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Key operational and institutional factors for improving food safety: a case study from Chile

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ABSTRACT
The worldwide demand for safe food is increased due to the population growth and the improvement of living standards. Different global standards are relevant in the food value chain including education and training of human resources, government regulations and surveillance. Different factors related to food safety risks in production can be taken into consideration in developing economies. Achieving food safety needs a highly integrated system in food supply and operations management. To meet demand for safe and higher quality food, food organisations especially in developing nations like Chile face numerous problematic issues. In terms of dynamic capabilities, this study takes account of supply chain re-conceptualisation, co-evolving and reflexive supply chain control. In this paper, we identify and prioritise key institutional and operational factors for improving the food safety in Chile. The factors were analysed using a Fuzzy analytic hierarchy process for illustrating the significance of key criteria to food safety concepts under uncertain environment. We provides a detailed and prioritised criteria for improving food safety practices, helping managers to understand the operational and institutional environment and makes a contribution to inform food organisations and government policy-making to reduce food losses and improve sustainability of food chains under fuzzy situations.

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Food supply chain management: food safety; operational and institutional factors; Fuzzy AHP; Chile

1. Introduction

In the last two decades, the credibility of food safety was heavily challenged after a series of food scandals, such as Bovine Spongiform Encephalopathy (BSE), horsemeat scandal, Dioxin in chicken food, Foot-and-Mouth Disease (FMD), trench oil and issues such as the use of Genetically Modified (GM) crops in agri-food products (Xiao, Liu, and Li 2012; Aung and Chang 2014). Unsafe food not only causes both acute and chronic illness to humans, for example, approximately 4,000 people died every day from Bovine Tuberculosis in developing countries, but also causes companies and their supply chain partners being exposed to internal and external risks such as financial and institutional risks (Leat and Revoredo-Giha 2013; Chan 2014; Lavastre, Angappa, and Spalanzani 2014). It is estimated that millions of people in OECD (Organisation for Economic Co-operation and Development) countries get ill every year due to contaminated food and improper food handling systems (Rocourt et al. 2003). Given the recognised and microbiological hazards of unsafe food to human health, the food safety has received increased international attention (Unnevehr 2015). Escanciano and Santos-Vijande (2014) stated that 'food safety refers to any problem related to hygiene and harmlessness of the food that reach consumers'. After conducting a literature review on food safety in the 21st century, Fung, Wang, and Menon (2018) proposed that there are four main challenges of food safety, which are chemical, microbiological, personal and environmental hygiene.

Producing and delivering safe food to the end consumers are becoming emerging research topics in food supply chain management (FSCM). For example, Mangla et al. (2018) examined the various key enablers that assist agri-food organisations to reduce food wastage and improve sustainability in their value chain context. Kirezieva et al. (2015) investigated the potential differences of underlying factors of food safety management systems (FSMSs) implemented at fresh produce companies in both European Union and non-European Union countries. Their research indicates that the legislative framework still requires the improvements in set-up and enforcement for chemical and microbiological risks, while the local institution legitimacy often fail to support companies in setting and implementing their FSMSs, and that is broadly reflected in emerging countries. Schoenherr, Narasimhan, and Bandyopadhyay (2015) conduct a research on developing a framework for assuring food safety via relational networking. They find that there is a positive effect of consumer pressure on both firm's learning orientation and

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risk aversion, which in turn affects both informal and formal relational networking. Furthermore, Uyttendaele et al. (2015) explored the advantages and disadvantages of the chemical and microbiological safety standards in the fresh produce supply chain. Their research illustrates that training and risk communication plays a vital role for well-accepted and functional food safety standards. However, even though researchers have shed lights on food safety in different perspectives, there is a lack of comprehensive view to consider improving food safety in a social system by taking into account of international and national regulations, operational dynamic capabilities and supply chain management (Henson and Humphrey 2010; Auler, Teixeira, and Nardi 2017). Achieving food safety needs a highly integrated system in SCM (Nooghabi et al. 2018). Lu et al. (2015) suggested that it has increasing urgent to publish a series of guidelines and standards for achieving food safety. Simultaneously, collaboration among government, academia, industry and farmers is also necessary to reduce the food safety risks in production.

Chemical food safety issues such as pesticide residues are an important concern for the fresh produce supply chain (Tait and Bruce, 2001) as it may pose a risk to human health (Szpyrka 2015). Different kind of chemical risks are important in vegetables and fruits. In Chile, there is a lack of scientific information about risk assessments in food supply management. The Food Information and Alert Network reported in 2019 a more detailed information of the current state of food safety in Chile. The report is based in the official notification in Chile due physical, biological and chemical contaminations detected in the official surveillance programmes. The RIAL (2019) shown that the main problems in Chile about food safety are related to pesticide residues, poor supply chain planning and dynamic capabilities and lack of standards in fresh food (RIAL 2019).

In response to the current research gap, this study will identify and analyse both institutional and operational factors that influence food safety to answer the research question of *how to improve Chile's food safety performance in coherence with the political, operational and supply chain transformations?*

The aim of this research is to identify and prioritise influential factors for effectively understanding and managing food safety practices in supply chains. Therefore, three research objectives are proposed to fulfil the aim of this study:

> Firstly to identify factors that influence food safety practices in operations and SCM, including consideration of global standards perspective, national perspectives, operational dynamic capabilities and supply chain perspective associated with food SCM.
>
> Secondly to propose an analytical model and prioritize the recognised food safety issues for managing the food supply chain efficiently.
>
> Finally to provide good advice for food supply chain managers based on the analysis results.

In the last few years, Chile has been positioning itself in the global economy due to their agricultural industry as an important exporter of fresh food (Handschuch, Wollni, and Villalobos 2013). The importance of export activity in the GDP of the country has increased significantly over the last 20 years (Rehner, Baeza, and Barton 2014). The country has emerged as one of the most important stakeholders in the food production worldwide showing a high efficiency in the agribusiness industry (Lakner, Brenes-Muñoz, and Brummer 2017). In this regard, this study shads the light on Chile, exemplifying the current issues in food safety operations and SCM in emerging economics.

The food safety involves multiple factors analysis in the agri-food value chain. Analytic hierarchy process (AHP) is one of the most commonly used approaches for addressing multiple-criteria decision-making problems in an attribute hierarchy (Saaty 1980). However, it has the limitation for capturing the sound-judgement in decision making due to the involvement of linguistic data (Ishizaka and Labib 2009) for using AHP alone. Simultaneously, there may have inaccurate and vague data presence in the process of analysing and prioritising the food safety factors (Wang, Li, and Shi 2012). Wu, Tzeng, and Chen (2009) stated that fuzzy theory is a useful tool for automating human activities with uncertainty-based information. Therefore, the fuzzy set theory integrated with the AHP method is proposed to cope with the uncertainty and imprecision in the process of analysing and prioritising the food safety factors.

The remaining of this paper is organised as follows. A comprehensive literature review relevant to this study is presented in Section 2 followed by the research methodology in Section 3. The food safety issues related to Chile are described in Section 4. Then, the application of fuzzy AHP approach in the context of Chile is illustrated in Section 5. The results and managerial implications of the study are discussed in Section 6. To examine the food safety issues ranking and sensitivity analysis is conducted in Section 7. Further, the conclusion is drawn in Section 8.

2. Relevant background and literature review

Food safety is the concept that food will not cause harm to the consumer at the point of consumption when it is prepared and/or eaten according to its intended use (International Organization for Standardization 2005). Currently, FSMSs in developing countries are not always effective due to both public reasons and SCM challenges. For example, the large number of food fraud incidents determine a lack of sufficient documentations of such regulations, compliance and measure in emerging economics (Zhang et al. 2018); Meanwhile, consumers' knowledge and training influence on their willingness to pay for food safety; Finally, operations and supply chain capabilities hinder the food safety performance to transform consumer preferences down to a set of progresses in processing, packaging, trading and farming (Joshi et al. 2012). By taking these factors into account, a comprehensively review of literatures on food safety finds four aspects emphasised: managing food safety at global level, national level, supply chain level and operational dynamic capabilities.

2.1. Managing food safety at global level

Managing food safety issues is multifaceted. At global level, there are four main organisations to deal with food safety issues: the Food and Agricultural Organisation (FAO), the World Health Organisation (WHO), the World Trade Organisation (WTO) and the UN organisations (Trienekens and Zuurbier 2008).

Food safety regulations have been implemented since 1990s in developed countries, and then spread the impact of these standards on developing countries through international trading (Unnevehr 2015). Simultaneously, more free international trade is facilitated by new food, new transportation technology and a friendly policy environment, it is in this context standards have emerged to take on a prominent role in global management (Henson and Reardon 2005). Meanwhile, public regulations has been increasingly addressed on improving FSMSs and food safety performance such as using a risk analysis framework in food safety policy design for risk assessment and communications (FAO & WHO 2003) and having compliance for market access requirements in exports (Ferro, Wilson, and Otsuki 2013). Thus, food safety has received increasing international attention in public regulations, private supply chain coordination, and international trade for the past two decades (Unnevehr 2015; Zhang et al. 2018). To maintain food safety at global level, different stakeholders need to be engaged with three dimensions – policy and regulations of food safety risks, surveillance systems and their enforcements, and education and training of human resources.

- Policy and regulations of food safety risks: The aim of food safety regulations is to force firms to produce higher quality, safer products for consumers (Antle 1999). Condera et al. (2015) underlined that improving the quality and safety of foods, ensuring consumer protection and strengthening consumer confidence is the first priority of the policy and regulations. In the global level, ISO 22000 standard is developed to harmonise with different countries, the standard combines interactive communication, system requirements, prerequisite programme, and HACCP principles to assure food safety (Mensah and Julien 2011). However, Escanciano and Santos-Vijande (2014) argue that there are some constraints to implementing policy and regulations such as ISO 22000 FSMS in a global level: (1) current economic constraints in some countries may affecting many firms are the cause of the diffusion of ISO22000 not being wider; (2) given the standard's coexistence with other standards, for example, in the EU, many firms do not see it as being a licence required to complete in that market; (3) the standard is little known and poorly understood by food sector enterprises. Therefore, these enterprises are often unware of its real potential, seeing its usefulness.
- Surveillance systems and their enforcement: Having Food and Drug Administration (FDA) or similar agency in most countries of the world, which plays a vital role for compliance of food safety law in protecting public health and safety from three dimensions: (1) have the responsibility to inform citizens of nutrition and components of important food products; (2) enforce existing laws and regulations on food industry to ensure supply of safe food products; (3) investigate and eliminate potential chemicals or toxic contaminations and prosecute fraud via regular monitoring and surveillance on chain of food supply (Fung, Wang, and Menon 2018). However, Fosu et al. (2017) stated that most of the surveillance systems in developing countries are often limited due to lack of resources and rigorous regulations. For example, in some developing countries the main regulation to cover the food safety are related to use of pesticide in the agriculture and the compliance of maximum residue levels (MRL) of pesticides in food commodities, that are often no fully enforced or promulgated (Wanwimolruk et al. 2015).
- Education and training of human resources: FAO & WHO (2003) stated that delivery information, education and suggestion to all stakeholders plays an important role in keeping safety of food. Saeed et al. (2017) emphasised that training and education programmes should be held regularly to provide adequate knowledge and skills for the safe use of pesticide in the agriculture. If the farm workers receive proper education and training, food safety can be significantly improved (Shinbaum, Crandall, and O'Bryan 2016). In addition, sharing information and database among different organisations is a necessary replenishment to enforce food safety (Johnson 2015). Jia and Jukes (2013) suggested that it is necessary for food control authorities to train their staff as professional inspectors. After conducting a research on food-borne diseases in low and middle income countries, Grace (2015) proposed that training farmers on inputting use and good practices have great benefits on improving food safety.

2.2. Managing food safety at national level

Fung, Wang, and Menon (2018) stated that safe food not only provides basic human necessity, but also supports national economy, trade and tourism, and underpins sustainable development. In contemporary global agri-food system, the modus operandi used by different countries to ensure the safety of food is to impose product standards and also process standards related to safe working methods for each process and good hygienic practices during production, processing, trade, and storage (Jacxsens et al. 2015). For example, the British Retail Consortium's global food safety standard (BRC) was developed to respond to the need of UK retailers and brand manufacturers in 1998 (Mensah and Julien 2011). In other countries, such as Chile, the government has formulated different regulations to control the food safety mainly for the use of pesticide in the agriculture and their impacts in the human health and environment. Different Chilean regulations have been created to control the use of pesticide including the regulation of package labels (Resolution 2195 of 2000), toxicological classifications (Resolution 2196 of 2000), origin and codifications

(Resolution 5392 of 2009), use in the agriculture (Resolution 3670/1999), and cost related to the registration process (Resolution 7, 7935 of 2010). In Chile, three elements are important for managing food safety at national level: food safety standards, pesticide residue levels and safety standard.

- Food safety standards: For ensuring food safety, more stringent measures are implemented and tariffs and quotas as trade barriers are lowered in most developed and developing countries (Mensah and Julien 2011). Compared with developed economics where food safety is assured by robust infrastructure, whereas in developing economies, logistics pose substantial challenges because of unpredictable conditions, weak infrastructure and uncertainty in the eco-system, such as availability for unpolluted water and soil (Henson and Humphrey 2010).
- Pesticide residue levels: Pesticide residues are an important concern for the fresh produce at national level because it is relevant to monitoring the pesticide residues and to assess if it pose a risk to human health (Tait and Bruce 2001; Szpyrka 2015). Handford et al. (2015) stated that pesticide residues varied greatly worldwide, normally, developed countries have more stringent requirements than developing countries because developed countries have more resource and expertise to adequately implement and enforce legislation. For example, the European Union has the strictest requirements on maximum residue limits (MRL) of pesticide, and the United States has the weakest requirements in several cases for pesticide such as acetamiprid on apple and spinosad on corn (Handford et al. 2015).
- Food safety standards: According to the Sanitary and Phytosanitary Agreement of WTO, food safety standards include the law, decrees, regulations, requirements, procedures, inspections, certifications, approval procedures, sampling procedures, methods of risk assessments, packaging and labelling requirements related to food safety (Jongwanich 2009). Food safety standards have become a more prominent issue for international trade of fresh vegetables and fruits in the last few years. The emergence of new stringent food safety standards in industrialised countries is the results of factors such as the growth in trade of perishable food, scientific and regulatory consensus on best approaches to risk management, the recognition of global standards and approaches under the World Trade Organisation (WTO) (Unnevehr 2015).

2.3. Managing food safety at the level of operational dynamic capabilities

2.3.1. Definition of dynamic capabilities

Following the discussion of macro institutional environmental in emerging economics, the question we ask, from an operational perspective, is how supply chain enterprises generate dynamic capabilities to cope with current issues and breed both business and social competencies for pursing food safety standards. A dynamic capability view draws great attention in operation and SCM to link companies' decision making with their existing resource configuration. Dynamic capabilities to explain competitive advantage and performance on high velocity and dynamically change of markets (Teece, Pisano, and Shuen 1997; Zahra, Sapienza, and Davidsson 2006). The notion of dynamic capabilities is riddled with inconsistencies in literature, this study adopts the definition from Teece, Pisano, and Shuen (1997, 516) that dynamic capabilities is 'firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments.' This approach was built considering several main elements which highlights the underpinning theories, including nature, role, context, creation, outcome and heterogeneity.

The natural of the concept is an 'ability' or 'capacity', and the key role of dynamic capabilities as linked to the change of internal components, operating routines and recourses routines of firms (Barreto 2010). Some researchers extend Teece, Pisano, and Shuen (1997) study investigate dynamic capabilities from a resource based view (RBV). Danneels (2002) demonstrates the essentiality for the RBV embedding a dynamic perspective to understand how firms evolve overtime, via their accumulation and acquisition of resources for continuously renewing and reconfiguring for survival. More recently, Helfat et al. (2007, 1) define a dynamic capability as 'the capacity of an organisation to purposefully create, extend or modify its resource base'. By undertaking the views from different perspective, we believe that dynamic capability is the ability to integrate and reconfigure internal and external competences for specific purposes of integrating and reconfiguration resources and sustaining competitive advantage.

2.3.2. Current research gap of dynamic capabilities in food safety

The dynamic capabilities view in operations and SCM is of infancy (Ambrosini et al. 2009), yet there is a lack of comprehensive discussions on the theory for solving food safety issues in emerging economics. The operations and SCM literature has developed the research which can both explain the behaviour of operational processes and capture the problems in decision making on design, planning, controlling and executing operations (Akkerman, Poorya, and Grunow 2010; Bertrand and Fransoo 2002). Current studies explore food safety from distinct levels. Wiengarten et al. (2016) from an institutional view claimed that the adoption of multiple food safety standards certainly drives better performance for environmental and practices. Strategically, Vellema, Loorbach, and Notten van (2006) explore the cultural perspective, presenting the roles of food industries, governments, consumers and civil society, and their interactions for food transparency and safety. Uncertainty and vulnerability were also discussed, inherent to dynamic and biological production systems. With competition and dynamics in the food industry rising, acquiring capabilities in operations and SCM has nowadays a key to the grocers' success. Capabilities are considered including buyer and supplier relationship, information flow, cost control for supply networks, human capital and logistics performance in delivery and ordering systems (Marcus and

Anderson 2006). Food sustainability is another area of research interest in operational and supply chain dynamics. Savino, Manzini, and Mazza (2015) investigate environmental and economic assessment of food supply chain through the discussion of supply chain dynamics at different levels. Beske, Land, and Seuring (2014) have conducted a systematic literature review on sustainable SCM and dynamic capabilities in the food industry and evoked the importance of food safety in the entire supply chain quality control. Drawing on the food-specific challenges – perishability, food distribution management regarding to 'the physical flows and storage of products from the final production point to the customer or end user' was addressed for controlling food quality and safety in different chain types and supporting decision-making process (Akkerman, Poorya, and Grunow 2010, 866). Regardless the increase of research interest in investigating dynamic capabilities in food supply chain, there is a substantial theoretical gap in researching on food safety and how companies can build their dynamic capabilities to incorporate related issues. As such, this study attempts to fill the gap and focus on the discussion and implementation in emerging economics, where institutional regulation and make conditions are distinguished with the Western societies.

2.3.3. The research scope of dynamic capabilities and food safety

Often firm capabilities are majorly focussed in the discussion of dynamic capabilities, addressing a lack of knowledge at SCM level (Beske, Land, and Seuring 2014). However, when organisations source via multi-tiers suppliers, a lack of operational alignment for same expectation and standards in food safety will make the supply chain vulnerable (Roth et al. 2007). To help supply chain managers and decision makers understand how to solve food safety issues, this study evokes to link external environment with internal capabilities to perform satisfactory standards in their value chains.

Supply chain re-conceptualisation: It is the notion that requires companies having the dynamic capabilities to involve all stakeholders, including suppliers, manufacturers, food processors, retailers, government lobbies, and third party organisations in food safety management. The literature suggests reconceptualization as to change what the chain does, move towards closed loop systems and reconceptualise who should be involved in the chain (Wu and Pagell 2011). Current literature has claimed the need to achieve food traceability, transparency and visibility to tackle food safety issues (Ali, Nagalingam, and Gurd 2017; Beske, Land, and Seuring 2014), however, without the dynamic capabilities to reconceptualise a traditional supply chain, hardly a food supply chain can be truly traceable, transparent and visible. Often, it is common to hear from food companies indicating the difficulty of knowing who they are sourcing from; neither consumers have the information and knowledge to know whether what they eat is safe. In a conventional supply chain where firms operate without reconceptualise who should be involved in their supply chain, limited efforts could be achieved for food safety control.

Co-evolving: The rationale of dynamic capabilities is to explain why certain firms have competitive advantage in a changing market. In such dynamic situation, co-evolving addresses the capabilities 'by which managers reconnect webs of collaboration […] to generate new and synergistic resource combinations among business' (Eisenhardt and Martin 2000, 1107). Food firms need the capabilities to obtain their resource and information in operations to ensure food safety; meanwhile the evolving environmental also requires them to implement new capabilities in food supply chains broadly, referring to all competences which leverage food quality (Wiengarten et al. 2016), safety (Wang, Li, and Shi 2012), traceability and sustainability (Kiil et al. 2018; Vlajic, Mijailovic, and Bogdanova 2018).

Reflexive control: It refers to those capabilities that allow a company to constantly check, evaluate and improve business practices and strategic making against the requirements of the business environment to remain competitive advantage (Seuring 2006; Beske, Land, and Seuring 2014). Giving the distinctive requirements for food safety in different regions and to different products, applying one or more such dynamic capabilities can enhance temporary competitive advantage (Eisenhardt and Martin 2000) which in turn can drive a sustained leading position in the market.

2.4. Managing food safety at supply chain level

Food supply chains is the sets of processes, operations and corporations that contribute to serve the food from raw materials to end consumers' plates (Despoudi et al. 2018). It is not a singular chain of an entity but a complex web of connections working to make food available. Therefore, this study also investigates food safety standards at the supply chain level for better engaging with various stakeholders to tackle the current issues.

2.4.1. Supply chain collaboration for food safety management

The concept of supply chain collaboration is nothing new in literature, yet it is highly important in food supply chain research. Supply chain collaboration is defined as an inter-organisational relationship type where the participants attempt to invest resources, share information and achieve mutual goals for decision making and problem solving (Spekman et al. 1998; Stank, Crum, and Arango 1999; Barratt and Oliveira 2001; Soosay, Hyland, and Ferrer 2008). There are various forms of potential supply chain collaboration, which has been distinguished as two main categories: vertical collaboration with customer and suppliers; and horizontal collaboration which include competitors and other external organisations (Barratt 2004). Supply chain collaboration is a distinct decision making process where significantly impacts on the new product development process and financial performance (Allred et al. 2011; Mishra and Shah 2009) and relational outcomes, such as trust and commitment (Ralston, Richey, and Grawe 2017).

We have witnessed a number of changes in the food sector since the last decade. The movement of global food retailing, the changing consuming behaviour, and the existence of more strict institutional regulation for food operation and production. In such circumstance, global food retailers are building partnerships and collaboration, both vertical and horizontal collaborations, with many of their supplier and customers in order to achieve competitiveness and performance improvements (Matopoulos et al. 2007). The product features in food supply chain are predominantly logistics-related activities, for example, transportation, ordering, and procurement instead of activities such as joint development of new products or demand management. The structure of the sector determines the need for further integration upstream and downstream, which could be operational and tactical rather than strategic (Matopoulos et al. 2007). Yet literature remains unclear on how and where we can collaborate in the plant food supply chain to cope with safety issues for improving economic performance and human health.

2.4.2. Knowledge management and food safety

Managing food supply chain requires to consider all practices that deal with the acquisition and assessment of new and current knowledge of all processes and stakeholders (Beske, Land, and Seuring 2014). However, food industry is one of the low tech sectors where have no or low research and development expenditures, while being a very dynamic industrial sector for many regions (Karagouni and Kalesi 2011). In this regard, knowledge management in supply chains assist entities to remain competitiveness via information sharing and skills improvements by working with external partners in their products, services, strategies and best practices in food industry (Ahmed and Eldin 2018).

2.4.3. Supply chain risk management food safety management

Supply risk and supply chain vulnerability is an emerging key challenge in SCM. Supply chain risk management is to develop approaches to identification, assessment, analysis and treatment of areas where cause vulnerability and risks in SCM (Wang, Li, and Shi 2012). As mentioned above that institutional regulation, media and external stakeholders are paying more attention to constrain food safety control, industrial practice is under pressure to improve food safety through implementation of efficient risk management from ‘farm to fork’. However, there has also been an increasing number of food safety alerts, which has contributed to a loss of company reputation, economic and social performance, and consumer confidence (Houghton et al. 2008). Therefore, it is of value to investigate to what extent Chilean corporation incorporates supply chain risk management in food safety in practice.

3. Solution methodology

The present work underpinned by fuzzy AHP technique as the solution methodology. In this work, fuzzy AHP prioritise the food safety focussed criteria and their sub-criteria. AHP can help managers in an effective decision-making through formation of hierarchal structure of elements (Saaty1980; Mangla, Govindan, and Luthra 2016). Followed the fuzzy AHP, this study employed the sensitivity analysis to test the robustness of model. As small change in relative weights of criteria might show large change in final ranking it is necessary to investigate the ranking for stability of results (Mangla, Govindan, and Luthra 2017).

The AHP/Fuzzy AHP reveals superior results compared to other knowledge-based decision methods like ANP, TOPSIS/fuzzy TOPSIS and ELECTRE (Harputlugil et al. 2011) AHP is relatively easy to apply and simple to understand. In so doing, AHP has its own limitations such as rank reversal issue, human subjectivity problems and variable independence criteria (Ishizaka and Labib 2009; Mangla, Govindan, and Luthra 2016). In addition, AHP also fails to deal with the ambiguity in human judgement in decision problems (Chang 1996; Ordoobadi 2010; Mangla, Kumar, and Barua 2015). To help decision makers, AHP method can be revised to Bayesian-based modified AHP, Fuzzy AHP and Grey AHP (Kar 2015; Govindan, Mangla, and Luthra 2017). This work prefer to apply fuzzy-based AHP, as it has higher consistency and capability to deal with human judgements (Jakhar and Barua 2014; Rana et al. 2019). In this sense, fuzzy-based AHP technique is employed to evaluate the priority of issues in food safety in Chile. The fuzzy AHP supported flow map for this research is illustrated in Figure 1.

The fuzzy AHP has a specific procedure (Chan et al. 2008) to apply, which is described in Section 4.

4. Data analysis

In order to collect data, thirty professionals having expertise in food safety and food operations management were approached through phone, email and social media. These thirty professionals were listed using the personal contacts of

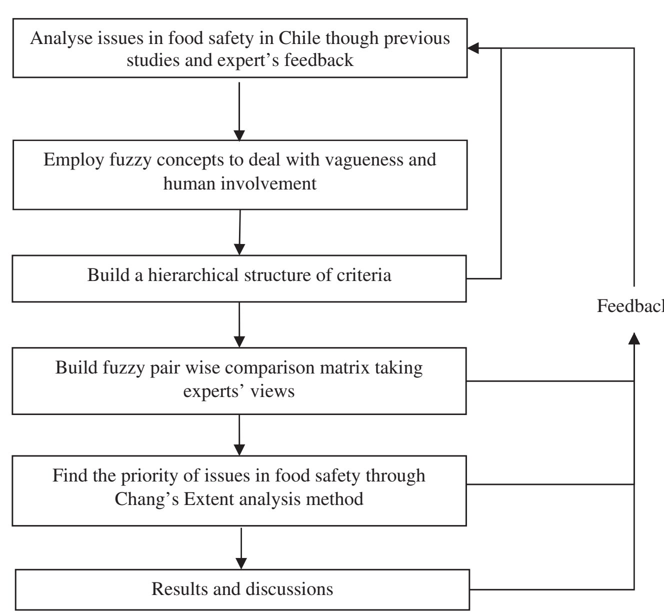

Figure 1. Fuzzy AHP flow diagram.

Table 1. Experts' characteristic details and major responsibilities.

Experts	Education/Qualification	Experience (in years)	Key responsibilities
FAO Latin America assessor (food safety expert)	Agronomist	20	To evaluate the current state of Food Safety of Latin American countries
Assessor Food Safety Agency Chile	Food Engineering	20	To control the National Food Safety Programmes in Chile
Farmer: Leafy vegetables (medium farm)	Not professional	15	Production of leafy vegetables in local markets
Researcher Vegetable	Agronomist	10	Research I&D
Director Regional Centre INIA	Economic Engineering	12	Business
Farmer: Leafy vegetables (big farm)	Agronomist	9	Production vegetables in the retail market
Farmer: Leafy vegetables (medium farm)	Not professional	12	Production of leafy vegetables in local markets
Researcher Food Safety	Agronomist	25	Research I&D
Centre of Distribution of vegetables of Chile	Food Engineering	8	Distribution of vegetables in Chile
Director I&D Regional Centre INIA	Biochemist	18	Research I&D

researchers involved in this project. However, ten experts responded positively and agreed to involve as a decision making body in this work. All the professionals are brilliant in their skills and equipped with a vast working experience in domain of food safety and policy, food planning, supply, distribution and operations management. Group size can affect the results but an over large decision-making group is also not recommended; it should be roughly from 5 to 50 (Gumus 2009). This is the reason sample size with 30 experts in considered as satisfactory in this work (Venkatesh et al. 2017). A detailed demographic profile of experts along with their responsibilities is illustrated in Table 1.

The experts were initially contacted to finalise the literature-based criteria and sub-criteria to food safety in Chile context. The experts were asked to analyse the literature-based criteria and further requested to add/delete any criteria in its suitability in Chile. All experts were agreed on identified criteria and sub-criteria. Next, the experts were contacted for knowing the priority of these criteria and sub-criteria. Thus, the fuzzy AHP technique with its procedural steps is applied to this research context. A questionnaire set for collecting data for fuzzy AHP application is provided in Appendix A.

Step 1: State the objective of research: This step elucidate the objective of particular research, i.e. prioritising the issues in food safety is stated in this work. This research reveals 12 sub-criteria within 4 main criteria using literature support to evaluate food safety issues in Chile.

Step 2: Extend the fuzzy set theory: Zadeh (1965) developed fuzzy set theory to capture human (qualitative) judgements in a decision problem. Fuzzy set theory allows managers to elucidate human responses in crisp form. In this sense, fuzzy set theory provides apparent information for evaluating the decision-making problem under vague and unclear surroundings (Zimmermann 1996). In this study, the triangular fuzzy number (TFN) – most suited to pragmatic situations (Mangla, Kumar, and Barua 2015) is used. Additionally, many authors selected triangular fuzzy sets to appraise linguistic variables in industrial problems (Ouzrout, Apolloni, and Savino 2008; Savino and Sekhari 2009; Mazza and Savino 2014; Brun, Xiang, and Savino 2017). Fuzzy set represent each number through binary numbers, 0 and 1, which are specified in an interval [0, 1]. According to Zadeh (1965) the fuzzy set based analysis can be illustrated as – if '*X*' elucidate a set of elements and the general component of '*X*' is elucidated through 'x' having values ($x_1\ , x_2, x_3\ \ldots\ldots\ldots x_n$). In this case, the fuzzy set C for X is expressed as $\{(x,\ \mu_C(x))\mid x\in X\}$. The membership of this fuzzy set C is defined through $\mu_C(x)$. Let us assume, '*A*' and '*B*' are two TFNs and represented as – $A = (p_1,\ q_1,\ r_1)$ and $B = (p_2,\ q_2,\ r_2)$. The membership function for the TFN (p, q, r) is calculated using expression provided in Eq. (1). The boundaries and threshold values for TFN are significant items to decide, we referred the work of Ouzrout, Apolloni, and Savino (2008) and Brun, Xiang, and Savino (2017).

$$\mu_C(x) = \left\{\begin{array}{c} 0, x \le p \\ \dfrac{x-p}{q-p}, x \in [p,q] \\ \dfrac{x-r}{q-r}, x \in [q,r] \\ 0, \text{otherwise} \end{array}\right\} \tag{1}$$

Step 3: Build a hierarchical structure of criteria: A hierarchical structure of criteria in relation to objectives of research is built as shown in Figure 2. This hierarchical structure is underpinned by experts' views.

Step 4: Build a fuzzy pair wise comparison matrix: We asked experts to build a fuzzy pair wise comparison matrix of criteria through a fuzzy linguistic scale as provided in Table 2. This scale and its linguistic statements are very important for making correct judgements, thus, keeping this in mind, we adopted those from the previous works of Wang, Chu, and Wu (2007) and Mangla, Kumar, and Barua (2015).

The linguistic judgements provided by experts are recorded and converted into equivalent numbers.

We asked experts for their agreement to form a final fuzzy pair wise comparison matrix, which is expressed as $M = [m_{uv}]_{n\times m}$.

Where m_{uv} represents the entries (i_{uv}, j_{uv}, k_{uv}) corresponds to final fuzzy pair wise matrix. The fuzzy pair wise

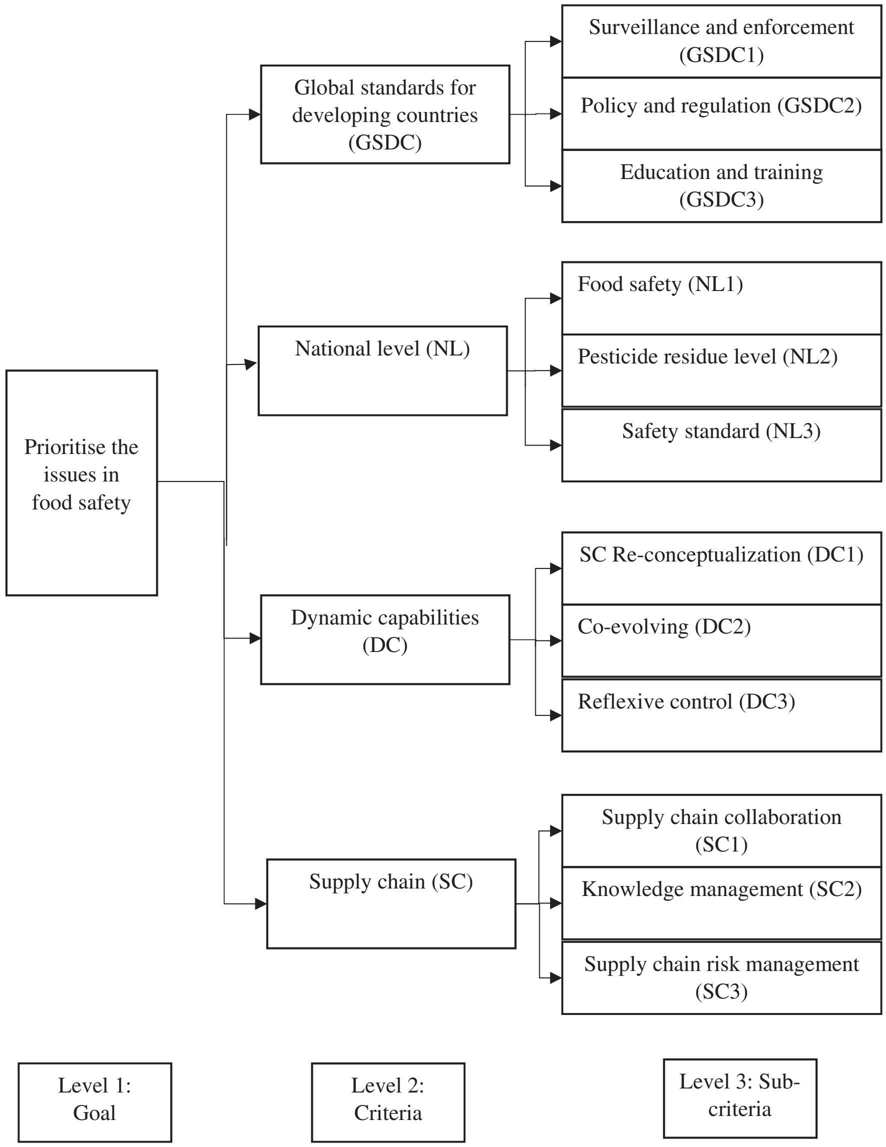

Figure 2. A hierarchy model of criteria and sub-criteria to food safety.

Table 2. Fuzzy linguistic scale.

Uncertain judgement	Fuzzy score
Nearly same	1/2,1,2
Nearly *x* times more significant	*x*-1, *x*, *x* + 1
Nearly *x* times less significant	1/*x* + 1, 1/*x*, 1/*x*-1
Between *y* and *z* times more significant	*y*, (*y* + *z*)/2, *z*
Between *y* and *z* times less significant	1/*z*, 2/(*y* + *z*), 1/*y*

Note: The values of *x* range from 2, 3 … 9, whereas the values of *y* and *z* can be 1, 2 … 9 with $y < z$.
Source: Wang, Chu, and Wu 2007 and Mangla, Kumar, and Barua 2015

comparison matrix for criteria is shown in Table 3. The fuzzy pair wise comparison matrix for sub-criteria is also developed (please refer Appendix B).

Step 5: Find the priority weights of criteria: The finalised fuzzy pair wise comparison matrix of criteria needs to be assessed for finding their priority weights of criteria. In this research, the priority weights are computed using Chang's Extent Analysis method (Chang 1996; Mangla, Govindan, and Luthra 2017).

In doing so, the associated S_i values are determined as:

$$S_1 = (5.25,\ 7.33,\ 9.50) \times \left(\frac{1}{29.0303},\ \frac{1}{21.9270},\ \frac{1}{15.7467}\right)$$

$$= (0.1808,\ 0.3343,\ 0.6033)$$

$$S_2 = (3.58,\ 4.3333,\ 5.5) \times \left(\frac{1}{29.0303},\ \frac{1}{21.9270},\ \frac{1}{15.7467}\right) = (0.1233,\ 0.1976,\ 0.3493)$$

$$S_3 = (4.3333,\ 6.4303,\ 8.5) \times \left(\frac{1}{29.0303},\ \frac{1}{21.9270},\ \frac{1}{15.7467}\right) = (0.1493,\ 0.2933,\ 0.5398)$$

Table 3. Pair-wise comparison matrix for criteria to food safety.

Criteria to food safety	GSDC			NL			DC			SC		
GSDC	1.00	1.00	1.00	2.00	3.00	4.00	0.25	0.33	0.50	2.00	3.00	4.00
NL	0.25	0.33	0.50	1.00	1.00	1.00	2.00	2.50	3.00	0.33	0.50	1.00
DC	2.00	3.03	4.00	0.33	0.40	0.50	1.00	1.00	1.00	1.00	2.00	3.00
SC	0.25	0.33	0.50	1.00	2.00	3.03	0.33	0.50	1.00	1.00	1.00	1.00

Table 4. Rank of criteria to food safety.

Criteria to food safety	Priority weights	Ranking
GSDC	0.3372	1
NL	0.1861	3
DC	0.3026	2
SC	0.1741	4

$$S_4 = (2.5833,\ 3.8333,\ 5.5303) \times \left(\frac{1}{29.0303,}, \frac{1}{21.9270}, \frac{1}{15.7467}\right) = (0.0890,\ 0.1748,\ 0.3512)$$

Next, we computed the degree of possibility for two fuzzy numbers,

$$V\ (S_1\ \geq\ S_2)\ = \frac{(0.1233-0.6033)}{(0.3343-0.6033)-(0.1976-0.1233)} = 1.0000$$

$$V\ (S_1\ \geq\ S_3)\ =\ 1$$

$$V\ (S_1\ \geq\ S_4)\ =\ 1$$

Finding the least weight vectors for every fuzzy number is given as:

$$z'(C_1) = \min V(S_1 \geq S_{2,}\ S_{3,},\ S_4\ )\ =\ \min\ (1,\ 1,\ 1)\ =\ 1$$

$$z'(C_2) = 0.5520$$

$$z'(C_3) = 0.8975$$

$$z'(C_4) = 0.5165$$

The obtained values are normalised for finding their priority weights. Hence, the importance rank for criteria are mentioned as shown in Table 4.

The relative and global priority weights of sub-criteria are also computed. This further helps in determining their importance rank (see Table 5).

5. Sensitivity analysis

The sensitivity analysis is considered to be an essential component to validate any developed framework or model (Gupta and Barua 2017). It is important to identify how a particular model will behave under different working environments (Bai and Sarkis 2014; Yadav et al. 2018), hence for the present case changes in expert's inputs are considered while conducting the sensitivity analysis. The outcome of this research reveals that Global standards for developing countries (GSDC)' criterion has the highest rank (refer Table 6). This shows that particular criteria has a tendency to influence remaining criteria to food safety. In this sense, the author (s) conducted a sensitivity test, by varying the 'GSDC' criteria relative priority weights from values 0.1–0.9. As a resultant, we noted the corresponding shifts in weights of remaining criteria (see Table 6).

From sensitivity analysis, at 0.1 value of GSDC criteria, the sub-criteria GSDC1 acquires the minimum weight and DC2 acquires the utmost weight. These weights values remains until we reached the 0.3 value of GSDC criteria. By changing the weights of GSDC further from absolute value to 0.9, the sub-criteria GSDC2 obtains highest priority weights, along with changes in weights of other sub-criteria as well.

The changes in weights of sub-criteria are mentioned in terms of sensitivity analysis results (see Table 7). The global priority weights for the sub-criteria are determined by multiplying their priority weights with priority weights of their respective criteria. However, ideally, there should be no significant variation in weights of sub-criteria, if there is any change in weights of criteria. The aim is to minimse this variation and to check the robustness of work; therefore, sensitivity analysis is conducted in this research.

The sensitivity analysis results are also plotted graphically, as shown in Figure 3. In view of this, no significant variation is observed in patterns of weights of sub-criteria for this research problem. This makes the findings of this research robust enough that can manage the problems of human involvement and vagueness in data under fuzzy environment.

6. Findings

Findings reveals that criteria 'Global standards for developing countries (0.3372)' has the highest priority followed by 'Dynamic capabilities (0.3026)'; 'National level (0.1861)'; 'and 'Supply chain (0.1741)'. Further, the global priority weights of food safety focussed criteria is also computed. 'Lack of involvement of citizens (SOC1)'; 'Lack of competitiveness (ECO2)'; 'Global economy volatility (ECO4)'; 'Political instability (GOV3)' and 'Low awareness level of community (SOC2)' are highlighted as top five criteria to food safety in Chile background. food safety concepts are extremely context dependent (governments, nations etc.). Within this main criteria, 'Policy and regulations (GSDC2)' obtains the highest priority. 'Education and training (GSDC3)' holds next rank in list. At the end, the 'Surveillance and enforcement (GSDC1)' is placed in list.

Dynamic capabilities (DC) comes next considering the priority order of criteria. This main criteria contains three sub-criteria. Among them, 'Co-evolving (DC2)' obtains the highest priority. Based on priority rank, 'SC Re-conceptualisation (DC1)' criteria comes next. The 'Reflexive control (DC3)' sub-criteria comes in last in priority list.

National level (NL) obtained the third priority rank. Within this main criteria, 'Food safety (NL1)' obtains the first rank. Next to this, is safety standard (NL3)', which holds second

Table 5. Priority rank of sub-criteria.

Criteria to food safety	Sub-criteria	Relative priority weights	Relative rank	Global priority weights	Global rank
GSDC	GSDC1	0.1295	3	0.0437	11
	GSDC2	0.5429	1	0.1831	1
	GSDC3	0.3275	2	0.1104	3
NL	NL1	0.4165	1	0.0775	5
	NL2	0.2272	3	0.0423	12
	NL3	0.3563	2	0.0663	7
DC	DC1	0.2773	2	0.0839	4
	DC2	0.4806	1	0.1454	2
	DC3	0.2421	3	0.0733	6
SC	SC1	0.3730	1	0.0649	8
	SC2	0.3326	2	0.0579	9
	SC3	0.2945	3	0.0513	10

Table 6. Relative priority weights for criteria due to changes in weights of GSDC.

Criteria to food safety	Relative priority weights for criteria due to changes in weights of GSDC criteria									
	Absolute	GSDC = 0.1	GSDC = 0.2	GSDC = 0.3	GSDC = 0.4	GSDC = 0.5	GSDC = 0.6	GSDC = 0.7	GSDC = 0.8	GSDC = 0.9
GSDC	0.3372	0.1001	0.2001	0.3000	0.4000	0.5000	0.6002	0.7001	0.8001	0.9001
NL	0.1861	0.2527	0.2246	0.1965	0.1685	0.1404	0.1123	0.0842	0.0561	0.0281
DC	0.3026	0.4109	0.3652	0.3196	0.2739	0.2283	0.1825	0.1369	0.0913	0.0456
SC	0.1741	0.2364	0.2101	0.1839	0.1576	0.1313	0.1050	0.0788	0.0525	0.0262
Total	1	1	1	1	1	1	1	1	1	1

Table 7. Global priority weights of sub-criteria due to sensitivity analysis.

Sub criteria to food safety	GSDC = 0.1	GSDC = 0.2	GSDC = 0.3	GSDC = 0.3372 (Absolute)	GSDC = 0.4	GSDC = 0.5	GSDC = 0.6	GSDC = 0.7	GSDC = 0.8	GSDC = 0.9
GSDC1	0.0130	0.0259	0.0389	0.0437	0.0518	0.0648	0.0777	0.0907	0.1036	0.1166
GSDC2	0.0543	0.1086	0.1629	0.1831	0.2172	0.2715	0.3258	0.3801	0.4344	0.4887
GSDC3	0.0328	0.0655	0.0983	0.1104	0.1310	0.1638	0.1966	0.2293	0.2620	0.2948
NL1	0.1052	0.0935	0.0818	0.0775	0.0702	0.0585	0.0468	0.0351	0.0234	0.0117
NL2	0.0574	0.0510	0.0446	0.0423	0.0383	0.0319	0.0255	0.0191	0.0127	0.0064
NL3	0.0900	0.0800	0.0700	0.0663	0.0600	0.0500	0.0400	0.0300	0.0200	0.0100
DC1	0.1139	0.1013	0.0886	0.0839	0.0760	0.0633	0.0506	0.0380	0.0253	0.0126
DC2	0.1975	0.1755	0.1536	0.1454	0.1316	0.1097	0.0877	0.0658	0.0439	0.0219
DC3	0.0995	0.0884	0.0774	0.0733	0.0663	0.0553	0.0442	0.0331	0.0221	0.0110
SC1	0.0882	0.0784	0.0686	0.0649	0.0588	0.0490	0.0392	0.0294	0.0196	0.0098
SC2	0.0786	0.0699	0.0612	0.0579	0.0524	0.0437	0.0349	0.0262	0.0175	0.0087
SC3	0.0696	0.0619	0.0542	0.0513	0.0464	0.0387	0.0309	0.0232	0.0155	0.0077

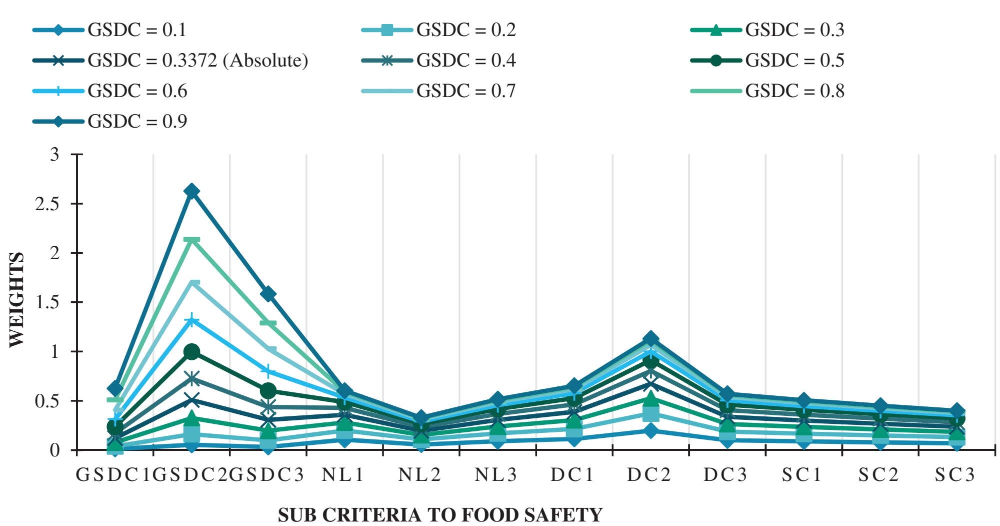

Figure 3. Sensitivity analysis results for sub-criteria to food safety.

highest priority in the list. Finally, 'Pesticide residue level (NL2)' is last in the list.

Supply chain (SC) main criteria comes at last place in the list. This main criteria contains three sub-criteria. Among them, 'Supply chain collaboration (SC1)' obtains the highest priority. Based on priority rank, 'Knowledge management (SC2)' criteria comes next. The 'Supply chain risk management (SC3)' sub-criteria comes in last in priority list.

7. Discussion

7.1. Discussion on research findings

Managing food safety related issues are multifaceted and there is a contingent nature with traditional global business. Drawing on the supply chain vulnerability and risks in a complex social system where stakeholders are interconnected (Vellema, Loorbach, and Notten van 2006). This research found that criteria 'Global standards for developing countries' has the highest priority followed by 'Dynamic capabilities'; 'National level'; 'and 'Supply chain'. Food safety implementations are extremely context dependent on global standards and national governments. Being aligned with current researches (Unnevehr 2015), observations in this study highlight the emphasis on policy and regulation. The use of good agricultural practices (GAP) has been described to be the most important control measure to assure the safety and quality of fresh produce. In addition, the application of good hygienic practices (GHP) and the certifications safety management systems (FSMS) are relevant to assure food safety standards (Van Boxstael et al. 2013). There is a relevant scrutiny of the production or processing techniques employed along the associated supply chains and number of meta systems such as hazard analysis and critical control points (HACCP) and ISO 9000 have increasingly become global food safety standards (Henson and Jaffee 2008). The relevance of international standards have increased the government support for legitimating food safety standards, which is fundamentally important for protecting human health and sustain environmental ecosystem (Melo et al. 2014). The global value chains come along with a shift from public to private voluntary standards such as GlobalGAP have become mandatory food safety standards in some countries due to supermarkets require standard compliance from their suppliers.

The increasing importance of safety standards is relevant for policies and regulations that usually imply significant costs of compliance that could prevent low-income countries, in particular, to benefit from agricultural markets (Ehrich and Mangelsdorf 2018). Therefore, single, globally harmonised pesticide standards are beneficial in increasing productivity, profits and trade with the aim to protect public health and environment (Handford et al. 2015).

The relevance of international standards and food safety regulations in Chile have increased the government supports for the harmonisation of sanitary and phytosanitary-trading regulations due to different technical barriers that may affect the Chilean exports (Melo et al. 2014). Chemical safety standards are measures of compliance regulations enacted by the Chilean Government. In addition, The Ministry of Health has the mission of the enforcement of food policies and regulations in Chile. The Supreme Decree 977/1996 on Food Health Regulations is the key food safety regulation and establishes the sanitary conditions for protect the public health and nutrition.

According to ISO/IEC 17025, an international accreditation standard through a national body seem to respond better to the specific need of an official quality control than the quality assurance scheme under Good Laboratory Practice, which is mandatory for the elaboration of studies necessary at national level (FAO 2012). The ISO provide a standard thorough application of a framework for verifying key aspects of a firm's production process that assures quality (Unnevehr, 2015). However, the legislation standards and implementation levels are fairly diver at national levels, especially in emerging economics, such as Chile, India and China, a result of inconsistency in the enforcement and processes of risk control being reflected in interdisciplinary researches of food safety assessment (Elgueta et al. 2017; RIAL 2016). In this regards, there is a need to examine institutional regulation, enforcement and implementation in each sourcing origin for global food safety control.

This study determines a collaborative approach to improve food safety practices in Chile. At operational and supply chain levels, this research reveals the evolving nature where primarily addresses the co-evolving and supply chain reconceptualization capabilities in the Chilean food safety system. Companies need to broadly refer to all competences to improve food quality and safety (Wiengarten et al. 2016). Being aligned with literature (Attia and Eldin 2018), this research suggests that supply chain collaboration is of importance to integrate knowledge management, education and training with food producers, processors, distributes and end consumers for food safety practices. A dynamic capability view provides the opportunity to reveal the interaction at operational and supply chain levels from different stakeholders, which could lead to higher performance (Ouzrout, Apolloni, and Savino 2008). Given the inconsistency of food safety enforcement in Chile, it is co-evolving and long term mission, rather than short term pursing for practitioners to address the reconceptualization in food supply chains and to keep changing and evolving, and reconceptualising the food safety in SCM.

Apart from addressing the necessity of posting the advantages of adopting the dynamic capability view and the collaborative approach, we also need to realise that hardly managers can generalise the process of supply chain reconceptualization. Rather, they will need to include the concerns of various stakeholders for obtaining ample opportunities from different resources (Marcus and Anderson 2006). However, there are substantial difficulties for food companies to involve all stakeholders, such as farmers and small retailers in street markets; in this regard, we provoke the consider managing food safety issues in a systematic way at different levels as we investigate in this study in order to reconceptualise their supply chain for achieving the collaborative approach.

7.2. Contributions

The main academic contributions of this study are in twofold. Firstly, it employs an integrated view to investigate the FSMS in Chile by discussing on the major factors on food safety within international and national regulations, policies, operations and SCM. The research further indicates the representative criteria for the fourth influential factors with statistical results, revealing the current needs to collaborate and provoke co-evolving and reconceptualising food supply chains in Chile.

This research also makes significant contributions for practical implications. For food supply chain enterprise, this study provides detailed, prioritised criteria for improving food safety practices, helping managers to understand the institutional environment, and the important role in building dynamics capabilities and supply chain collaboration. Particular in the problem of inconsistency in political regulations and their enforcement, food companies need to proactively act on institutional requirements, meanwhile, collaborate with supply chain stakeholders, including farmers and consumers who are lack of knowledge and awareness of food safety, to improve the FSMS in Chile. This study also makes contribution to inform government policy-making in emerging economics to improve surveillance and enforcement in food safety, such as regulations and standards to govern local street markets. Finally, even though it is a case study in Chile, food safety issues are more broadly reflected in emerging economics, such as India and China (Zhang et al. 2018), rather than being specific to Chile. Therefore, the findings and discussions in this study will exemplify how food safety can be improve in other regions.

8. Conclusions

Food safety is amongst the imperative issue in context of food value chains. To meet demand for safe and higher quality food, food industries especially in developing nations like Chile face numerous problematic issues. In this work, therefore, we aim to address food safety practices, along with determine and rank the criteria to food safety. This contribution seeks to assist practicing managers in improving the collaboration among stakeholders (supplier, management, government and non-governmental bodies and customer) of food supply chains to manage operations for achieving sustainability in Chile perspective. This work seeks to identify and analyse both of institutional and operational factors that influence food safety to improve Chile's food safety performance in coherence with the political, operational and supply chain transformations. As a methodological contribution, we employ fuzzy-based AHP technique for illustrating the significance of key criteria to food safety concepts under fuzzy environment. In this work, we identified various key criteria along with their respective sub criteria through literature analysis, which were confirmed for their applicability in Chile context using expert's feedback.

Findings of this research show that criteria 'Global standards for developing countries' has the highest priority followed by 'Dynamic capabilities'; 'National level'; 'and 'Supply chain'. This research also reveals global priority of criteria to food safety. In view of this, 'Lack of involvement of citizens (SOC1)'; 'Lack of competitiveness (ECO2)'; 'Global economy volatility (ECO4)'; 'Political instability (GOV3)' and 'Low awareness level of community (SOC2)' are highlighted as top five criteria to food safety in Chile background. At the end, the model is tested for its robustness through sensitivity analysis test.

This research also contains some limitations. This work has been designed in context of a developing nation in Chile. Thus, when implementing the findings in this study, criteria might need some modifications in order to fix with the contexts in other regions. Future research can extend from this study to explore more contemporary topics in SCM in details, such as how the use of innovative technology, acting as an important role as operational capabilities (Zangiacomi et al. 2017), can leverage the monitor for food safety in emerging economics.

Disclosure statement

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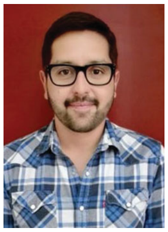

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Appendix A

Questionnaire for collecting data for fuzzy AHP analysis

Dear respondent, this research reveals 12 sub-criteria within 4 main criteria using literature support to evaluate food safety issues in Chile. We seek to establish the relative importance of the criteria to food safety. Prior to that, you may also modify the list based on your expertise and applicability in Chile context.

Table A.1. Fuzzy linguistic scale.

Uncertain judgement	Fuzzy score
Nearly same	1/2,1,2
Nearly x times more significant	x-1, x, $x+1$
Nearly x times less significant	$1/x+1$, $1/x$, $1/x$-1
Between y and z times more significant	y, $(y+z)/2$, z
Between y and z times less significant	$1/z$, $2/(y+z)$, $1/y$

Note: The values of x range from 2, 3 … 9, whereas the values of y and z can be 1, 2 … 9 with $y < z$.
Source: Wang, Chu, and Wu 2007 and Mangla, Kumar, and Barua 2015

Table A.2. Pair-wise comparison matrix for main criteria to food safety.

Criteria to food safety		GSDC			NL			DC			SC	
GSDC	1.00	1.00	1.00									
NL				1.00	1.00	1.00						
DC							1.00	1.00	1.00			
SC										1.00	1.00	1.00

Appendix B

Table B.1. Pair-wise comparison matrix for GSDC.

		GSDC1			GSDC2			GSDC3	
GSDC1	1.00	1.00	1.00	0.33	0.50	1.00	0.33	0.50	1.00
GSDC2	1.00	2.00	3.03	1.00	1.00	1.00	2.00	2.50	3.00
GSDC3	1.00	2.00	3.03	0.33	0.40	0.50	1.00	1.00	1.00

Table B.2. Pair-wise comparison matrix for NL.

		NL1			NL2			NL3	
NL1	1.00	1.00	1.00	3.00	4.00	5.00	0.25	0.33	0.50
NL2	0.20	0.25	0.33	1.00	1.00	1.00	1.00	2.00	3.00
NL3	2.00	3.03	4.00	0.33	0.50	1.00	1.00	1.00	1.00

Table B.3. Pair-wise comparison matrix for DC.

		DC1			DC2			DC3	
DC1	1.00	1.00	1.00	0.25	0.33	0.50	1.00	1.50	2.00
DC2	2.00	3.03	4.00	1.00	1.00	1.00	2.00	3.00	4.00
DC3	0.50	0.67	1.00	0.25	0.33	0.50	1.00	1.00	1.00

Table B.4. Pair-wise comparison matrix for SC.

		SC1			SC2			SC3	
SC1	1.00	1.00	1.00	3.00	4.00	5.00	0.33	0.50	1.00
SC2	0.20	0.25	0.33	1.00	1.00	1.00	2.00	3.00	4.00
SC3	1.00	2.00	3.03	0.25	0.33	0.50	1.00	1.00	1.00

Next, you need to make pair-wise comparisons considering two criteria (main/sub-criteria) at a time. In order to make pair-wise comparisons, please use the following fuzzy linguistic scale.