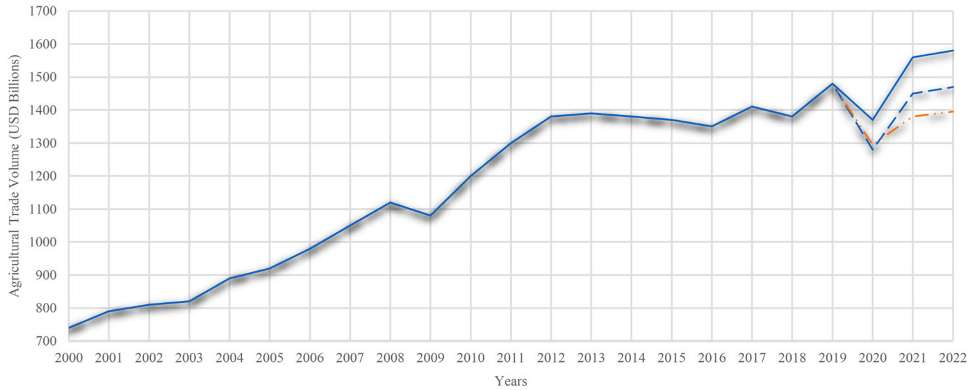

Figure 2. Impact of COVID-19 on global agricultural trade.

shortages, which lead to potential bottlenecks between crushers and millers, which hamper the retail and distribution phase in the ASCs. Stockford (2020) highlights the impacts of COVID-19 on the storage and transportation phase, which would increase the costs of procurement, thereby cause potential delays within the ASC. Ker (2020) highlights the potential financial risks which the ASCs will face during the ongoing pandemic hampering the agricultural trade and 'farmers' financial status. Shih (2020) reports on the COVID-19 related shutdown of Chinese production and the subsequent drop in North American demand due to import restrictions have created a shortage of empty containers for the backhaul to Asia. Gray (2020) investigates the various transportation risks (such as labour issues, reduced marine container movements, and regulatory closures of transportation services) induced by COVID-19. Haley et al. (2020) investigate various risks faced by the migrant workers involved in the ASCs and provide preventive measures to ensure occupational health and safety hazards.

3. Methodology

3.1. Data collection

For the study, we used the definition given by the Ministry of Small and Medium Enterprises, India (*dcmsme.gov.in),* to classify the firms. A micro-enterprise has an investment in plant and machinery that does not exceed twenty-five lakh rupees. In a small enterprise, the investment in plant and machinery is more than twenty-five lakh rupees. Still, it does not exceed five crore rupees, whereas, in the medium enterprises, the investment in plant and machinery is more than five crore rupees but does not exceed ten crore rupees. Multinational companies are defined as the organisations that are registered, their operations are spread across different countries, and 25% of their revenues are earned from out of home-country activities. In lieu of the pandemic situation, the survey was sent to respondents through emails. We sent 75 requests for participation, and twenty practitioners agreed to participate in the study. Considering the lockdown measures imposed by the Government of India, the interviews were conducted in online mode using cellular voice and video calls (via Skype, Zoom, and Microsoft Teams). Each meeting was for an average duration of 20 min and used structured questions guided by the risks identified from the literature review (see Table 1). The details of the participating organisations are provided in Appendix I.

3.2. Data analysis

Different state-of-art approaches are used to perform supplier evaluation. These include mathematical and multi-criteria decision making (MCDM) based techniques. The literature suggests the use of knowledge based/ knowledge-driven or data-driven strategies (Carranza 2008). The knowledge-based approaches rely on the decision maker's/expert's judgment whereas the data-driven approaches use the historical information. Few prominent techniques with their limitations are provided in Table 2.

Realising the fact that no single existing model is perfect, finally, we propose FLQOWA, which is a combination of knowledge-guided (fuzzy set theory) and data-driven approach. It is a novel approach in our context and not used in the supplier evaluation of resilient project-driven supply chains. The concept of OWA was introduced by Yager (1988), much later than the fuzzy set theory introduced by Zadeh (1965). 'The word importance indicates the difference in degree and is defined fuzzily' (Zadeh 1983). Assigning a definite value to a weight is inappropriate because it fails to capture the subjective perception of an individual. FLQOWA provide an opportunity to combine fuzzy ontologies and aggregation operators which are powerful tools to solve decision problems and achieve more reliable results under uncertain conditions using imprecise information.

An order weighted aggregation (OWA) operator is a multicriteria aggregation procedure that is found to be an appropriate tool for decision-making in a fuzzy environment (Yager 1988) is used in

Table 2. Limitations of prominent decision making techniques.

Method	Limitations	References
Mathematical Models	Subjective attributes or qualitative factors are not considered in these models.	Chaudhry, Forst, and Zydiak (1993); Weber, Current, and Desai (1998, 2000); Ghodsypour and O'Brien (1998); Mızrak Özfirat, Tuna Taşoglu, and Tunçel Memiş (2014)
Goal Programming	The coefficients are not assigned the weights. Are more efficient when used in combination with other MCDM methods to weight coefficients.	Kumar, Vrat, and Shankar (2004); Velasquez and Hester (2013)
Outranking Methods	The assignment of weightages to different criteria is not clear as it difficult to articulate the process and outcomes.	Konidari and Mavrakis (2007); Velasquez and Hester (2013)
Categorical Methods	Heavily depends on personal judgment. It is largely an intuitive process of evaluation. The major limitation is that it assigns equal weightage for all the factors.	Timmerman (1986); Hillman Willis and Huston (1990); Ordoobadi and Wang (2011)
Multi-Attribute Utility Theory (MAUT)	Highly data intensive to accurately obtain preferences. The amount of data and precision required in decision maker's preferences is quite difficult to obtain thereby makes it difficult to apply.	Velasquez and Hester (2013)
Data Envelopment Analysis (DEA)	This technique does not deal with imprecise data and assumes all input and output are exactly known. This assumption does not hold always in real life situations.	Liu, Ding, and Lall (2000); Wang, Greatbanks, and Yang (2005); Ramanathan (2007); Ordoobadi and Wang (2011)
Analytic Hierarchy Process (AHP)	The consistency of individual's judgments is an issue which is not always obtainable due to pairwise comparisons. If the criteria are independent the results obtained via AHP could be biased which shows incapability of handling correlation between criteria. The outputs are highly susceptible to rank reversal.	Saaty (1980); Levary (2007); Konidari and Mavrakis (2007); Ordoobadi and Wang (2011); Velasquez and Hester (2013); Mangla et al. (2018)
Analytical Network Process (ANP)	This technique ignores 'the different effects among clusters'. The application of this technique becomes limited due to its complex procedure.	Velasquez and Hester (2013); Ordoobadi and Wang (2011); Mangla et al. (2018)
TOPSIS	The major limitation of this method is that Euclidean Distance does not consider attributes correlation. This method is difficult to weight attributes and providing consistency of judgment with additional attributes.	Boran et al. (2009); Ordoobadi and Wang (2011)
Case Based Reasoning (CBR)	This method is highly sensitive to inconsistencies in data because previous cases could be invalid or special cases sometimes result in invalid answers requiring large data sets.	Ng and Skitmore (1995); Choy, Fan, and Lo (2003); Mızrak Özfirat, Tuna Taşoglu, and Tunçel Memiş (2014)

the study. It encompasses two sets of weights, i.e. criterion importance weights and order weights. The concept of fuzzy linguistic quantifiers has been proposed by Zadeh (1983). These objects are represented by terms such as *most, many, some, at least, one, or all,* and are represented by fuzzy sets. The fuzzy linguistic quantifier based OWA is adopted to capture the qualitative information the decision-maker may have regarding his/her perceived relationship between the different evaluation criteria. The qualitative statements are quantified to fuzzy linguistic scales and used in the OWA procedure (Yager 1988; 1996). Typically, conventional operators found to have a limited application involving broader criteria sets based on 'all the criteria have to be 'satisfied' to 'at least one criterion must be 'satisfied'. In OWA, a set of order weights represents the operator behaviour using orness[3] and trade-off among criteria, which in turn helps to formulate a decision strategy (Malczewski and Rinner 2005). The arguments viz., most of the criteria, at least half of the criteria, or all criteria should be satisfied. Fuzzy linguistic quantifier ordered weighted aggregation (FLQ-OWA) involves four main steps:

(i) Estimation and sorting of criterion weights
(ii) Specification of the fuzzy linguistic quantifier (Q)
(iii) Generation of order weights that is associated with Q, and
(iv) Computation of the overall evaluation using OWA combination function for each of the alternative.

The detailed steps of the FLQ-OWA are derived from Zadeh (1975a, 1975b), Yager (1996), Herrera, Herrera-Viedma, and Verdegay (1996), Chang, Wang, and Wang (2006), Malczewski (2006), and Shishodia, Verma, and Dixit (2019) for computing risks in ASCs. Table 3 shows the notations used in evaluating the organisational risk score.

Step 1 Identification of ASC organisations impacted by various risks.
Let $O_p = \{O_1, O_2, O_3, \ldots\ldots, O_s\}$ be a set of s organisations, where $p = (1, 2, 3, \ldots, s)$.

Step 2 List all the risks impacting ASC organisations. Let there be a set of n independent risk factors, named as Organizational risk factors (ORFs) [i.e. $\{ORF_1, ORF_2, ORFF_3, \ldots\ldots, ORF_t\}$, where $q = (1, 2, 3, \ldots, t)$].

Step 3 Construct a multiple factor matrix $A = [a_{pq}]$ based on 'experts' inputs for different risks faced by their organisation.

Step *4* Convert the multiple factor matrix $A = [a_{pq}]$ into a fuzzy multiple factor matrix $B = [b_{pq}]$ using the fuzzy membership function as shown in Equation (1) and Equation (2) (Zhang et al., 2003; Chang, Wang, and Wang 2006).

Table 3. Notations used for computing organisational risk score.

Notations	Description
P	*Index used for organisations, where p = (1,2,3 … .,s)*
Q	*Index used for organisational risk factors, where q = (1,2,3 … .,t)*
a_{pq}	*Input data of 'q^th' organisational risk factors of 'p^th' organisation*
b_{pq}	*Normalised input data of 'q^th' organisational risk factors of 'p^th' organisation*
a_q^{min}	*Minimisation value of 'p^th' organisation among all 'q^th' organisational risk factors* $\{a_{1q}, a_{2q}, \ldots\ldots\ldots, a_{sq}\}$
a_q^{max}	*Maximisation value of 'p^th' organisation among all 'q^th' organisational risk factors* $\{a_{1q}, a_{2q}, \ldots\ldots\ldots, a_{sq}\}$
w_q	*Aggregation weighted vector W of 'q^th' organisational risk factors*
w_q^*	*Maximal entropy aggregation weighted vector W**
OR_p	*Organisation risk score (p)*

For the maximisation factor,

$$[b_{pq}] = \frac{a_{pq} - a_q^{\min}}{a_q^{\max} - a_q^{\min}} \tag{1}$$

where $p = 1,2,3, \ldots s$; $q = 1,2,3, \ldots .t$

For the minimisation factor,

$$[b_{pq}] = \frac{a_q^{\max} - a_{pq}}{a_q^{\max} - a_q^{\min}} \tag{2}$$

where $p = 1,2,3, \ldots s$; $q = 1,2,3, \ldots .t$

$$a_q^{\max} = \max \ \{a_{1q}, a_{2q}, \ \ldots\ldots\ldots., a_{sq}\}$$

$$a_q^{\min} = \min \ \{a_{1q}, a_{2q}, \ \ldots\ldots\ldots.., a_{sq}\}$$

Step 5 Computation of aggregation weighted vector (W)

The aggregation weighted vector (W) is then mapped to the membership function Q(r). The membership function Q(r) varies with the fuzzy linguistic quantifier (Q). The weights corresponding to the fuzzy linguistic quantifier ‘as many as possible’ are computed using Equations (3) and (4) because it represents the perception of practitioners.

As reported by Boroushaki and Malczewski (2008), there are two general classes of the linguistic quantifiers: absolute and relative quantifiers. Absolute quantifiers can be defined as fuzzy subsets of [0, +N]. They can be used to represent linguistic terms such as about 4 or more than 10. The relative quantifiers are closely related to imprecise proportions. They can be represented as fuzzy subsets over the unit interval, with proportional fuzzy statements such as few, half, many, etc. In the context of multicriteria decision making, it can be assumed that the relationship between the criteria or objectives (based on decision-maker judgment) can be described as: “Q of the important criteria (objectives) are satisfied by an acceptable alternative”, where Q is a regularly increasing monotone (RIM) linguistic statement (for example, Q = “as many as possible”). The concept of linguistic quantifiers provides a method for generating ordered weights based on the RIM linguistic quantifiers.

The quantifier ‘as many as possible’ highlights all the possible risks that would be affecting or affect the scenario (Figure 3).

$$w_q = Q\left(\frac{q}{t}\right) - Q\left(\frac{q-1}{t}\right), \tag{3}$$

where $q = 1,2,3, \ldots .,n$

$$Q(r) = \begin{cases} 0 & \text{if} \quad r < 0.5 \\ \dfrac{r-0.5}{1-0.5} & \text{if} \quad 0.5 \le r \le 1, \ a, \ b, \ r\epsilon[0,1] \\ 1 & \text{if} \quad r > 1 \end{cases} \tag{4}$$

Step 6 Optimisation of the FLQ-OWA operator.

To optimise the fuzzy linguistic driven aggregation, we compute the degree of orness and degree of entropy to obtain the weights. Equation (5) is used to calculate the degree of orness.

$$\text{Orness} \ \ (W) = \frac{1}{t-1}\sum_{q=1}^{t}(t-1)w_q \tag{5}$$

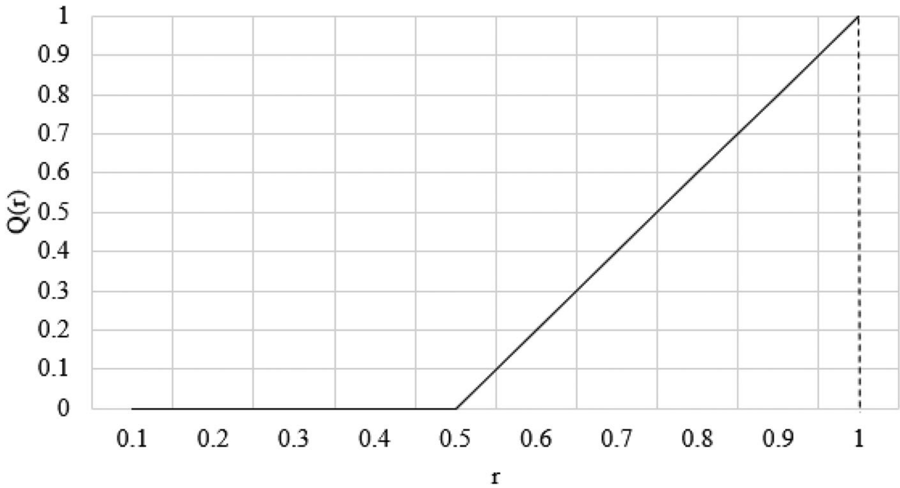

Figure 3. Fuzzy Linguistic Quantifier 'as many as possible' function.

The OWA operator shows aggregation behaviour depending upon the arguments, for instance, considering only one argument then orness equals 1, aggregation is similar to an *or-like* operation if orness equals to 0 then aggregation resembles an *and-like* operation and if treating all arguments equally then orness equals to 0.5, the aggregation is identical to the arithmetic mean operation.

Equation (6) is used to define the entropy for an OWA operator that signifies high value of dispersion if the weights w_j are closer to each other. Entropy is used for the purpose to constrain the optimisation problem.

$$\text{Entropy}\quad(\text{W}) = \; -\sum_{q=1}^{t} w_q \ln w_q \tag{6}$$

The use of Lagrange multipliers to obtain the maximal entropy aggregation weighted vector W* aggregates maximum information from the objectives. Therefore, the weights are referred as maximal entropy for a given degree of orness. The same is depicted in Equation (9).

The procedure to obtain the maximal entropy is illustrated in Equation (7).

Maximise

$$-\sum_{q\,=\,1}^{t} w_q \; \ln w_q \tag{7}$$

Subject to

$$\text{Orness}\quad(\text{W}) = \frac{1}{t-1}\sum_{q\,=\,1}^{t}(t-q)w_q, \tag{7a}$$

$$\sum_{q\,=\,1}^{t} w_q, \tag{7b}$$

$$w_q = \; \epsilon\,[0,\,1], \tag{7c}$$

where $q = 1,2,3, \ldots, t$

Upon simplification the Equations (8a), (8b), and (9) are obtained from Equation (7) to optimise the fuzzy driven OWA (FLQOWA) operator. The initial value of W is replaced to W*.

$$\sum_{q=1}^{t}\left(\frac{t-q}{t-1} - \text{Orness}\ \ (W)\right)h^{t-q} = 0 \tag{8a}$$

$$\text{Orness}\ \ (\text{W}) = \frac{1}{t-1}\sum_{q=1}^{t}(t-q)\frac{h^{t-q}}{\sum_{q=1}^{t} h^{t-q}} \tag{8b}$$

$$w_q^* = \frac{h^{t-q}}{\sum_{q=1}^{t} h^{t-q}}, \tag{9}$$

where $q = 1,2,3, \ldots ., t$

Step 7 Determination of the risks in ASC organisations.

The risks in ASC organisations can be computed using Equation (10).

Risks in ASC organisations

$$OR_p = [\ w_q^* * b_{pq}] \tag{10}$$

Numerical Illustration: The input data of risk factors for evaluation of different organisational risk scores are shown in Table 4. The input data was obtained through e-discussions with experts of various ASC organisations (small, medium, micro, and MNC) and derived from literature. During the discussion, the experts were requested to rate the risk factors based on their impact on the organisation.

Numerical Illustration: The procedure for the computation of the organisational risk score is illustrated below:

The normalisation of the input data is done following the procedure mentioned in Step 1, Step 2, and Step 3. This is followed by computation of the OWA weights using Step 4, Step 5, and Step 6 corresponding to the fuzzy linguistic quantifier 'as many as possible'.

$$w_1 = Q\left(\frac{1}{4}\right) - Q\left(\frac{1-1}{4}\right) = 0;\ \because \frac{1}{4} < 0.5,\ Q(0) = 0 \because 0 < 0.5 \therefore w_1 = 0$$

Similarly,

$$w_2 = Q\left(\frac{2}{4}\right) - Q\left(\frac{2-1}{4}\right) = Q\left(\frac{2}{4}\right) - Q\left(\frac{1}{4}\right) = 0$$

$$w_3 = Q\left(\frac{3}{4}\right) - Q\left(\frac{3-1}{4}\right) = Q\left(\frac{3}{4}\right) - Q\left(\frac{2}{4}\right) = 0.5$$

$$w_4 = Q\left(\frac{4}{4}\right) - Q\left(\frac{4-1}{4}\right) = Q\left(\frac{4}{4}\right) - Q\left(\frac{3}{4}\right) = 0.5$$

Table 4. Sample calculation for computing organisational risk score of MI_1.

Risk	Sub-Risk	w_q^*	Normalised ordered argument (b_{pq})	Weighted score
Supply Risk	S1	0.031	0.75	0.023
	S2	0.085	0.75	0.064
	S3	0.235	0.5	0.118
	S4	0.647	0	0.000
Risk Score				0.205

NB: The computations are presented in the appendix (Table A2).

Using Equation (5), Orness is computed, as shown below:

$$\mathrm{W} = \frac{1}{4-1}(3w_1 + 2\,w_2 + \,w_3)$$

$$\mathrm{W} = \frac{0\, +\, 0 + 0.5}{3} = 0.1667$$

Using Equations (7), (8a), (8b) and (9), maximal entropy is obtained as shown below:

$$\sum_{j\,=\,1}^{n}\left(\frac{n-j}{n-1} - \text{orness}\;\;(W)\right)h^{n-j} = 0$$

$h = 0.36321$

The organisational risk score (OR_1) for MI_1 is calculated using Equation (10) as follows:

$$w_1^* = \frac{h^3}{\sum_{j=1}^{4} h^{4-j}} = \frac{0.36^3}{0.36^3 + 0.36^2 + 0.36^1 + 1} = \;0.031$$

$$w_2^* = \frac{h^2}{\sum_{j=1}^{4} h^{4-j}} = \frac{0.36^2}{0.36^3 + 0.36^2 + 0.36^1 + 1} = 0.085$$

$$w_3^* = \frac{h^1}{\sum_{j=1}^{4} h^{4-j}} = \frac{0.36^1}{0.36^3 + 0.36^2 + 0.36^1 + 1} = 0.235$$

$$w_4^* = \frac{1}{\sum_{j=1}^{4} h^{4-j}} = \frac{1}{0.36^3 + 0.36^2 + 0.36^1 + 1} = 0.647$$

Similarly, for risk factors having five subfactors using OWA weights corresponding to the fuzzy linguistic quantifier 'as many as possible' are computed using Step 4, Step 5, and Step 6 as follows:

Using Step 7, the organisational risk score calculation for MI_1 is shown in Table 4. Normalised values are obtained using Equations (1) and (2).

4. Results and discussion

The results are analysed based on risk scores impacting different ASC organisations, namely, micro (MI), small (SI), medium (ME), and multinational (MNCs). Based on the data analysis of the 20 selected organisations, prominent risks and their impact (%) are highlighted in Figure 4(a–d) and discussed in detail.

4.1. ASC risks in micro enterprises

MI_1 deals with agroforestry products. It is observed that in MI_1, the impact of financial risks was found to be 50.8%. This can be attributed to delayed accessibility to financial support, depressed sales, and suspension of field activities. The supply risks were observed to be 29% due to shortages in the supply markets and underperformance of the logistics providers, which were predominantly induced due to nation-wide lockdowns and safety measures. The demand risks were found to 29% due to transportation issues and information about demand quantities. Then, logistics and infrastructure risks were observed to be 29% due to a lack of infrastructure services and labour shortages. It is found that 75% of financial risk impacted MI_2, which deals with food processing. The supply risks were found to be 31%, which can be attributed to capacity fluctuations and shortages in the supply market. The demand risks were found to be 23%, which can be attributed to inaccurate customer demand. In MI_3, which deals with Agri inputs, the impact of financial risk was 77%, which

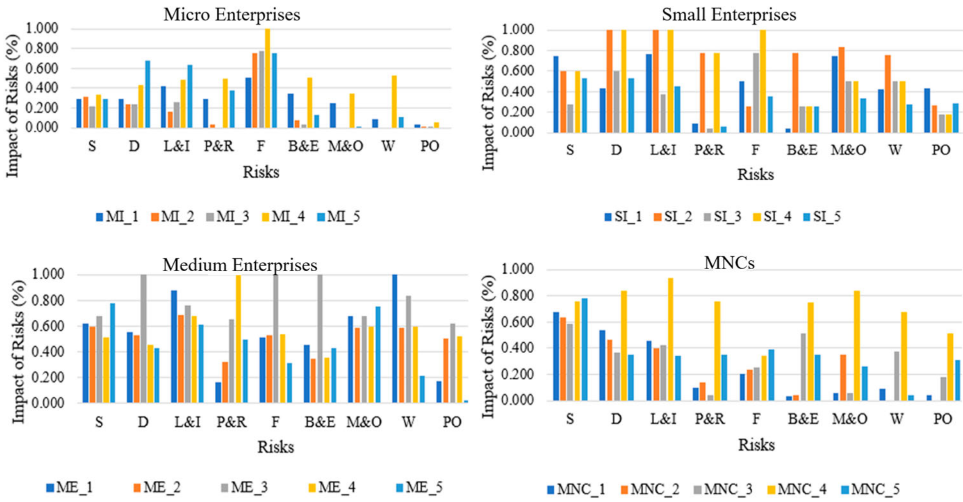

Figure 4. Impact of risks on ASC organisations (Micro, Small, Medium, and MNC). Legend: Major risks – Supply-side (S), Demand-side (D), Logistics and infrastructural, (L&I), Policy and regulatory (P&R), Financial (F), Biological and environmental (B&E), Management and operational (M&O), Weather-related (W); Political (PO).

can be attributed to the unavailability of cash facilities. Logistics and infrastructure risk were found to be 26%, which can be attributed to changes in transportation and labour shortages. MI_4 deals with agriculture trading and is severely affected by financial risks (almost 99%) due to delays in accessing financial support. The logistics and infrastructure risks were observed to be nearly 48%. This can be attributed to labour shortages and lack of infrastructural and service units. Biological and environmental hazards were found to be 50.8%, which can be attributed to contamination and degradation of processing and production processes and contaminations affecting food safety. The weather-related risks accounted for 52.9% due to unprecedented weather conditions, which affected the production and harvest cycles. MI_5 deals in greenhouse farming and the impact of financial risk was found to be 75.8%, which can be attributed to lack of access to credit facilities. Logistics and infrastructural risks were found to be 63.5% and can be attributed to undependable transport and labour shortages.

4.2. ASC risks in small enterprises

SI_1 deals with agriculture commodities processing. It has been observed that 75% are supply-side risks, which are attributed to supplier quality problems, capacity fluctuations, and shortages in the supply market. 76.4% of risks are logistics and infrastructural risks, which can be attributed to undependable transport and labour shortages. 75% of management and operational risks which are caused due to poor planning and forecasting errors and poor management decisions. SI_2 deals with warehousing. The significant dangers observed are demand risks and logistics and infrastructural risks, which can be attributed majorly to transportation issues. Other risks affecting their operations are policy and regulatory risks, which were induced due to regional trade restrictions introduced given the nation-wide lockdowns. The biological risks can be majorly attributed to contamination related to food safety. Management and operational risks contribute 84%, which were prominently due to inaccurate planning and forecasting. Weather-related risks add to 76%, which were present due to unexpected and excessive rainfalls in certain parts of the country.

SI_3 deals in Agri trading. The significant risks identified are financial risk (78%), which can be attributed to lack of financial support, interruptions in accessing financial aid, indefinite credit support. Demand risk (59.6%) can be attributed to unanticipated consumer demand, insufficient information about demand quantities, transportation issues, and changes in food safety requirements. Management risks (50%) can be attributed to poor management decisions, poor quality control, planning and forecast errors, and usage of outdated inputs. Weather-related risks (50%) can be associated with dynamic weather patterns.

SI_4 is an Agri inputs firm. The predominant risks are demand risk (99%), which was due to unprecedented demand and inaccurate forecasts, which led to increased operational costs. Logistics and infrastructure risks (99%) were chiefly contributed due to labour shortages and restricted movement of transport. Financial risk (99%) was chiefly attributed to the lack of cash availability and inadequate credit support. Supply-side risks (60%) were presented due to the underperformance of logistics providers. Management and operational risks (50%) were present due to the inability of the administration to anticipate the effects of the pandemic. Weather-related risks (50%) had an impact due to dynamic climatic patterns. SI_5 is a dairy unit. Significant risks affecting this organisation are demand and supply risks (52.9%) and logistics and infrastructural risks.

4.3. ASC risks in medium enterprises

ME_1 is a farmer producer company. The prominent risks that have affected ME_1 are policy and regulatory risks (88%), which are attributed to the ' 'government's actions and measures for containing the spread of the pandemic. These measures included lockdowns of marketing yards, movement restrictions on transports and labour, and other safety norms. Among other risks, weather-related risks (99%) were predominantly due to the dynamic weather conditions which affected crop harvests. Management and operational risks (68%) were mainly due to a lack of planning and forecasting, which led to a considerable drop in sales. The supply-side risks (62%) were primarily due to capacity fluctuations in the supply market and inaccurate supply planning. ME_2 deals with warehousing and collateral management. Logistics and infrastructure risks (69%) were predominantly present due to restrictions on interstate transportation. Supply risks (68%) affected the operations as there were problems with supplier quality problems and underperformance of the logistics providers. Management and operations risks (59%) occurred as the volumes dropped by almost 30%. Weather risks (59%) also hampered the operations as the weather conditions slowed down the production and harvest.

ME_3 dealt with food processing and were severely affected by demand risks (99%), financial risks (99%), and biological risks (99%). The demand risks were majorly due to unanticipated consumer demand and insufficient information about demand quantities. Financial risks were mostly due to reduced business capacity and operations (almost 40%), and revenues had dropped to the tune of 20%. Biological and environmental risks were mostly brought about by contamination of the products, which would have affected affecting food safety and the contamination and degradation of production and processing processes. Weather-related risks (84%) also hampered their operations.

ME_4 deals in agricultural trading. It was profoundly affected by policy and regulatory risks (99%) due to uncertainties in legal policies and enforcements and indefinite trade and market restrictions due to the pandemic. Logistics and infrastructural risks (68%) also hampered their operations because of incremental changes in energy cost, i.e. fuel prices, undependable transport, labour shortages, and lack of infrastructure and service units. Management and operations risks (60%) were mainly due to the lack of planning. Weather risks (60%) also affected their operations to a greater extent.

ME_5 deals in farm to the retail supply chain. The operations were heavily impacted by supply risk (78%), which were mostly due to a drop in volumes. Management and operational risks (75%) were brought about by inaccurate planning and forecasting. Logistics and infrastructural risks (62%) were also present due to transportations and labour shortages, which were mainly due to ' 'government's restriction on the movement of goods and labour given the pandemic.

4.4. ASC risks in multinational enterprises

MNC_1 deals with Agri-tech and farm equipment. They were severely affected by supply risks (67.6%), demand risks (54%), and logistics and infrastructural risks (46%). As their operations are on a global scale, their activities were affected profoundly. The supply and demand risks can be attributed to supplier quality problems, sudden default of suppliers (in terms of transportation, payments, etc.), the underperformance of logistics providers, capacity fluctuations/shortages in the supply market due to unanticipated consumer demand. The logistics and infrastructural risks were brought about by the lack of availability of transport and labour shortages.

MNC_2 deals in trade of Agri commodities. The risks affecting this organisation are supply risks (63.9%), demand risks (46.6%), and logistics and infrastructural risks (39.8%). Supply-side risks are majorly due to reasons such as delays in the arrivals of primary raw materials due to sudden supplier defaults. Demand-side risks arise primarily due to drops in demand volume (up to 60%) and reduced production. Logistics and infrastructural risks were mostly due to labour shortages and movement restrictions on transport.

MNC_3 deals in Agri inputs (seeds). The organisation primarily faced risks such as supply risks (58.8%), logistics and infrastructural risks (42%), and biological and environmental risks (51.6%). Supplier quality problems and underperformance of the logistics providers were the chief reasons for supply-side risks. Logistics and infrastructural risks were introduced due to a lack of service units and labour shortages. Contaminations affecting food safety and contamination and degradation of processing and production processes were the primary reasons contributing towards biological and environmental risks.

MNC_4 deals with fertilisers and Agrichemicals. Supply-side risks (75.8%), demand-side risks (83.8%), logistics and infrastructural risks (93.9%), policy and regulatory risks (75.8%), biological and environmental risks (75%.), management and operational risks (83.8%) were the significant risks which had a substantial impact on the operational performance of MNC_4. Prominent reasons for the risks were due to the delays in arrivals of the raw materials, which unsettled the demand-supply equation. Moreover, reduced distribution also led to a drop in the sales volume. Yield losses were the primary reasons contributing to biological and environmental risks. Management and operational risks can be attributed to poor management decisions and improper planning during the pandemic.

MNC_5 deals with dairy and milk processing. They faced supply-side risks (77.9%), financial risks (38.8%), demand-side risks (35.2%), policy and regulatory risks (35.2%), and biological and environmental risks (35.2%). The supply-side risks were caused due to capacity fluctuations in the supply markets. Financial risks can be primarily attributed to supplier defaults in settling the payments and other delays in accessing financial support. Demand-side risks were caused due to inaccurate demand forecasts. Policy and regulatory risks were caused due to the bans on international trade among countries. The biological and environmental risks were basically due to sanitary and phytosanitary measures.

This section highlighted the risks and how they affected the ASC organisations. Inputs from the respondents were used for evaluating the pandemic impacts on ASC operations. The results from the study highlight that all set of market players, i.e. micro, small, medium, and multinational enterprises, have had their ASC operations profoundly affected by the pandemic. In the next section, we discuss the strategies and implications for research and practice.

5. Implications from the study

As the study pertains to ASCs, the findings are confined to ASC operations and the risks identified are different vis-à-vis other sectors. For example, Ivanov (2020a) highlights the impact of COVID-19 on logistics and supply chain risks (which are further segregated into operational and disruption risks). In the study by Ivanov and Dolgui (2020) and Ivanov (2020a). The viability (sustainability and longevity) of the supply chain following the disruptions events such as COVID-19. Rizou et al. (2020) investigate the potential impacts of COVID-19 on the food supply chains pertaining to food safety. Govindan, Mina, and Alavi (2020) report the impact of COVID-19 related to disruption management in healthcare supply chains. The present study differs from other studies as we have estimated the impact of risks induced by COVID-19 on ASCs using empirical investigation. Also, other studies are mainly perspective based i.e. reviews, modelling and simulation based.

The present study has three main contributions. First, this is one of the earliest studies which has used FLQOWA for evaluating impact of risks in ASC organisations. Secondly, various ASC risks were identified from the literature and were empirically validated through a survey methodology of 20 ASC organisations. In particular, ASC organisations belonging to micro, small, medium enterprises and MNCs were surveyed for assessing the impact of COVID 19. Thirdly, the findings suggest that the risks and response strategies varied across ASC organisations with significant differences. The following sub-sections highlight the implications from the study.

5.1. Theoretical implications

The present study makes two vital contributions: first, the study investigated the risks associated with ASCs and the most prominent risks which emerged due to COVID 19 pandemic in Indian ASC organisations; second, the risks are identified using published literature and scores are computed using FLQOWA.

As there were multiple risks (criteria); therefore, to solve such problems adequately, two approaches could be applied; one is knowledge-based/ knowledge-driven, and another method is data-driven (Carranza 2008). Knowledge-based approaches are affected by the decision-' maker' s/' 'expert's judgment, whereas data-driven strategies use prior data. The use of FLQOWA combines a knowledge-guided (fuzzy set theory) and data-driven approach (combination operator) for solving the problem instead of exclusively using any knowledge-based or data-driven approach. It is a novel approach in the context of COVID-19. We have applied this approach for evaluating the identified risks and their impact on various Indian ASC organisations. The concept of OWA is relatively newer as it has been introduced by Yager (1988) as compared to the fuzzy set theory introduced by Zadeh (1965). '*The word importance indicates the difference in degree and is defined fuzzily*' (Zadeh 1983). Assigning a definite value to weight is inappropriate because it fails to capture the subjective perception of an individual. FLQOWA provides an opportunity to combine fuzzy ontologies and aggregation operators, which are powerful tools to solve decision problems and achieve more reliable results under uncertain conditions using imprecise information.

5.2 Managerial implications

The results presented in this study have significant implications for practitioners. The study offers to highlight the risks posed by the recent pandemic on ASCs and the strategies agribusiness organisations need to adapt to mitigate the risks. Organisations should exploit their technological resources and strengthen their information technology capabilities for building strategic partnerships with key stakeholders. This will help in efficient material planning with real-time information flow and enhance transparency and visibility of the ASC processes (Pigni, Piccoli, and Watson 2016). Organisations should invest and deploy industry 4.0 technologies (such as the internet of things, blockchain technology, big data analytics, digital twins) to benefit from the industry 4.0 technology capabilities. Industry 4.0 technologies will not only help in enhancing productivity but will help in improving the ASC resilience through enhanced transparency and visibility throughout the ASC processes.

Our study suggests specific strategies for reducing the impact of prominent risks identified due to the COVID-19 pandemic on various Indian ASC organisations. Primarily, logistics and infrastructure-related risks led to the suspension of field activities for an indefinite period, which in turn affected the ASC operations, causing an increase in the operational costs. Thus, it is suggested that practitioners change their delivery methods through advanced information and communication technologies (ICTs) and ASC virtualisation applications such as the internet of things (Kamble, Gunasekaran, and Gawankar 2020). The interaction between the objects in the real world and the digital paradigm is an essential component of virtualisation. Supply risk refers to the shortages in the supply markets, which are predominantly induced due to nation-wide lockdowns and safety measures. These can be resolved by redesigning their internal systems using occupational safety and health hazards precautionary measures for worker and product safety (Ragasa and Lambrecht 2020). Some of the essential steps include separation mechanisms based on thermal imaging, usage of facemasks/ gloves during handling and processing, and reducing single skilled personnel with a multiskilled workforce with technical support (robots and cobots) for balancing efficiency and safety. As most of the respondents highlighted reduced sales, which were mostly due to demand risks (insufficient information about demand quantities), practitioners are advised to invest in autonomous decision-making tools such as big data analytics and artificial intelligence platforms which would help in analysing real-time data and provide insightful market intelligence (Sharma et al. 2020; Kamble, Gunasekaran, and Gawankar 2020). This would help in accurately forecasting the customer demand and thereby reduce the bullwhip effects, which would otherwise hamper the production processes through inaccurate forecasts. Machine learning algorithms can help in constantly reassessing and demand re-planning (Zhu et al. 2019). The practitioners are advised to invest in the modification of their machine layout (flexible processing) for the processing of alternative products with an enhanced shelf life to reduce waste and to improve sustainability (Dora, Kumar, and Gellynck 2016; Dora and Gellynck 2015). Moreover, organisations can focus on switching to packaged foods with the available raw material and focus on sustainable packaging to reduce the environmental impact of food waste (Licciardello 2017).

Agribusiness organisations should focus on smart farming and building short agricultural supply chains (SASCs), which are a move beyond the traditional food production systems. The SASCs is based on the cooperation between the farmers and consumers of a local community wherein the farmers directly sell their produce to the consumers without an intermediary. They are useful in tackling supply-demand risks (Lioutas and Charatsari 2020). SASCs can play a critical role during the periods when the movement of inter-state transport is restricted. Smart farming practices enabled by the usage of industry 4.0 technologies and intelligent decision-making tools can help the farmers and agribusiness organisations in optimising their farm planning procedures (Monteleone, de Moraes, and Maia 2019) which, is efficient (as it saves resources and time) (Das V, Sharma, and Kaushik 2019) and increases the decision-making capabilities (Mekala and Viswanathan 2017). Overall, smart farming practices help in enhancing farm and production efficiency (O'Grady and O'Hare 2017), thereby minimising the supply-demand risks. Advantages of using smart farming practices and intelligent decision-making tools that go beyond the farm level are optimal resource allocation practices leading to reduced wastages (Wang, Lu, and Capareda 2020), reduce the environmental footprint and enhance sustainable agricultural practices (Kernecker et al. 2020), reduce the energy and water footprints (Mekonnen et al. 2018; Walter et al. 2017) thereby improving food quality and safety (Kamble, Gunasekaran, and Sharma 2020) and enhancing the overall food security (Lioutas and Charatsari 2020).

Management and operational risks can be reduced by using effective communication strategies for motivating the staff/migrants to return or replace them. The practitioners are suggested to regularly communicate with their staff, provide them assurance through policy changes, release their unpaid salaries and to support them during the crisis; approach retired employees to rejoin organisation for 6–12 months in the time of crisis and explore the availability of local workforce (with necessary skills/minor skill which can be trained using online supervision). The major focus should be enhancing the resilience capabilities of the organisation by fostering employee engagement and well-being (Malik and Garg 2020). Organisations should focus on enhanced collaboration and integration with the focal firms for effectively managing the risks (through integrated risk management practices) (Munir et al. 2020).

5.3. Implications for policymakers

In regard to implications for policy makers, the present study makes useful contributions. The policy makers should focus on promoting smart farming techniques to deal with such pandemics in the near future. Dedicated ministry offices should focus on industrial development in states so as to minimise labour migration. Policy and regulatory risks can be controlled through collaboration, which is the use of SASCs as they are less affected by international trade restrictions and are near to consumers. The government guidelines can focus on strengthening of SASCs for maximising local agricultural production. Local agricultural production can be boosted by providing the necessary support for reducing the mass migration of labour, providing supply of agricultural inputs (including seeds, fertilisers, and pesticides) for the production of primary and perishable foods and provision of training, extension services, financial and credit support to help them expand the area produced and reduce the time taken to harvest the products (minimising post-harvest losses), establishing food processing communities/ farmer producer organisations in remote and isolated agricultural regions, etc. The financial risks arise due to limited liquidity available for demand fulfilment and the lack of availability to arrange cash. Therefore, to reduce the effects of financial risks, the policymakers are consequently suggested to reduce or defer non-critical projects and provide financial relief to the stakeholders in supply chain. Other strategies to provide access to working capital through low-interest loans needs to be emphasised.

6. Conclusion, limitations, and future scope

The ASCs play an essential role in achieving the United Nation's Sustainable Development Goals, i.e. SDG 2 (to end hunger through achieving food security and improved nutrition) and SDG 12 (to ensure sustainable consumption and production). Therefore, it is necessary to investigate the impact of risks and to create resilient ASC organisations. The current study identified and assessed the effects of risks on Indian ASC organisations during the COVID-19 pandemic. The prominent dangers are highlighted in four different organisations, namely, micro, small, medium, and multinational enterprises, and are assessed using the FLQOWA approach. It has been observed that supply risks, demand risks, financial risks, logistics and infrastructure risks, management and operational, policy and regulation, and biological and environmental are found to have a significant impact in the different organisations depending upon their scope and scale. Various strategies are suggested for controlling the risks and their impacts for charting the path towards the new normal, i.e. rapid adjustment, adoption of industry 4.0 technologies (that can enhance agile processing and supply chain ecosystem for meeting the dynamic demand) and collaboration and shared responsibility for sustainable future. As the present study shows the impact of COVID-19 in Indian context, future studies can be done in other sectors as well to highlight the similarities and differences of risks across different sectors. The present study was done during the pandemic; therefore, it was practically difficult to get information from a large number of participants. Therefore, studies should be carried out post-pandemic encompassing a larger dataset. Future studies can make use of simulation and modelling techniques. Similarly, other MCDM techniques can be used. Future studies can focus on comparing the impact of risks in developing and developed countries during the COVID-19 pandemic. Other methodologies can be considered for assessing and increasing the reliability of the obtained results.

Notes

1. SARS-COV-2 (Severe acute respiratory syndrome coronavirus 2) is the name of the virus that caused the coronavirus disease 2019. In this paper we refer this disease as COVID-19.
2. See: https://time.com/5818819/imf-coronavirus-economic-collapse/
3. *Orness* is defined as the numerical quantification of the degree of disjunctive behavior of an operator (Dujmović 1974). Further, *orness* can be interpreted as the mode of decision-making in the aggregation process (Yager 1988).

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Adelaja, A., and J. George. 2019. "Effects of Conflict on Agriculture: Evidence From the Boko Haram Insurgency." *World Development* 117: 184–195.

Ali, S. M., M. A. Moktadir, G. Kabir, J. Chakma, M. J. U. Rumi, and M. T. Islam. 2019. "Framework for Evaluating Risks in Food Supply Chain: Implications in Food Wastage Reduction." *Journal of Cleaner Production* 228: 786–800.

Badraoui, I., J. G. Van der Vorst, and Y. Boulaksil. 2020. "Horizontal Logistics Collaboration: an Exploratory Study in Morocco's Agri-Food Supply Chains." *International Journal of Logistics Research and Applications* 23 (1): 85–102.

Barichello, R. 2020. "The COVID-19 Pandemic: Anticipating its Effects on Canada's Agricultural Trade." *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie*, doi:10.1111/cjag.12244. Forthcoming.

Behzadi, G., M. J. O'Sullivan, T. L. Olsen, F. Scrimgeour, and A. Zhang. 2017. "Robust and Resilient Strategies for Managing Supply Disruptions in an Agribusiness Supply Chain." *International Journal of Production Economics* 191: 207–220.

Bellemare, M. F., K. Chua, J. Santamaria, and K. Vu. 2020. "Tenurial Security and Agricultural Investment: Evidence From Vietnam." *Food Policy*. doi:10.1016/j.foodpol.2020.101839.

Bhagat, D., and U. R. Dhar. 2011. "Agriculture Supply Chain Management: A Review." *IUP Journal of Supply Chain Management* 8 (3): 7-25.

Bloemhof, J. M., J. G. van der Vorst, M. Bastl, and H. Allaoui. 2015. "Sustainability Assessment of Food Chain Logistics." *International Journal of Logistics Research and Applications* 18 (2): 101–117.

Boran, F. E., S. Genç, M. Kurt, and D. Akay. 2009. "A Multi-Criteria Intuitionistic Fuzzy Group Decision Making for Supplier Selection with TOPSIS Method." *Expert Systems with Applications* 36 (8): 11363–11368.

Boroushaki, S., and J. Malczewski. 2008. "Implementing an Extension of the Analytical Hierarchy Process Using Ordered Weighted Averaging Operators with Fuzzy Quantifiers in ArcGIS." *Computers & Geosciences* 34 (4): 399–410.

Boyabatlı, O., J. Nguyen, and T. Wang. 2017. "Capacity Management in Agricultural Commodity Processing and Application in the Palm Industry." *Manufacturing & Service Operations Management* 19 (4): 551–567.

Bozkurt, H., K. Y. Phan-Thien, F. van Ogtrop, T. Bell, and R. McConchie. 2020. "Outbreaks, Occurrence, and Control of Norovirus and Hepatitis a Virus Contamination in Berries: A Review." *Critical Reviews in Food Science and Nutrition*. doi:10.1080/10408398.2020.1719383.

Brewin, D. G. 2016. "Competition in Canada's Agricultural Value Chains: The Case of Grain." *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie* 64 (1): 5–19.

Brewin, D. 2020. "The Impact of COVID-19 on the Grains and Oilseeds Sector." *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie*. doi:10.1111/cjag.12239.

Carranza, E. J. M. 2008. *Geochemical Anomaly and Mineral Prospectivity Mapping in GIS (Vol. 11)*. Elsevier Science. https://books.google.co.in/books?id=YN6GgZWtwRoC.

Chandrasekaran, N., and G. Raghuram. 2014. *Agribusiness Supply Chain Management*. CRC Press. Boca Raton, Florida.

Chang, S. L., R. C. Wang, and S. Y. Wang. 2006. "Applying Fuzzy Linguistic Quantifier to Select Supply Chain Partners at Different Phases of Product Life Cycle." *International Journal of Production Economics* 100 (2): 348–359.

Chaudhry, S. S., F. G. Forst, and J. L. Zydiak. 1993. "Vendor Selection with Price Breaks." *European Journal of Operational Research* 70 (1): 52–66.

Choi, T. M. 2020. "Innovative "Bring-Service-Near-Your-Home" Operations Under Corona-Virus (COVID-19/SARS-CoV-2) Outbreak: Can Logistics Become the Messiah?" *Transportation Research Part E: Logistics and Transportation Review*. doi:10.1016/j.tre.2020.101961.

Choy, K. L., K. K. Fan, and V. Lo. 2003. "Development of an Intelligent Customer-Supplier Relationship Management System: The Application of Case-Based Reasoning." *Industrial Management & Data Systems* 103 (4): 263–274.
Dai, M., S. Huang, Q. Huang, G. Leng, Y. Guo, L. Wang, W. Fang, P. Li, and X. Zheng. 2020. "Assessing Agricultural Drought Risk and its Dynamic Evolution Characteristics." *Agricultural Water Management* 231: 106003.
Dani, S., and A. Deep. 2010. "Fragile Food Supply Chains: Reacting to Risks." *International Journal of Logistics: Research and Applications* 13 (5): 395–410.
Das V, J., S. Sharma, and A. Kaushik. 2019. "Views of Irish Farmers on Smart Farming Technologies: An Observational Study." *AgriEngineering* 1 (2): 164–187.
Deaton, B. James, and Brady J Deaton. 2020. "Food Security and Canada's Agricultural System Challenged by COVID-19." *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 68 (2): 143–149. doi:10.1111/cjag.v68.2.
de Janvry, A., and E. Sadoulet. 2020. "Using Agriculture for Development: Supply-and Demand-Side Approaches." *World Development* 133: 105003.
Deng, F., J. Sun, R. Dou, X. Yu, Z. Wei, C. Yang, X. Zeng, and L. Zhu. 2020. *Contamination of Pyrethroids in Agricultural Soils From the Yangtze River Delta, China*. Science of The Total Environment. doi:10.1016/j.scitotenv.2020.139181.
de Paulo Farias, D., and M. G. dos Santos Gomes. 2020. "COVID-19 Outbreak: What Should be Done to Avoid Food Shortages?" *Trends in Food Science & Technology*. doi:10.1016/j.tifs.2020.06.007.
Dong, M. 2006. "Development of Supply Chain Network Robustness Index." *International Journal of Services Operations and Informatics* 1 (1-2): 54–66.
Dora, M., and X. Gellynck. 2015. "House of Lean for Food Processing SMEs." *Trends in Food Science & Technology* 44 (2): 272–281.
Dora, M., M. Kumar, and X. Gellynck. 2016. "Determinants and Barriers to Lean Implementation in Food-Processing SMEs–a Multiple Case Analysis." *Production Planning & Control* 27 (1): 1–23.
Dujmović, J. J. 1974. "Weighted Conjunctive and Disjunctive Means and Their Application in System Evaluation." *Publikacije Elektrotehničkog Fakulteta. Serija Matematika i Fizika*, 461: 147–158. https://www.jstor.org/stable/43667685.
FAO. 2020. "Food and Agriculture Organization. Q&A: COVID-19 Pandemic - Impact on Food and Agriculture. http://www.fao.org/2019-ncov/q-and-a/en/.
Ghodsypour, S. H., and C. O'Brien. 1998. "A Decision Support System for Supplier Selection Using an Integrated Analytic Hierarchy Process and Linear Programming." *International Journal of Production Economics* 56: 199–212.
Glowacz, M., and D. Rees. 2016. "Using Jasmonates and Salicylates to Reduce Losses Within the Fruit Supply Chain." *European Food Research and Technology* 242 (2): 143–156.
Golmohammadi, A., and E. Hassini. 2019. "Capacity, Pricing and Production Under Supply and Demand Uncertainties with an Application in Agriculture." *European Journal of Operational Research* 275 (3): 1037–1049.
Govindan, K., H. Mina, and B. Alavi. 2020. "A Decision Support System for Demand Management in Healthcare Supply Chains Considering the Epidemic Outbreaks: A Case Study of Coronavirus Disease 2019 (COVID-19)." *Transportation Research Part E: Logistics and Transportation Review* 138: 101967.
Gray, R. S. 2020. "Agriculture, Transportation, and the COVID-19 Crisis." *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie*. doi:10.1111/cjag.12235.
Hailu, Getu. 2020. "Economic Thoughts on COVID-19 for Canadian Food Processors." *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 68 (2): 163–169. doi:10.1111/cjag.v68.2.
Haley, E., S. Caxaj, G. George, J. Hennebry, E. Martell, and J. McLaughlin. 2020. "Migrant Farmworkers Face Heightened Vulnerabilities During COVID-19." *Journal of Agriculture, Food Systems, and Community Development* 9 (3): 1–5.
Herrera, F., E. Herrera-Viedma, and J. L. Verdegay. 1996. "Direct Approach Processes in Group Decision Making Using Linguistic OWA Operators." *Fuzzy Sets and Systems* 79 (2): 175–190.
Hey, J. 2020. "Coronavirus: Measuring the Market Impact." In *Fruitnet* [Online]. London. www.fruitnet.com/asiafruit/article/181021/coronavirus-measuring-the-market-impact.
Hillman Willis, T., and C. R. Huston. 1990. "Vendor Requirements and Evaluation in a Just-in-Time Environment." *International Journal of Operations & Production Management* 10 (4): 41–50.
Hobbs, Jill E. 2020. "Food Supply Chains During the COVID-19 Pandemic." *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 68 (2): 171–176. doi:10.1111/cjag.v68.2.
Hou, D., D. O'Connor, A. D. Igalavithana, D. S. Alessi, J. Luo, D. C. Tsang, D. L. Sparks, Y. Yamauchi, J. Rinklebe, and Y. S. Ok. 2020. "Metal Contamination and Bioremediation of Agricultural Soils for Food Safety and Sustainability." *Nature Reviews Earth & Environment*, 1: 366-381.
IMF. 2020. "Policy responses to Covid-19." Washington, DC: International Monetary Fund. https://www.imf.org/en/Topics/imf-and-covid19/ Policy-Responses-to-COVID-19#I.

Ivanov, D. 2020a. "Predicting the Impacts of Epidemic Outbreaks on Global Supply Chains: A Simulation-Based Analysis on the Coronavirus Outbreak (COVID-19/SARS-CoV-2) Case." *Transportation Research Part E: Logistics and Transportation Review* 136: 101922.

Joffre, O. M., P. M. Poortvliet, and L. Klerkx. 2019. "To Cluster or not to Cluster Farmers? Influences on Network Interactions, Risk Perceptions, and Adoption of Aquaculture Practices." *Agricultural Systems* 173: 151–160.

Kamble, S, Gunasekaran, A, Gawankar, S. 2020. "Achieving Sustainable Performance in a Data-Driven Agriculture Supply Chain: A Review for Research and Applications." *International Journal of Production Economics.*

Kamble, S. S., A. Gunasekaran, and R. Sharma. 2020. "Modeling the Blockchain Enabled Traceability in Agriculture Supply Chain." *International Journal of Information Management* 52: 101967.

Kernecker, M., A. Knierim, A. Wurbs, T. Kraus, and F. Borges. 2020. "Experience Versus Expectation: Farmers' Perceptions of Smart Farming Technologies for Cropping Systems Across Europe." *Precision Agriculture* 21 (1): 34–50.

Kleindorfer, P. R., and G. H. Saad. 2005. "Managing Disruption Risks in Supply Chains." *Production and Operations Management* 14 (1): 53–68.

Komarek, A. M., A. De Pinto, and V. H. Smith. 2020. "A Review of Types of Risks in Agriculture: What we Know and What we Need to Know." *Agricultural Systems* 178: 102738.

Konidari, P., and D. Mavrakis. 2007. "A Multi-Criteria Evaluation Method for Climate Change Mitigation Policy Instruments." *Energy Policy* 35 (12): 6235–6257.

Kumar, M., P. Vrat, and R. Shankar. 2004. "A Fuzzy Goal Programming Approach for Vendor Selection Problem in a Supply Chain." *Computers & Industrial Engineering* 46 (1): 69–85.

Lemaire, A., and S. Limbourg. 2019. "How can Food Loss and Waste Management Achieve Sustainable Development Goals?" *Journal of Cleaner Production* 234: 1221–1234.

Levary, R. R. 2007. "Ranking Foreign Suppliers Based on Supply Risk." *Supply Chain Management: An International Journal* 12 (6): 392–394.

Li, M., Q. Fu, V. P. Singh, Y. Ji, D. Liu, C. Zhang, and T. Li. 2019. "An Optimal Modelling Approach for Managing Agricultural Water-Energy-Food Nexus Under Uncertainty." *Science of the Total Environment* 651: 1416–1434.

Licciardello, F. 2017. "Packaging, Blessing in Disguise. Review on its Diverse Contribution to Food Sustainability." *Trends in Food Science & Technology* 65: 32–39.

Lioutas, E. D., and C. Charatsari. 2020. "Smart Farming and Short Food Supply Chains: Are They Compatible?" *Land Use Policy* 94: 104541.

Liu, J., F. Y. Ding, and V. Lall. 2000. "Using Data Envelopment Analysis to Compare Suppliers for Supplier Selection and Performance Improvement." *Supply Chain Management: An International Journal* 5 (3): 143–150.

Liu, H., J. Zhang, C. Zhou, and Y. Ru. 2018. "Optimal Purchase and Inventory Retrieval Policies for Perishable Seasonal Agricultural Products." *Omega* 79: 133–145.

Long, T. B., V. Blok, and I. Coninx. 2016. "Barriers to the Adoption and Diffusion of Technological Innovations for Climate-Smart Agriculture in Europe: Evidence From the Netherlands, France, Switzerland and Italy." *Journal of Cleaner Production* 112: 9–21.

Mahajan, P. V., O. J. Caleb, Z. Singh, C. B. Watkins, and M. Geyer. 2014. "Post-harvest Treatments of Fresh Produce." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 372 (2017): 20130309.

Makate, C., M. Makate, M. Mutenje, N. Mango, and S. Siziba. 2019. "Synergistic Impacts of Agricultural Credit and Extension on Adoption of Climate-Smart Agricultural Technologies in Southern Africa." *Environmental Development* 32: 100458.

Malczewski, J. 2006. "Ordered Weighted Averaging with Fuzzy Quantifiers: GIS-Based Multicriteria Evaluation for Land-use Suitability Analysis." *International Journal of Applied Earth Observation and Geoinformation* 8 (4): 270–277.

Malczewski, J., and C. Rinner. 2005. "Exploring Multicriteria Decision Strategies in GIS with Linguistic Quantifiers: A Case Study of Residential Quality Evaluation." *Journal of Geographical Systems* 7 (2): 249–268.

Malik, P., and P. Garg. 2020. "Learning Organization and Work Engagement: The Mediating Role of Employee Resilience." *The International Journal of Human Resource Management* 31 (8): 1071–1094.

Mangla, S. K., S. Luthra, N. Rich, D. Kumar, N. P. Rana, and Y. K. Dwivedi. 2018b. "Enablers to Implement Sustainable Initiatives in Agri-Food Supply Chains." *International Journal of Production Economics* 203: 379–393.

Mekala, M.S. and Viswanathan, P., 2017, August. "A Survey: Smart Agriculture IoT with Cloud Computing." In 2017 *International Conference on Microelectronic Devices, Circuits and Systems (ICMDCS)*, 1–7. IEEE.

Mekonnen, Y., Burton, L., Sarwat, A. and Bhansali, S., 2018, October. "Iot Sensor Network Approach for Smart Farming: An Application in Food, Energy and Water System." In *2018 IEEE Global Humanitarian Technology Conference (GHTC)*, 1–5. IEEE.

Meyer-Aurich, A., and Y. N. Karatay. 2019. "Effects of Uncertainty and Farmers' Risk Aversion on Optimal N Fertilizer Supply in Wheat Production in Germany." *Agricultural Systems* 173: 130–139.

Michler, J. D., K. Baylis, M. Arends-Kuenning, and K. Mazvimavi. 2019. "Conservation Agriculture and Climate Resilience." *Journal of Environmental Economics and Management* 93: 148–169.

Mittenzwei, K., T. Persson, M. Höglind, and S. Kværnø. 2017. “Combined Effects of Climate Change and Policy Uncertainty on the Agricultural Sector in Norway.” *Agricultural Systems* 153: 118–126.
Mızrak Özfirat, P., G. Tuna Taşoglu, and G. Tunçel Memiş. 2014. “A Fuzzy Analytic Hierarchy Process Methodology for the Supplier Selection Problem.” *Journal of Enterprise Information Management* 27 (3): 292–301.
Monteleone, S., E. A. de Moraes, and R. F. Maia. 2019, June. “Analysis of the Variables That Affect the Intention to Adopt Precision Agriculture for Smart Water Management in Agriculture 4.0 Context.” In *2019 Global IoT Summit (GIoTS)*. doi:10.1109/GIOTS.2019.8766384.IEEE.
Munir, M., M. S. S. Jajja, K. A. Chatha, and S. Farooq. 2020. “Supply Chain Risk Management and Operational Performance: The Enabling Role of Supply Chain Integration.” *International Journal of Production Economics* 227: 107667.
Mvumi, B., L. T. Matsikira, and J. Mutambara. 2016. “The Banana Post-Harvest Value Chain Analysis in Zimbabwe.” *British Food Journal* 118 (2): 272–285. doi:10.1108/BFJ-08-2014-0293.
Ng, S. T., and R. M. Skitmore. 1995. “CP-DSS: Decision Support System for Contractor Prequalification.” *Civil Engineering Systems* 12 (2): 133–159.
Nyamah, E. Y., Y. Jiang, Y. Feng, and E. Enchill. 2017. “Agri-food Supply Chain Performance: an Empirical Impact of Risk.” *Management Decision* 55 (5): 872-891
O’Grady, M. J., and G. M. O’Hare. 2017. “Modelling the Smart Farm.” *Information Processing in Agriculture* 4 (3): 179–187.
Ordoobadi, S. M., and S. Wang. 2011. “A Multiple Perspectives Approach to Supplier Selection.” *Industrial Management & Data Systems* 111 (4): 629–648.
Ortega, D. L., and D. L. Tschirley. 2017. “Demand for Food Safety in Emerging and Developing Countries.” *Journal of Agribusiness in Developing and Emerging Economies*. doi:10.1108/JADEE-12-2014-0045.
Pigni, F., G. Piccoli, and R. Watson. 2016. “Digital Data Streams: Creating Value From the Real-Time Flow of big Data.” *California Management Review* 58 (3): 5–25.
Ragasa, C., and I. Lambrecht. 2020. “COVID-19 and the Food System: Setback or Opportunity for Gender Equality?” *Food Security*, 12: 877–880.
Ramanathan, R. 2007. “Supplier Selection Problem: Integrating DEA with the Approaches of Total Cost of Ownership and AHP.” *Supply Chain Management: an International Journal* 12 (4): 258–261.
Rizou, M., I. M. Galanakis, T. M. Aldawoud, and C. M. Galanakis. 2020. “Safety of Foods, Food Supply Chain and Environment Within the COVID-19 Pandemic.” *Trends in Food Science & Technology* 102: 293–299.
Roy, R., A. K. Gain, N. Samat, M. Hurlbert, M. L. Tan, and N. W. Chan. 2019. “Resilience of Coastal Agricultural Systems in Bangladesh: Assessment for Agroecosystem Stewardship Strategies.” *Ecological Indicators* 106: 105525.
Saaty, T. 1980. *The Analytic Process: Planning, Priority Setting, Resources Allocation*. New York: McGraw.
Savary, S., L. Willocquet, S. J. Pethybridge, P. Esker, N. McRoberts, and A. Nelson. 2019. “The Global Burden of Pathogens and Pests on Major Food Crops.” *Nature Ecology & Evolution* 3 (3): 430–439.
Sgarbossa, F., and I. Russo. 2017. “A Proactive Model in Sustainable Food Supply Chain: Insight From a Case Study.” *International Journal of Production Economics* 183: 596–606.
Sharma, R., S. S. Kamble, A. Gunasekaran, V. Kumar, and A. Kumar. 2020. “A Systematic Literature Review on Machine Learning Applications for Sustainable Agriculture Supply Chain Performance.” *Computers & Operations Research*. https://doi.org/10.1016/j.cor.2020.104926.
Shih, W. 2020. “COVID-19 and Global Supply Chains: Watch out for Bullwhip Effects. Forbes.” https://www.forbes.com/sites/willyshih/2020/02/21/covid-19-and-global-supply-chains-watch-out-for-bullwhip-effects/#6928db537195.
Shishodia, A., P. Verma, and V. Dixit. 2019. “Supplier Evaluation for Resilient Project Driven Supply Chain.” *Computers & Industrial Engineering* 129: 465–478.
Shukla, V., and M. M. Naim. 2018. “Sensing Endogenous Seasonality in the Case of a Coffee Supply Chain.” *International Journal of Logistics Research and Applications* 21 (3): 279–299.
Siche, R. 2020. “What is the Impact of COVID-19 Disease on Agriculture?” *Scientia Agropecuaria* 11 (1): 3–6.
Stephens, E. C., G. Martin, M. van Wijk, J. Timsina, and V. Snow. 2020. “Impacts of COVID-19 on Agricultural and Food Systems Worldwide and on Progress to the Sustainable Development Goals.” *Agricultural Systems* 183: 102873.
Stockford, A. 2020. “Truckers Deal with New Reality Under COVID-19.” *Manitoba Cooperator*. https://www.manitobacooperator.ca/news-opinion/news/truckers-deal-with-new-reality-under-covid-19/?utm_source=GFM+Publications&utm_campaign=13b44f3e94-Manitoba+Co-operator+daily+enews+Mar+28%2C+2020&utm_medium=email&utm_term=0_2da8244677-13b44f3e94-88576345.
Thomson, H. 2019. *Food and Power: Regime Type, Agricultural Policy, and Political Stability*. Cambridge: Cambridge University Press.
Timmerman, E. 1986. “An Approach to Vendor Performance Evaluation.” *Journal of Purchasing and Materials Management* 22 (4): 2–8.
Torero, M. 2020. “Without Food, There can be no Exit From the Pandemic. Countries Must Join Forces to Avert a Global Food Crisis From COVID-19.” *Nature* 580: 588–589. doi:10.1038/d41586-020-01181-3.

Tsolakis, N. K., C. A. Keramydas, A. K. Toka, D. A. Aidonis, and E. T. Iakovou. 2014. "Agrifood Supply Chain Management: A Comprehensive Hierarchical Decisionmaking Framework and a Critical Taxonomy." *Biosystems Engineering* 120: 47–64.

Tummala, R., and T. Schoenherr. 2011. "Assessing and Managing Risks Using the Supply Chain Risk Management Process (SCRMP)." *Supply Chain Management* 16 (6): 474–483. doi:10.1108/13598541111171165.

van der Vorst, J. G., A. J. Beulens, and P. van Beek. 2000. "Modelling and Simulating Multi-Echelon Food Systems." *European Journal of Operational Research* 122 (2): 354–366.

Velasquez, M., and P. T. Hester. 2013. "An Analysis of Multi-Criteria Decision-Making Methods." *International Journal of Operations Research* 10 (2): 56–66.

Verdonk, T. 2019. "Planting the Seeds of Market Power: Digital Agriculture, Farmers' Autonomy, and the Role of Competition Policy." In *Regulating New Technologies in Uncertain Times*, edited by L. Reins, 105–132. The Hague: TMC Asser Press. doi:10.1007/978-94-6265-279-8_7.

Walter, A., R. Finger, R. Huber, and N. Buchmann. 2017. "Opinion: Smart Farming is key to Developing Sustainable Agriculture." *Proceedings of the National Academy of Sciences* 114 (24): 6148–6150.

Wang, Y. M., R. Greatbanks, and J. B. Yang. 2005. "Interval Efficiency Assessment Using Data Envelopment Analysis." *Fuzzy Sets and Systems* 153 (3): 347–370.

Wang, G., Q. Lu, and S. C. Capareda. 2020. "Social Network and Extension Service in Farmers' Agricultural Technology Adoption Efficiency." *Plos one* 15 (7): e0235927.

Weber, C. A., J. R. Current, and A. Desai. 1998. "Non-cooperative Negotiation Strategies for Vendor Selection." *European Journal of Operational Research* 108 (1): 208–223.

Weber, C. A., J. Current, and A. Desai. 2000. "An Optimization Approach to Determining the Number of Vendors to Employ." *Supply Chain Management: An International Journal* 5 (2): 90–98.

Wesana, J., X. Gellynck, M. K. Dora, D. Pearce, and H. De Steur. 2019. "Measuring Food and Nutritional Losses Through Value Stream Mapping Along the Dairy Value Chain in Uganda." *Resources, Conservation and Recycling* 150: 104416.

WHO (World Health Organisation). 2020. "Coronavirus Disease (COVID-19) Pandemic." https://www.who.int/emergencies/diseases/novel-coronavirus-2019.

WTO (World Trade Organization). 2020. "Trade Set to Plunge as COVID-19 Pandemic Upends Global Economy." Geneva. (also available at from www.wto.org/english/news_e/pres20_e/pr855_e.htm).

Xu, D., and Y. Long. 2020. "The Role of Supply Chain Integration in the Transformation of Food Manufacturers: A Case Study From China." *International Journal of Logistics Research and Applications*. doi:10.1080/13675567.2020.1729707.

Yager, R. R. 1988. "On Ordered Weighted Averaging Aggregation Operators in Multicriteria Decision-Making." *IEEE Transactions on Systems, Man, and Cybernetics* 18 (1): 183–190.

Yager, R. R. 1996. "Quantifier Guided Aggregation Using OWA Operators." *International Journal of Intelligent Systems* 11 (1): 49–73.

Yazdani, M., E. D. Gonzalez, and P. Chatterjee. 2019. "A Multicriteria Decisionmaking Framework for Agriculture Supply Chain Risk Management Under a Circular Economy Context." *Management Decision*. doi:10.1108/MD-10-2018-1088.

Zadeh, L. A. 1965. "Fuzzy Sets." *Information and Control* 8: 338–353.

Zadeh, L. A. 1975a. "The Concept of a Linguistic Variable and its Application to Approximate Reasoning—I." *Information Sciences* 8 (3): 199–249.

Zadeh, L. A. 1975b. "Fuzzy Logic and Approximate Reasoning." *Synthese* 30 (3-4): 407–428.

Zadeh, L. A. 1983. "A Computational Approach to Fuzzy Quantifiers in Natural Languages." *Computers & Mathematics with Applications* 9 (1): 149–184.

Zhao, G., S. Liu, C. Lopez, H. Chen, H. Lu, S. K. Mangla, and S. Elgueta. 2020. "Risk Analysis of the Agri-Food Supply Chain: A Multi-Method Approach." *International Journal of Production Research*. doi:10.1080/00207543.2020.1725684.

Zhu, Y., Y. Zhao, J. Zhang, N. Geng, and D. Huang. 2019. "Spring Onion Seed Demand Forecasting Using a Hybrid Holt-Winters and Support Vector Machine Model." *PloS one* 14 (7): e0219889.

Zirham, M., and R. Palomba. 2016. "Female Agriculture in the Short Food Supply Chain: a new Path Towards the Sustainability Empowerment." *Agriculture and Agricultural Science Procedia* 8 (1): 372–377.

Appendix I

Table A1. Organisation detail summary of respondents.

Micro Enterprises				
Organisation Code	Designation	Organisation Location	Agribusiness sector	Market Scope
MI1	Managing Director (MD)	Western India	Agroforestry Products	Local
MI2	MD/ CEO	Western India	Food Processing	Regional
MI3	MD	Eastern India	Agri Inputs	Local
MI4	MD/ CEO	Northern India	Agriculture Trading	Regional
MI5	General Manager	Southern India	Greenhouse Farming	Regional
Small Enterprises				
Organisation Code	Designation of Respondent	Organisation Location	Agribusiness sector	Market Scope
SI1	MD	Northern India	Agricultural Commodities Processing	Regional
SI2	MD/ CEO	Western India	Warehousing and Collateral Management	National
SI3	MD/ CEO	Northern India	Agri Trading	Regional
SI4	MD/ CEO	Eastern India	Agri Inputs	Regional
SI5	MD	Southern India	Dairy	Regional
Medium Enterprises				
Organisation Code	Designation of Respondent	Organisation Location	Agribusiness sector	Market Scope
ME1	MD/ CEO	Eastern India	Farmer Producer Company	National
ME2	General Manager	Southern India	Warehousing and Collateral Management	National
ME3	MD/ CEO	Western India	Food Processing	National
ME4	MD	Western India	Agricultural Trading	National
ME5	Vice President	Southern India	Farm to Retail Supply Chain	National
MNCs				
Organisation Code	Designation of Respondent	Organisation Location	Agribusiness sector	Market Scope
MNC1	Director	Northern India	Agri Tech and Farm Equipment	International
MNC2	General Manager	Western India	Agri Commodities Trade	International
MNC3	Vice President	Southern India	Agri Inputs (Seeds)	International
MNC4	Managing Director/ CEO	Southern India	Agri Chemicals and Fertilisers	International
MNC5	Territory Sales Manager	Western India	Dairy and Milk Processing	International

NB: Micro Enterprises are enterprises wherein the investment in plant and machinery does not exceed twenty-five lakh rupees. Small Enterprise are enterprises wherein the investment in plant and machinery is more than twenty-five lakh rupees but does not exceed five crore rupees Medium Enterprises are enterprises wherein the investment in plant and machinery is more than five crore rupees but does not exceed ten crore rupees. (Source: dcmsme.gov.in).

MNCs are defined as the organisations that are registered and their operations are spread across different countries. 25% of their revenues are derived from out of home country operations.

Professional Qualification of the Respondents

Professional qualification of the respondents was a crucial aspect for the study. The information is shown statistically with the help of a pie chart below in Figure A1.

Work experience of respondents

Work experience of the respondents gives information about their level of expertise in their domain of work. Data collected on respondents work experience details is shown in the pie chart in Figure A2.

Similar to calculation in Table 4, after substituting the values for different risks, we get the values as described below.

Table A2. Computation of organisational risks in continuation with Table 4.

	Micro Industries				
Risks	MI1	MI2	MI3	MI4	MI5
Supply side	0.295	0.311	0.213	0.338	0.287
Demand side	0.287	0.234	0.234	0.426	0.676
Logistics and infrastructural	0.425	0.162	0.262	0.480	0.635
Policy and regulatory	0.287	0.031	0.000	0.500	0.375
Financial	0.508	0.750	0.779	1.000	0.758
Biological and environmental	0.346	0.074	0.037	0.508	0.133
Management and operational	0.250	0.000	0.000	0.346	0.016
Weather related	0.088	0.000	0.000	0.529	0.104
Political	0.037	0.016	0.015	0.051	0.000
Risks	Small Industries				
	SI1	SI2	SI3	SI4	SI5
Supply side	0.750	0.596	0.279	0.596	0.529
Demand side	0.434	1.000	0.596	1.000	0.529
Logistics and infrastructural	0.764	1.000	0.379	1.000	0.450
Policy and regulatory	0.088	0.779	0.045	0.779	0.058
Financial	0.500	0.258	0.779	1.000	0.354
Biological and environmental	0.045	0.779	0.258	0.258	0.258
Management and operational	0.750	0.838	0.500	0.500	0.338
Weather related	0.426	0.758	0.500	0.500	0.279
Political	0.434	0.266	0.176	0.176	0.287
Risks	Medium Industries				
	ME1	ME2	ME3	ME4	ME5
Supply side	0.617	0.596	0.676	0.516	0.779
Demand side	0.558	0.529	1.000	0.455	0.426
Logistics and infrastructural	0.879	0.689	0.758	0.676	0.615
Policy and regulatory	0.162	0.324	0.654	1.000	0.500
Financial	0.516	0.529	1.000	0.539	0.316
Biological and environmental	0.455	0.346	1.000	0.356	0.434
Management and operational	0.676	0.588	0.676	0.598	0.750
Weather related	1.000	0.588	0.838	0.598	0.213
Political	0.176	0.508	0.617	0.518	0.023
Risks	MNCs				
	MNC1	MNC2	MNC3	MNC4	MNC5
Supply side	0.676	0.639	0.588	0.758	0.779
Demand side	0.539	0.466	0.367	0.838	0.352
Logistics and infrastructural	0.456	0.398	0.420	0.939	0.341
Policy and regulatory	0.098	0.135	0.037	0.758	0.352
Financial	0.205	0.234	0.250	0.346	0.388
Biological and environmental	0.035	0.039	0.516	0.750	0.352
Management and operational	0.055	0.350	0.058	0.838	0.264
Weather related	0.088	0.000	0.375	0.676	0.045
Political	0.045	0.000	0.176	0.516	0.308

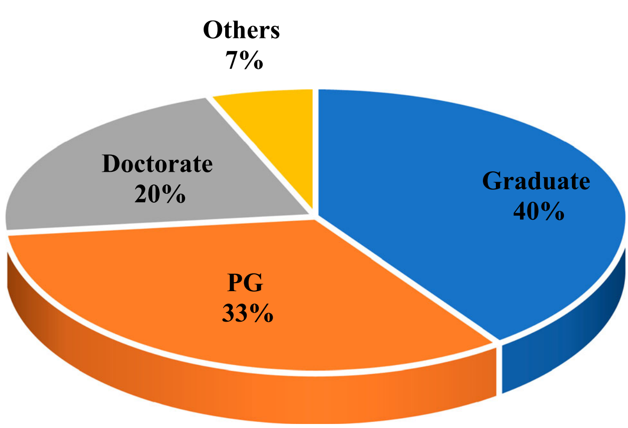

Figure A1. Professional qualification of respondents.

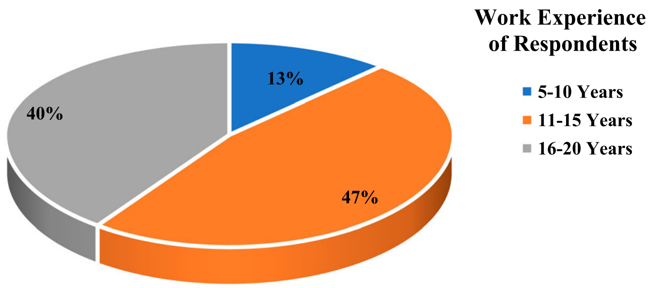

Figure A2. Work experience of respondents (in years).

Questionnaire

What is the respondent's designation?
Where is respondent's organisation located?
The agribusiness sector in which your organisation operates.
Organisation size.
What is the market scope of your organisation?
What is the impact of COVID19 on your business?
What are the various response strategies being adopted by your organisation for mitigating the impact of COVID-19 outbreak?
The following section presents the various ASC risks and their sub-factors. You are requested to rate them on a scale of 1-5.

ASC Risks	Sub-Factors	Rate on a scale of 1–5
Supply side	Supplier quality problems	
	Sudden default of a supplier (transportation, payments, etc.)	
	Underperformance of logistics providers	
	Capacity fluctuations/ shortages in the supply market	
Demand side	Unanticipated consumer demand	
	Insufficient information about demand quantities	
	Transportation issues	
	Changes in food safety requirements	
Logistics and infrastructural	Changes in transportation	
	Incremental changes in energy cost	
	Undependable transport	
	Conflicts, labour disputes, labour shortages	
	Lack of infrastructure and service units	
Policy and regulatory	Uncertain monetary, fiscal, tax policies	
	Uncertain legal policies and enforcements	
	Uncertain trade and market policies	
	Uncertain land policies and tenurial systems	
Financial	Inadequate financial support	
	Delays in accessing financial support	
	Uncertain credit support	
	Uncertain interest and exchange rate policies	
Biological and environmental	Pests, diseases, yield losses	
	Contamination related to poor sanitisation and illnesses	
	Contamination affecting food safety	
	Contamination and degradation of production and processing processes	
Management and operational	Poor management decisions	
	Poor quality control	
	Planning and forecast errors	
	Use of outdated inputs	
Weather related	Periodic deficit/ excess rainfall	
	Extreme drought	
	Flooding	

(*Continued*)

Continued.

ASC Risks	Sub-Factors	Rate on a scale of 1–5
	Extreme winds/ cyclone	
Political	Political instability/ crisis	
	Trade interruptions/ restrictions	
	Legislation risks	
	Changes in the political environment	