How logistics contribute to the complexity of global agri-food supply chains and thus to potential food safety risks – Experience gained by a sector stakeholder case study based on a conceptual framework for global agri-bulk commodity flows

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CAC	Codex Alimentarius Commission
CF	Conceptual Framework
EFSA	European Food Safety Authority
ERI	Emerging risks identification
FAO	UN Food and Agricultural Organisation
HACCP	Hazard Analysis and Critical Control Point
RA	Risk Assessment
RM	Risk Management
QM	Quality Management
WHO	World Health Organisation
WTO	World Trade Organisation

1 Introduction

In the course of globalisation, world agricultural trade is steadily increasing, and global food and feed supply chains have become more complex with far-reaching consequences for food safety. It is generally assumed that the more actors, processes, locations etc. involved in global food supply chains, the higher the possibility of errors resulting in food safety risks (van Asselt *et al*., 2010). In particular, the global feed industry expands in volume and value in response to increases in world population, urbanisation and changing consumption patterns towards an increase in products of animal origin, especially in developing and emerging countries (FAO/IFIF, 2010; Swick, 2011). Since most countries rely on imports of agricultural resources to meet the national feed demand, globally traded agricultural commodities[1] have a growing share in the supply of food to the population and thus an increasing influence on consumer health (Fricke, 2015).

Talking about global trade is talking about international logistics as trade is symbiotically linked with logistics. Logistics plays the key role in global commodity flows linking the supply chain stages primary production and processing in global food and feed supply chains. However, due to the fact that logistics - compared to production and processing - do not have a fixed location but take place across borders, it has to deal with diversity and a high number of entities, processes and locations as well as complexity in product and information flow (Marucheck *et al.*, 2011). As a result, logistics is often seen as a complex system that is difficult to grasp and therefore contributes greatly to the complexity of global food and feed supply chains.

The occurrence of various national, European and international food safety problems in recent decades has shown that food safety risks are inevitable in the era of globalisation. The most prominent examples of issues have emerged mainly in the feed sector, such as the BSE (bovine spongiform encephalopathy) (Reilly, 2014) as well as the Belgian dioxin scandal (Verbeke, 2001). Examples in the feed sector that gained public attention in Germany more recently are Aflatoxin milk contamination in 2013 (Kos *et al*., 2014) and Fipronil egg contamination in 2017 (EFSA *et al*., 2018a). These issues have not only increased consumer awareness of the importance of feed safety in producing safe food. Still, they have also largely contributed to a general decline in public trust in food safety governance within and outside Europe (Houghton

[1] Hereafter synonymously used with agricultural bulk commodities, abbreviated as agri-bulk commodities.

et al., 2008). Therefore, globalisation has made food safety a key public health issue, confronting the international and national food safety authorities with the challenge of managing and assessing food safety risks. In response to serious food crises such as the BSE scandal, the EU food safety policy was fundamentally reorganised. In the Basic Regulation (EC) No 178/2002, the focus was set amongst others on preventive approaches such as the "from farm to fork"-approach, which implies the management and assessment of safety risks along all steps of food supply chains to pursue a high level of protection for human and animal health – both at the food company and authority level.

Further, the Basic Regulation included the mandate to set up a pan-European system for emerging risks identification (ERI) (Noteborn *et al*., 2005). The European Food Safety Authority EFSA, as well as other national and international organisations (e.g. UN Food and Agricultural Organisation FAO), have dedicated themselves to the development of such systems (FAO, 2013a; Marvin *et al*., 2009). These go a step further than the "farm to fork" concept and are based on holistic approaches that consider not only factors within but also factors that influence the food supply chain from the outside. Thus, the paradigm shift in risk management (RM) requires broader international cooperation, exchange of information and involvement of stakeholders (Kruse, 2015).

In risk assessment (RA), the retrospective clarification of complex international food safety incidents that have already occurred is playing an increasingly important role. In this context, RA repeatedly encounters limitations due to the uncertainties resulting from the complex interplay of many (partly unknown) variables both outside and inside the global food supply (Buchholz *et al*., 2011). Due to the limited availability of relevant data and information, research on global supply chains is becoming increasingly important for RA work. It turned out that especially logistics characterising global commodity flows is marked by fundamental knowledge gaps. This is not surprising, as, for a long time, the focus of research and food safety improvements efforts was on the supply chains stages "production", "processing", and "retail" (Ryan, 2017). Consequently, it has often been difficult to assess the role that logistics has played in food safety incidents or foodborne illness outbreaks in the past.

It is indisputable that logistics plays an essential role in supplying sufficient food in a globalised world. However, "there is no food security without food safety", the FAO declares mantra-like (FAO, 2019; Vipham *et al*., 2020). There is a broad knowledge of critical points for food safety during transport, storage and handling in the context of quality management (QM) defined as

Hazard Analysis and Critical Control Point (HACCP). However, less is known how the complex interactions within logistics and its varying environment throughout global supply chains affect food safety-relevant dimensions in the logistics sector. It is assumed that the importance of logistics will continue to increase in parallel with international agricultural trade. Therefore, the question arises as to whether logistics will also play an increasing role in food safety in the future?

For these reasons, global commodity flows focusing on logistics have been identified as a new area of research in RA concerning food safety. However, there are still no strategies or approaches to holistically assess or scientifically evaluate the impact of logistics on food safety beyond the HACCP level. In this context, the RA community has generally recognised that the increasing complexity of global food supply chains urgently calls for an expansion of traditional RA. This should be reflected not only in the development of software tools (e.g. simulation models) and new analytical diagnostics but also - for a better understanding of complex interactions - in the application of proactive, holistic, and multidisciplinary approaches. This seems inevitable to meet the demand for more transparency in the EU RA process under the new Regulation (EU) 2019/1381 and to fulfil the task of consumer protection in times of globalisation.

1.1 Background information

1.1.1 Developments in global trade in agricultural commodities

Reasons for the increase in global agricultural trade

Trade of agricultural commodities has experienced continuous worldwide growth since 2000, at close to 8 % in real terms annually between 2001 and 2014 (OECD, 2021). On the demand side, this results from increasing world population, urbanisation and economic growth associated with higher demand for animal products. The market for meat and milk in 2050 is projected to increase by 73 and 58 per cent, respectively, compared to 2010 (Gerber *et al*., 2013). Whereas on the production side, the steady increase of produced agricultural commodities was mainly due to the growth in crop yields and crop intensification ("Green Revolution") and less due to expansion in the arable land (FAO, 2013b).

At the political level, the liberalisation process promoted the increase in world trade of agricultural products. Most international free trade agreements and investment protection agreements were established in the 1990s following the first world trade agreement in the agricultural and food sector ("Uruguay Round"), which resulted in the establishment of the

World Trade Organization (WTO). For more than 20 years, an increasing number of bilateral or regional free trade agreements has been observed globally; currently, the number goes up to 700 agreements (WTO, 2021). At the moment, the EU seeks additional trade agreements, mostly with Asian countries, Australia and New Zealand (DBV, 2021).

Rising demand of globally traded agricultural bulk commodities by the feed sector

The intensification of animal production systems is both the cause and the consequence of the increase in crop production. Especially the worldwide production of poultry and swine requires a large amount of grain to fulfil their dietary needs (FEFAC, 2019; Maes *et al*., 2020; Mottet and Tempio, 2017). Although animal production is a slower growing market in many developed countries, the European Union (EU) represents the leading feed compound producer after the USA and China. Therefore, the EU is a key player in producing safe feed (FEFAC, 2019). Today, the EU relies on imports to meet the increasing global demand for feed. In 2019, the total import volume of feed materials amounted to 51 million tons, whereas cereals (mainly maize) represented 42 % of the total EU feed import (thereof 81 % maize) and oilseed meals up to 45% (thereof 77 % soybean meal) (FEFAC, 2021). In comparison to the food industry, the largest share of cereals imported from third countries as well as produced within the EU generally flows into the feed industry: In 2019/2020, the total use of cereals in the EU was 262 million tons, of which about 62% (163 million tons) was used for the feed industry, 22% (59 million tons) went to the food industry and the rest to industrial use and seed (EU DG AGRI, 2021a).

Share of agricultural commodities in the world trade and main producer/export countries

According to the WTO, agricultural products accounted for 10 % of total world trade in 2017 (WTO, 2018). In terms of volume, agricultural bulk commodities, such as coarse cereals, maize, wheat and soybeans, account for the largest share of the global trade of agricultural products (Table 1.1) Therefore, a small number of products dominates the world trade of agricultural commodities.

Table 1.1: World production and trade of cereals and soybeans in 2020/2021 (USDA, 2021a, 2021b).

Agricultural bulk commodity	Production volume [mio. t]	Export volume [mio. t]
Common wheat	775	197
Coarse grain [a]	1 427	232
Maize	1 117	183
Barley	160	35
Sorghum	62	10
Soybeans	363	165

a: Coarse grains statistics include maize, barley, sorghum, oats, rye, millet and mixed grains

For the dominating traded agricultural bulk commodities, regular main trade routes have developed from the export to the import countries. Traditional exporters for all types of cereals and oilseeds such as soybeans are, for instance, the USA, Canada, Argentina, and Australia. In contrast, permanent importing for cereals are, for example, parts of Africa, Mediterranean countries, South and Southeast Asia, as well as transition countries in Eastern and South-eastern Europe (Woitschützke, 2006). However, trade flows of agricultural bulk commodities may vary for several reasons. First, weather-related crop failures associated with climate change have often been the reason for declines in crop production in major producing countries in the past, as was the case with the drought-related maize losses in the USA in 2012/2013 (Rippey, 2015). As a result, weather extremes can lead to fluctuations or interruptions in grain supplies.

In contrast, new producer countries have risen in Latin America and the Black Sea region, such as Ukraine, Russia and Moldavia (Schmid and Goldhofer, 2017; USDA, 2021a). In particular, the Black Sea region is playing an increasingly important role as a trading partner of the EU concerning cereals (Table 1.2). In addition to the consequences of climate change, the dynamics of economic development, especially of China, India, Brazil, and Mexico, are also leading to a change in the sources and sinks of agricultural commodities. This contributes to a change in the density of logistical flows or the cross-border movement of goods (Pfohl, 2010).

Table 1.2: Import volume of different agricultural bulk commodities into the EU and the respective main countries of origin/EU trading partners (EU DG AGRI, 2021b, 2021c).

Agricultural bulk commodity	Import volume [a] [1 000 t]	Countries of origin / EU trading partners [b]
Common Wheat	504	Ukraine, Russia, Serbia, Moldava
Maize	3 141	Brazil, Serbia, Canada, Ukraine, Russia
Barley	194	Serbia
Soybeans	14 957[b]	Brazil, USA, Canada, Ukraine

a: from 01/07/2021 to 19/09/2021, b: marketing year 2020/2021

Characteristics of the agricultural and market structure of agricultural commodities

Production and trade of agricultural commodities are highly concentrated on the world market. The producing countries are characterised by large-scale agriculture and are highly export-oriented. This is mainly due to favourable climatic conditions, knowledge base and access to the latest technology and capital. They include both developed countries such as the USA, Australia and New Zealand, and emerging countries like Brazil, Argentina and Ukraine (Robinson and Carson, 2015). These modern agro-holding companies are driving the restructuring of agriculture into agribusiness in many parts of the world (Pimbert *et al*., 2001).

Vertical integration, i.e. the integration of upstream (retailers) and downstream stages (primary producer) of the agri-food value chain, has become increasingly important for global corporations (Maertens and Swinnen, 2015). Accordingly, they are often no longer just part of the chain but the chain itself. Multinational agricultural corporations ("global players") are predominant, forming oligopolies through mergers at various points in the supply chain, e.g. production, trade, transport and processing. Since many global players also integrate the logistics part of the value chain, they may own seagoing vessels and even control ports (Slack and Frémont, 2005).

1.1.2 Logistics and its symbiosis with global trade

In recent decades, the logistics industry has grown in parallel with world trade growth and is considered as THE fuel for globalisation (Hess, 2010). The reduction of trade barriers, economic integration and deregulation have increased the demand for logistics services. With the growth of the gross national product and world trade, transport and storage volumes measured in units, weights, volumes and values have increased (Schieck, 2008). On the other hand, the mechanisation and specialisation of modes of transport have led to great advances in efficiency. For example, transport times have decreased, loading capacity has increased, and transport costs have been greatly reduced. As value added has increased and the share of transport costs in total costs has decreased, freight transport over longer distances has grown (Nuhn and Hesse, 2006). However, since transport flows are planned, triggered and controlled by information flows, the increase in the efficiency of information and communication technologies has been even more significant for internationalisation than the progress in the effectiveness of transport technology (Hess, 2010; Schieck, 2008).

Reasons for international sourcing in the feed sector

The international sourcing of agricultural commodities in the feed sector is being promoted by the increasing integration or liberalisation of the world economy. It allows a systematic utilisation of all procurement sources due to lower prices, the possibility of balancing temporal supply shortfalls by anti-cyclical purchasing (different growing/harvesting seasons in the northern and southern hemisphere), the utilisation of special knowledge and the flexibility in case of possible supply bottlenecks (Pfohl, 2010).

Definition of Logistics

Logistics originates from the military supply system (Russell, 2007). It commonly refers to the transportation, handling and storage of economic goods. According to Plowman's classic definition, the regiment of logistics functions based on the following seven R's: the availability of the right good, in the right quantity, in the right condition, at the right place, at the right time, for the right customer, at the right cost (Plowman, 1964). Logistics is therefore more than just delivering goods. Logistics companies are comprehensive system service providers; they organise the customer's flow of goods and information and offer as many additional services as possible as service packages (Schieck, 2008). Today, logistics is no longer understood as a simple supplier model but as supply chain management. The supply chain is viewed holistically and in its network character with respective external influences. These are, for example, demand forecasts, supply difficulties, production constraints, reduction of empty runs, cross-company production control, capacity planning and the adaptation to market changes (Christopher, 2016).

Relevant consideration levels and systems of logistics for the present study

In line with the new research focus on "Global Supply Chains" in the field of RA, the focus of the study lies on *international* logistics. At the *institutional* level, international logistics is understood as a metalogistic system, which includes the goods traffic of the cooperating organisations (e.g. supplier, wholesaler acting as an intermediary, retailer and freight forwarder). Metalogistic systems are considered as a connection point between micro (i.e. private or public organisation) and macroeconomy. They are inter-organisational systems that go beyond the legal boundaries of individual organisations and involve the cooperation of several organisations in the flow of goods. Due to the complexity resulting from the interrelations of concerned entities, international logistics requires more coordination, communication, and control compared to national logistics (Pfohl, 2010).

On a *functional level*, the present thesis deals with procurement logistics. Procurement logistics is defined as the logistics system, covering the first phase of global commodity flows and is therefore relevant to the investigation of agricultural commodities. Procurement logistics is also referred to as supply logistics or physical supply system (Pfohl, 2010).

Characteristics of international logistics

The increasing internationalisation process results in a quantitative and qualitative expansion of the logistics environment. In general, the quantitative expansion is expressed by the increase in transport distances, means of transport (sea and air), additional institutions, authorities and actors abroad, greater diversity of documents and the increase of information. Qualitative expansion, on the other hand, is reflected in logistics-relevant framework conditions that vary from country to country, such as legal/political, technical, infrastructural, cultural and natural (environmental) conditions (Göpfert and Braun, 2013). Next to transport conditions, the transport performance is extremely different on the continents due to the very different natural conditions (climate, surface form, water network) and the economic development of the states (Woitschützke, 2006).

Intermodal transport chain of agricultural commodities: The role of sea transport and ports

In the international procurement of agricultural commodities, transport must necessarily be organised as broken intermodal transport, i.e. with the help of different means of transport. In order to establish international transport chains, means of transport with very different characteristics must be combined with each other (Pfohl, 2010; Schieck, 2008). In the case of agri-bulk commodities, the main types used are sea vessels, trucks, freight wagons and inland waterway ships (Woitschützke, 2006).

There are fluctuating figures on the general share of sea transport in world trade, but it is estimated that 80% of global trade and 90% of the EU's overall external trade is based on sea transports (Schieck, 2008). This shows that maritime shipping has the highest transport performance and the highest share in the global modal split[2]and is therefore closely related to world trade. Around 60% of the sea transport volume is accounted for by bulk goods of lower value density and 40% by a general cargo of higher value density (Schieck, 2008). Agricultural raw materials such as cereals and soybeans are classified as dry bulk commodities. Dry bulk

[2] The importance of the individual modes of transport in the transportation system of an economic area can be seen from the modal split, which indicates their percentage share of traffic volume or traffic performance in a period under consideration.

commodities are transported in bulk carriers, which hold up to 300 000 dwt[3] *. Depending on the load, bulk carriers can be distinguished in dry freight carriers (for cereals, fertilisers, dry chemicals) as well as in "combination freighter", which besides dry material, may also comprise container and wet bulk goods (Trace, 2017).

Ports play a central role as the most important hubs in global commodity flows. Besides handling goods, they also constitute concentration points for trade and industry. Seaports must be connected to the hinterland with appropriate infrastructure through feeder services (coastal shipping), inland shipping, rail and road transport. This infrastructure plays an essential role in the competition between seaports (Pfohl, 2010). There are different types of ports, which are distinguished, for instance, by sea location (open or closed port), function (commercial port or multifunctional (universal or mixed) port) and their transport importance (local, regional or world port) (Woitschützke, 2006). Accordingly, agricultural bulk commodities can be handled in universal ports (e.g. Rotterdam, Tokyo, New York, Hamburg), in mixed ports (e.g. Rouen), and mono- or multifunctional (e.g. Brake, Germany) specialised ports.

1.1.3 Structure of the international food safety strategy and the consideration of logistics

The hierarchy of food safety governance has a three-tier structure: At the top/global level are the international standards, especially Codex Alimentarius and agreements, such as the SPS (Sanitary and Phytosanitary Measures) and TBT (Technical Barriers to Trade) agreements, as well as affiliated institutions such as Codex Alimentarius Commission (CAC), WTO and the International Office of Epizootics (OIE) (Theuvsen, 2010). The CAC, established by FAO and World Health Organization (WHO), is the organisation responsible for setting food safety standards, guidelines and recommendations (named Codex Alimentarius) relating to food additives, veterinary drug, pesticide residues, contaminants, methods of analysis and sampling as well as codes and guidelines of hygienic practice (Orriss and Whitehead, 2000). For example, the Code of Hygienic Practice describes sanitary practices for the production, processing and manufacturing of individual foods or groups of foods and includes logistics activities such as transport and storage practices. Accordingly, the Codex General Principles of Food Hygiene introduces the use of the HACCP system within the scope of a QM system of all actors involved in the food supply chain. HACCP is a systematic approach for identifying, evaluating, and

[3] Deadweight tons (dwt) describe the ship´s weight carrying capacity without the ship´s weight.

controlling different steps in food production, manufacturing, and handling that are critical to product safety.

The Codex standards are voluntary and serve as a template for EU (middle level) and national (lowest level) legislation or regulations. At the EU level, corresponding regulations, such as Basic Regulation 178/2002 and EU Hygiene Package VO/EG 852/2004, 853/2004 (which also apply to import companies), have been introduced, thus achieving EU-wide harmonisation and realignment of food law. The new principles of the EU Basic Regulation are "farm to fork-approach" (i.e. merging food and feed law), "risk orientation", "precautionary principle", "traceability" and "primary responsibility of food/feed entrepreneurs" for product safety. The European requirements are implemented on the national level, filling any remaining regulatory gaps.

Consideration of logistics in standards and certification

Since logistics operators are also involved in the food and feed chain, they are considered food business operators according to the EU Regulation. Therefore, they must comply with the corresponding food hygiene requirements to meet the precautionary principle requirement. The EU Hygiene Package states that all food business operators must establish, implement and maintain a permanent procedure or process based on HACCP principles. For this reason, logistics companies (e.g. warehouse keepers and transporters) are considered by many private standard setters, thus ensuring compliance with (mainly legal) minimum standards in food supply chains. Standards that comprise logistics either cover the entire food chain (e.g. QS) or individual sectors/stages such as the feed sector (e.g. GMP, FCA, AFS) or address the purchaser (e.g. IFS Logistics, BRC Global Standard Storage and Distribution). In addition, specifically for trade and logistics, there is the GAFTA Trade Assurance Scheme (GTAS), which includes the GAFTA International Standard of Best Trade Practice. According to the relevant EU and national legislation, these schemes shall provide guidance to traders, transporters, storage keepers, collectors, and manufacturers on establishing and implementing their own feed/food safety management system. However, all standards have in common that they are generally supported by relevant quality assurance programs incorporated into the HACCP plan. In the case of logistics, these are, for example, Good Storage Practices (GSP) and Good Handling Practices (GHP).

By implementing QM systems, information can be collected for both risk control (HACCP) and crisis management. The data generated include the (internal and external) tracing of movements

of the product within the plant (e.g. in the case of storage at a port) and throughout the chain (Kleter and Marvin, 2009). Traceability further includes documentation/recording of suppliers/customers, vendors, buyers and the locations where products were loaded/unloaded (Coceral *et al.*, 2015).

The various food safety systems or standards each require certification through an audit. For this purpose, they provide audit requirements and define the certification (audit) process. Accordingly, based on the standard, external inspections of companies will be carried out by independent, accredited certification companies (Meuwissen *et al*., 2003). In addition, individual or all stages of the food supply chain are subjected to external controls on a regular basis and, if necessary, on a case-by-case or random basis. The number of certification systems has increased significantly over the past 20 years. As early as 2006, there were already several hundred certification systems in the EU alone and 40 in German agribusiness (Theuvsen, 2010).

In addition to standards, there are food safety guidelines concerning agricultural products developed by trade and logistics associations. However, these do not provide for certification. An important guidance document in the EU for logistics and trade is, for example, the EU Good Hygiene Practices Guide "*European Good Hygiene Practices Guide for the collection, storage, trading and transport of cereals, oilseeds and protein crops*". The guideline was developed in cooperation with the EU associations COCERAL (EU Association representing the European cereals, rice, feedstuffs, oilseeds, olive oil, oils and fats and agro-supply trade), UNISTOCK (European association of professional portside storekeepers for agri-bulk commodities within the European Union) and COGECA (General Confederation of Agricultural Cooperatives in the European Union). In Germany, for example, the Central Association of German Seaport Operators (*Zentralverband der Deutschen Seehafenbetriebe*) has issued a guideline on handling and storage of grain, feed and oilseeds, which provides guidance on logistical processes from a food safety perspective.

Traditional Risk analysis approach and its shortcomings

In addition to the legal framework described above, for risk analysis, institutional counterparts (food safety authorities) to the world organisations FAO and WHO (CODEX Alimentarius) were also created on EU level (EFSA, The Food and Veterinary Office (FVO)) and national level (e.g. Germany: German Federal Institute for Risk Assessment (BFR) and Federal Office for Consumer Protection and Food Safety (BVL)). Furthermore, the CAC has developed an action plan for the development and application of risk analysis principles and guidelines, which

provide a reference on the EU and national levels. Codex defines risk analysis as a process consisting of three interrelated components: RA, RM, and risk communication.

RA (Risk assessment) (global level: FAO/WHO, EU level: EFSA, German level: BfR) is defined as the "scientific evaluation of known or potential adverse health effects resulting from human exposure to foodborne hazards" (FAO/WHO, 1995). RA is a scientifically based process consisting of hazard identification, hazard characterisation, exposure assessment and risk characterisation. "Hazard" is thus defined as "a biological, chemical, or physical agent in – or property of – food that may have an adverse health effect". Whereas "risk" means "a function of the probability of an adverse effect and the magnitude of that effect, consequential to a hazard in food" (FAO/WHO, 1995). RA is intended to provide the basis for RM decisions and shall be undertaken in an independent, objective, and transparent way.

RM (Risk management) (global level: CAC; EU level: EU commission, FVO; German level: BVL, Federal Ministry of Food and Agriculture (BMEL)) is defined as "the process of weighing policy alternatives in the light of the results of RA, together with other relevant evaluations and (if required), of selecting and implementing appropriate control options" (EC, 2000). This includes, monitoring and surveillance activities for instance in the form of official controls. *Risk communication* is defined as "the interactive exchange of information and opinions concerning risk and RM activities" among risk assessors, risk managers, consumers and other interested parties (EC, 2000).

Traditionally, analysis of food safety issues has been confined to scientific experts in RA and professional risk managers with very limited formal input from other interested parties such as industry, non-governmental organisations and consumers (Wentholt *et al.*, 2009). Furthermore, RA is limited to quantitative estimation of the magnitude of human health risk in terms of likelihood of exposure to a contaminant in food and the likelihood and impact of any adverse health effects after exposure. Yet, RA is often limited by the available data (Orriss and Whitehead, 2000). In addition, the "farm to fork" concept, an essential principle of the EU Basic Regulation, is considered in traditional RA more at the micro-level, e.g. through the evaluation of feed and the transfer of undesirable substances from feed into animal products. Hence, the complexities of global food and feed supply chains resulting from the interactions of supply chains with the environment are not considered in traditional RA and RM.

New approaches in RM and RA and their shortcomings concerning logistics

The international cooperation of food safety authorities has become more important than ever before due to the highly interconnected global food and feed industry and the associated increased likelihood of food safety issues. One focus of the work of EU and national regulatory and food control agencies (RM) is the early warning of food safety risks. The focus of existing early warning systems, such as the EU Rapid Alert System for Food and Feed (RASFF), lies in monitoring and managing risks. On the international level, the International Food Safety Authorities Network (INFOSAN) also serves as an important communication tool for exchanging information on food safety incidents. However, these systems bear several limitations: They react only when risks have already arisen for the consumer. Furthermore, unknown hazards and factors outside the food sector are not considered (Marvin *et al.*, 2009).

Therefore, another focus within the scope of RM is the development of systems for the early identification and evaluation of emerging risks (ERI). These are intended to identify new and unforeseeable risks before they occur and thus allow proactive interventions in the food production system (Marvin *et al.*, 2009). For this purpose, holistic approaches are being used, first presented by the OECD (Hood, 2005) and further elaborated upon, among others in the European projects EMRISK, PERIAPT and SAFEFOODS (Achterbosch, 2007) as well as by international organisations such as the FAO (FAO, 2013a). Such a broader approach should not only focus on the specific food supply, but also consider its host environment. It is argued that drivers of emerging food safety risks are often not directly linked to the food production chain and that a plurality of factors should be taken into account (Noteborn *et al.*, 2005). Examples of drivers include science, technology, environment, and policy, for which indicators to be monitored and corresponding data/information sources are defined.

The above mentioned systems consist of different methods and tools comprising both quantitative (e.g. IT tools for media monitoring, simulation models) as well as qualitative methods such as expert-judgment approaches (e.g. Delphi surveys[4]) and consultations with experts and stakeholders groups through workshops and/or web-based forums. The limitation, however, is that they lack due practicability and effectiveness as data collection and evaluation is very time and resource-consuming (EFSA *et al.*, 2018b; FAO, 2013a). In addition, there is often a lack of expertise concerning the food industry/business and trade (EFSA, 2015). To

[4] Delphi is an iterated survey with several 'rounds'. The technique is loosely defined and can be conducted in different ways.

date, it is largely unknown or not transparent whether and to what extent logistics is taken into account in the current ERI systems. Finally, EFSA recommends improving the understanding of the interactions and dynamics between actors and drivers (EFSA *et al.*, 2018b), which seems particularly relevant concerning logistics and its complexity.

In the field of RA, the clarification of complex food and feed safety issues is becoming increasingly important in the course of globalisation. In this regard, a lot of information and data on worldwide cultivation, transport and distribution is required to draw conclusions about the occurrence of chemical, biological and physical contaminants. In investigating food safety issues such as E.coli in 2011 and Fipronil in 2017, it became clear that major knowledge gaps exist in the field of logistics, which nevertheless play a crucial role in describing or characterising the global commodity flows. With the development of software, such as IT tools for supply chain analysis based on traceability data and for the analysis of EU and international trade relations based on Eurostat's Comext database, first steps have been taken towards more transparency regarding the role of logistics in foodborne disease outbreaks (de Alba Aparicio *et al.*, 2018; Weiser *et al.*, 2016).

However, in developing these computer modelling tools based on quantitative data, new questions have arisen regarding the impact of complex relationships in the logistics sector for food safety. On the one hand, conceptual and holistic, i.e., qualitative research approaches - as in the area of ERI - are required to support RA in complex food safety cases. On the other, more pro-active approaches, such as the involvement of stakeholders from logistics and trade, is needed as their knowledge and direct practical experience seems highly relevant for understanding the complexities in this sector.

1.2 Aim of the study

It was shown that the logistics sector is closely linked to agricultural trade. Since an increase in world trade and a shift in commodity flows or even issues in food security due to climate change are to be expected, it can be assumed that the importance of logistics for food safety and security will continue to increase in the future.

QM systems well cover the knowledge about critical points for food safety in logistic processes. However, from the perspective of the risk analysis community, the complexity of global supply chains is playing an increasing role in food safety - which is reflected in the development of holistic approaches taking the environment of food supply chains into account. Although practised so far mainly in ERI, data/information on the logistics and trade sector is not yet

systematically collected or monitored in current systems. Without any hard facts being available, the RA community identified the field of logistics as a critical knowledge gap and thus a weak point in current systems/approaches for evaluating food safety risks. However, hard facts aside, a better understanding of the complex interactions within and around supply chains is temporarily one of the main concerns of both RA and RM.

The main challenge lies in finding methodological starting points to close the current knowledge gaps in the field of logistics concerning food safety. Strategies must be examined that are suitable for gaining new knowledge based on recognised scientific methods. Therefore, the overarching question of the newly identified research field is: What is the overall impact of the logistics sector on food safety, and how can it be systematically investigated, evaluated and integrated into current approaches and systems to reduce the uncertainty and variability of RA in times of globalisation?

This dissertation makes an initial contribution to the main objective of the research area by examining the complexity of logistics and identifying vulnerabilities related to food safety. The research questions underlying the dissertation are, therefore:

1. How does the complexity of logistics contribute to food safety risks along global supply chains?

1.1. Which levels of consideration and concepts define the complexity of logistics?

1.2. What are the critical dimensions and factors for food safety in global commodity flows?

1.2.1. How does the interaction between the different dimensions affect food safety?

The subordinated questions above were addressed in the scope of two separate research papers.

The first sub-objective (Question 1.1) was to develop a holistic conceptual framework (CF) for identifying food safety risks in global commodity flows exemplified by agricultural bulk commodities. The construction of the CF is based on a systematic and comprehensive analysis of multidisciplinary literature concerning logistics in the form of qualitative text analysis, adapted from the Grounded Theory approach.

The second sub-objective (Questions 1.2 and 1.2.1) was to empirically identify critical dimensions, factors, and interrelationships in global commodity flows relevant to food safety. Here, we conducted a case study on mycotoxin contamination in agri-bulk commodity flows

by interviewing actors/experts, directly and indirectly, involved in the international logistics or procurement sector of agri-bulk commodities.

1.3 Rationale and description of the methodology used

Due to a lack of studies resulting in a poor data situation and rudimentary knowledge, the research field is largely exploratory. Therefore, we have chosen qualitative research approaches, such as conceptual framework building and case study, since they are adequate tools for studying complex and dynamic phenomena or systems as a whole. Both approaches are based on a holistic approach implying context sensitivity, which corresponds to the research on ERI by European food safety bodies and international organisations such as the FAO. The definition and delimitation of the phenomenon of global commodity flows as a new field of investigation in RA, by systematically summarising the literature and putting it into a CF, is a scientifically recognised first step in an exploratory research field. The development of the CF further supports the formation of application-oriented theories or research guiding propositions that can be used for empirical studies, such as case studies, as a second step. The construction of the CF is based on a qualitative text analysis of multidisciplinary literature, adapted from the Grounded Theory approach. Grounded Theory is a process of inductive theorisation, which seeks to discover a theory from systematically obtained data by generating and identifying a phenomenon's main elements and concepts (Glaser and Strauss, 2005). The specific technique of inquiry requires coding paradigms *(open coding, axial coding and selective coding)* to ensure conceptual development (Strübing, 2004). For this, the Qualitative Data Analysis Software MAXQDA (VERBI Software GmbH, Germany) was used.

Case studies are an empirical, explorative and pro-active approach that verifies and complements the developed conceptual knowledge with experiential or practical knowledge in the real-life context considering the influence of its social, political and other context (Yin, 2013). The CF - including the research guiding assumptions - formed the starting point for developing the research design of the case study. However, case studies are emphatic in the sense that despite prior planning, the research design evolves as the research process progresses. We chose a single case taking the example of mycotoxin contamination of agri-bulk commodities. Since very little information is available regarding the interacting dimension of global commodity flows, a detailed investigation of only one case seemed to be useful. We opted for a typical rather general situation as a single case so that conclusions can also be drawn about other comparable situations (Staake, 1994). We chose in-depth expert interviews as a data

collection technique since it is the most appropriate method for gaining a deep understanding and specific insights into interrelations, backgrounds, and contexts.

The expert sampling was done via deductive sampling, i.e. the selection of experts was derived from prior theoretical knowledge of the CF. Contacting the experts was mainly based on the "snowball principle", in which the first interview partners from the existing network referred to other possible interview partners (Patton, 2014). We chose the guided interview as the interview format based on a semi-standardised questionnaire with about ten guiding questions. A total of 18 interviews were conducted with 24 experts. Of the 18 interviews, 14 were conducted face to face on-site, three by phone and one by Skype. The experts were divided into four different groups of actors (GA1: Regulations and Standards, GA2: Agri-Food Trade, GA3: Logistics Sector, GA4: Procurement sector). As a result, three different questionnaires were developed with overlapping topics but a different focus (Guideline A = External controls, standards, regulations; B= Logistical processes, port activities; C= Cooperation).

The interviews were analysed by Qualitative content analysis, which involves coding the transcribed interviews according to specific criteria and described by categories (Mayring, 2004). The logic used to link the data collected to the propositions or research questions was based on pattern matching. Further, rival explanations were used as criteria for interpretation (Yin, 2013). Here, we also used MAXQDA as Computer-Assisted/Aided Qualitative Data Analysis software (CAQDAS) to support category building and data analysis. The transcribed and anonymised interviews and audio files were stored in an interview database. Accordingly, the collected data could be well organised and the entire research process documented so that the chain of evidence can be traced from the research questions to the case study report, which increases the reliability of the case study (Yin, 2013).

1.4 Outline of the thesis

After embedding this thesis into the overall research area through the background information in Chapter 1 and subsequently formulating research questions in 1.2, Chapters 2 and 3 present the papers that cover the described sub-objectives addressed by this thesis. The paper presented in chapter 2 aimed to develop a conceptual framework of the phenomenon "global commodity flows" exemplified by agricultural bulk commodities. Here, the research field of logistics from a food safety perspective is defined, delimited and structured. A comprehensive analysis of multidisciplinary literature concerning logistics in the form of qualitative text analysis, adapted from the Grounded Theory approach, was used. In Chapter 3, the article aimed to empirically

investigate critical dimensions, correspondent factors and food safety-relevant interrelationships in the logistics sector. For this purpose, we conducted a case study on mycotoxin contamination in agri-bulk commodity flows by interviewing actors/experts, directly and indirectly, involved in the international logistics or procurement sector of agri-bulk commodities. In Chapter 4, we discuss the main findings of the two papers and the limitations of the thesis. Finally, Chapter 5 presents the general conclusions and offers recommendations for policy and further studies stemming from this thesis.

2 Publication I

A conceptual framework for the identification of food safety risks in global commodity flows exemplified by agricultural bulk commodities

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2.1 Abstract

Globalization of agricultural trade has led to food supply chains becoming increasingly complex. A high number and diversity of entities, processes, and localisations can create food safety risks and vulnerabilities at all stages of the food supply chain. To date, food safety measures have focused mainly on production, processing, and retail. However, the dimension of commodity flows embedded in the logistics sector, which links the main stages, has largely been neglected. The resulting knowledge gaps pose a challenge to risk assessors concerned with consumer health protection. To map the research area of global commodity flows and investigate their impact on food safety, a conceptual framework (CF) was developed using agricultural bulk commodities (ABC) as an example. The construction of the CF is based on a qualitative text analysis of multidisciplinary literature, adapted from the Grounded Theory approach. Here we determined and illustrated different levels of the main concepts inside and outside of ABC flows relevant for the investigation of logistics in terms of food safety. The main internal concepts are Key processes and Management, Key actors and Cooperation, Routes and Nodes, and their Quality and Capacity. The external concepts can be divided into Logistics-related conditions and the associated Diversity, as well as Drivers of change associated with the Dynamics of globalization. The developed CF represents a first model for holistically investigating logistics in terms of food safety by defining, structuring, and delimitating logistics as a new field of investigation in risk assessment. It offers suitable concepts and application-oriented theories related to food safety that serve as a basis for empirical studies, such as the identification of critical factors in the logistics sector. Further, it serves as an aid to practitioners in dealing with complex food safety problems in the context of risk management.

Keywords: logistics, agri-food, globalization, food supply chain, risk

2.2 Introduction

Food safety risks related to the globalization of trade and food safety management along agri-food supply chains are identified as one of the most critical issues of today's food safety (Codex Alimentarius Commission, 2016). Agri-food supply chains comprise all productive and logistical measures from primary production to consumption of the final product. Due to the constant growth of international trade in the last decades and the resulting increased geographical segregation of food production, processing, and consumption, agri-food supply chains have become longer and more complex (Hertel, 2013; Marucheck et al., 2011). Outsourcing and offshoring have led to more diversity and a higher number of entities, processes, and localization as well as complexity in product and information flow (Dreyer et al., 2009; Matopoulos et al., 2004; Rodrigue et al., 2016). Characterized by supply, demand, and price variabilities as well as by a limited shelf life, agri-food supply chains can be more complex than other commodities (Ahumada and Villalobos, 2009; Bhat and Jõudu, 2019; Lowe and Preckel, 2004).

As a consequence, the global and highly interconnected agri-food supply chain creates food safety risks and vulnerabilities at multiple points at all supply chain stages (see red arrow in Fig. 1) (Chammem et al., 2018; Zhao et al., 2020). A single safety incident in a certain stage can have a significant impact on consumer health on a global scale (Kruse, 2015; Marucheck, 1987). This has been confirmed in the past by serious food safety incidents (e.g. Dioxin contaminated animal feed in 2003, Escherichia coli (EHEC) contaminated fenugreek seeds in 2011, Salmonella Enteriditis in 2014, Aflatoxin milk contamination in 2013, Fipronil egg contamination in 2017), with the result that consumer awareness and concern have increased and food safety has become an increasingly important public health issue. Over the past two decades, food safety authorities have therefore had to face the challenge of assessing and managing food safety risks in consumer health protection. On the other hand, traders and the food and feed industry have also been challenged to avoid or minimize food safety issues. Consequently, numerous measures have been taken to manage and handle food safety risks along global supply chains.

Based on the supranational "Food Code" Codex Alimentarius, the EU, for instance, has set the principle "from farm to fork" (EU-Regulation No 178/2002) to guarantee a continuous control and protection of food safety along the supply chain. Additionally, the food and feed industry, as well as non-governmental organizations, have established a large number of private standards and guidelines that include hazard analysis and critical control points (HACCP) and

cover the entire food supply chain such as Good Agricultural Practice (GAP), Good Manufacturing Practices (GMP), Good Handling Practices (GHP), Good Trading Practices (GTP) as well as international food safety standards (e.g. ISO 22000, FSC 2200). However, food safety incidents still occur despite respective regulations, standards, and correspondent measures (Marucheck et al., 2011). This implies that there are still unknown and unmanageable vulnerabilities in the food chain and leads to the assumption that the exclusive focus on internal critical control points for food safety within the diverse stages of the global agri-food supply chain is insufficient in times of globalized trade. Instead, it can be assumed that the more complex the system, the higher the probability of food safety risks (Chammem et al., 2018; van Asselt et al., 2010).

In response to serious food safety issues, the European Food Safety Authority EFSA, as well as international organizations such as the UN Food and Agricultural Organisation FAO have set focus on the development of Emerging Risk Identification (ERI) and Early Warning Systems (EWS). Based on a holistic approach, these systems emphasize the influential sectors of the food production chain such as market trends, technology and science by integrating these external factors in the identification of food safety risks (Noteborn et al., 2005). However, international foodborne disease outbreaks in the past have demonstrated the lack or limited availability of data and information required for clarification of complex food safety cases or related risk assessment. The revealed knowledge gaps resulting from the complexity of global food supply chains lead not only to uncertainties in the assessment of safety risks in the entire food system but also in health risk assessment (Manzini and Accorsi, 2013). In this context, the new Regulations (EU) 2019/1381 amends the EU General Food Law (EU-Regulation No 178/2002) to increase transparency in the EU risk assessment in the food chain.

One area that showed several data gaps and lack of information while the clarification of occurred food safety incidents is the logistics sector. It has become apparent that the transportation sector, for instance, lacks an oversight about food being moved. In the complex web of the supply chain, this lack results in generally little data and analysis (LeBlanc et al., 2015). In fact, the focus of food safety improvement measures, i.e., in risk management and risk assessment, has so far been on the supply chain stages "(primary) production", "processing" and "wholesale and retailing". The logistical processes such as transportation, interim storage, and handling that crosslink the major agri-food supply chain steps and characterize global commodity flows (Fig. 2.1) have yet received comparatively less attention (Ryan, 2017). However, logistics play a crucial role when considering global supply chains from a food safety

perspective. It is known that during transport, storage and handling, food safety can be compromised by chemical, physical and biological contamination. Little is known about how the quantitative and qualitative expansion of logistics with increasing internationalisation, such as the number of actors, distances, means of transport, documents and information, as well as the logistics-relevant conditions, affect food safety (Göpfert and Braun, 2013). Furthermore, as a global sector, logistics is subject to dynamic developments and global competition in the course of globalisation, which further increases the complexity.

Against the background of the complexity of global supply chains due to the interaction between multiple factors within and between tiers of the chain (Pope, 2020), it should not be assumed that food is being safely moved throughout global supply chains in general. However, as supply chain "risks" commonly refer to potential losses incurred by the companies in the supply chain due to disruptive events, most of the research lies in this area (Hudnurkar et al., 2017). Consequently, the knowledge and research gaps of logistics concerning food safety increase the uncertainties in risk assessment. Therefore, the questions arise: What is the impact of global commodity flows on food safety, and how can this be assessed?

To date, risk assessment lacks a strategy to evaluate global commodity flows or logistics regarding food safety. New comprehensive approaches are needed to capture logistics in its complexity and the context of food safety beyond the already known and practised HACCP in logistical processes such as transportation, handling, and interim storage. The phenomenon "global commodity flows" needs to be further defined and better understood in the context of food safety to be integrated into the corresponding risk assessment and ERI systems.

Therefore, the aim of the present study was to develop a comprehensive and holistic conceptual framework (CF) of the phenomenon "global commodity flows" in the context of food safety. It should illustrate the complexity and - at the same time - characterize, structure and delimitate the phenomenon as a new field of investigation in risk assessment.

It should provide information about the following key questions concerning global agri-food commodity flows:

- What are the physical boundaries?
- What are the key processes?
- Who are the key actors?
- What are the major influential sectors in terms of food safety?

In addition, the CF is expected to offer suitable concepts related to food safety that serve as application-oriented theories/propositions that can systematize further research to fill the knowledge by, for example, identifying critical factors related to food safety. In addition, it is intended to serve as an aid to practitioners in dealing with complex problems in the context of risk management. In the present study, the CF is exemplified using the dimension of global procurement/sourcing of agricultural bulk commodities (ABC), marking the first phase of agri-food commodity flows throughout global supply chains. The global sourcing/procurement segment within the agri-food supply chain defines the very boundary and scope of the present study, for which a CF was developed (Fig. 2.1) (Pfohl, 2010).

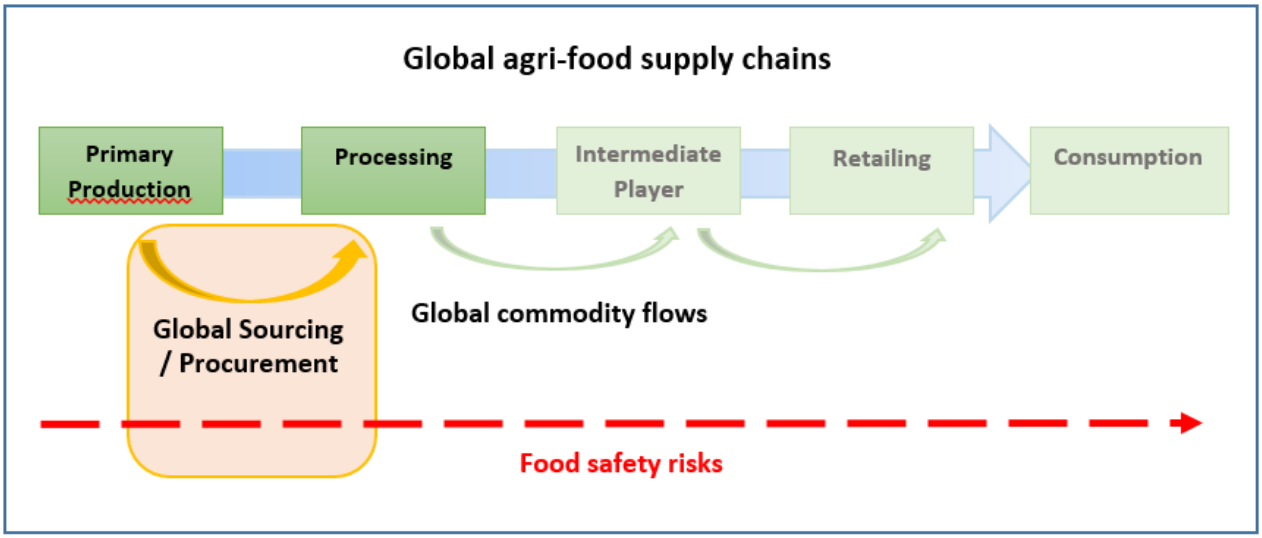

Figure 2.1: Food safety risks in 'Global Sourcing/Procurement' - marking the first phase of global commodity flows of agri-food supply chains - represent the focus of the study.

ABC, such as cereals and soy beans, intended for human nutrition and animal feeding, are the primary traded agricultural raw materials worldwide with rising trade volumes (USDA, 2018). In the EU, most of the imported ABC is intended for the animal feed sector (FEFAC, 2018; Schmid and Goldhofer, 2017). For example, about 800 shiploads or 58,000 containers of soy reach Europe every year. From this, 26.5 million tons of feed are produced in 5,000 feed mills. This dimension already shows how complex the logistics of agricultural commodities are (Baaken and Lehnen, 2015).

We have developed and constructed a CF for global ABC flows for the identification of critical factors related to food safety through a process of qualitative text analysis of multidisciplinary literature, adapted from the Grounded Theory methodology.

2.3 Methodology

2.3.1 Conceptual framework building

Based on the identified research gap and the intended knowledge contribution of the present field of work, the qualitative approach CF-building appears to be an adequate tool to study global commodity flows in the context of food safety. It is used to better understand a complex phenomenon that is linked to multidisciplinary bodies of knowledge. It, therefore, includes a holistic approach that is also used in the scope of ERI by European food safety bodies and international organizations such as the FAO. Situating the study in the relevant knowledge fields allows demonstrating the importance of a problem (Rocco and Plakhotnik, 2009). Furthermore, the development of a CF aims at defining and structuring ideas about a complex phenomenon of reality and supporting the formation of presumed effects. Accordingly, it forms the starting point for developing the concrete research model of empirical studies that must be connected to literature or concepts. Therefore, a CF not only provides the foundation but also serves as a reference point for the interpretation of findings of further studies. Hence, knowledge generation through CF building has a normative dimension. It seeks to identify the best concepts and, through this, be able to provide recommendations on the concepts that should be used (Aven, 2018).

The construction of the present CF is based on a qualitative text analysis of multidisciplinary literature, adapted from the Grounded Theory approach. Grounded Theory is a process of inductive theorization, which seeks to discover a theory from systematically obtained data by generating and identifying a phenomenon's main elements and concepts (Glaser and Strauss, 2005). The emerging theory results from a steady interplay between data collection and analysis characterized by discovering patterns through constant comparison of data. Grounded Theory contains the fundamental and analytical pursuing of the interpretation of data rather than an objective and static description of the data and the phenomenon.

2.3.2 Information sources and data

Data collection should be a comprehensive and complete "scoping" in order to ensure validity and a holistic mapping (Morse and Mitcham, 2002). Whereas data collection is unstructured and open at the beginning, it gets controlled by the emerging theory in the further course.
The literature selected for the CF analysis represents the diverse and relevant elements of ABC flows, such as technological, political, environmental, and cultural aspects. Moreover, multidisciplinary literature that has a link to ABC flows was chosen. An important point is that

the literature should also represent practices that are related to global commodity flows. The data come from a variety of information sources. Research articles were found via a systematic keyword search (e.g. “logistics”, “risks”, “food safety”) on Google Scholar and Web of Science. Reports about global agricultural trade and logistics from international organisations such as Organization for Economic Co-operation and Development OECD (e.g. International Transport Forum), United Nations Conference on Trade and Development UNCTAD (e.g. Transport and Trade Facilitation Newsletter), World Trade Organization WTO, and World Food Programme WFP, as well as books about international logistics and traffic/transportation geography, were included as well. Further, practical guidelines from European trade and logistics associations such as COCERAL (European association, representing the trade in cereals, rice, feedstuffs, oilseeds, olive oil, oils and fats, and agro-supply) and standards such as GMP and QS were also used as a basis for data. Moreover, data of initial conversations with practitioners from a European logistics association and an international organization involved in food logistics were used. The sources of data reveal theories that belong to specific disciplines. These discipline-oriented theories served as the empirical data of the CF analysis.

2.3.3 Data analysis

The specific technique of inquiry requires coding paradigms (open coding, axial coding, and selective coding) to ensure conceptual development (Strübing, 2004). In the present study, Qualitative Data Analysis Software MAXQDA (VERBI Software GmbH, Germany) was used for the (iterative) process that includes the constant comparative method:

1. Open coding: Categorizing the selected data, i.e. similar data are grouped by discovering patterns and given conceptual labels (interpretation step).
2. Axial Coding: Making comparisons at the concept and sub-concept level, i.e. defining relationships between the concepts.
3. Selective coding: Integrating, renaming, relocating concepts to key categories until the researcher recognizes a general CF that makes sense.

The process is accompanied by memo writing that includes reflection on the process and the content and consequently builds the research infrastructure.

2.4 Results

To map the research terrain of global ABC flows for investigating their impact on food safety, a CF was developed through qualitative text analysis, adapted from the Grounded Theory technique. The identified main concepts characterizing global ABC flows from a food safety perspective are illustrated in a graphical representation (Fig. 2.2). The CF presents ABC flows as a system in which the phenomenon is influenced by a complex environment. The phenomenon "ABC flows" is thereby divided into three aggregation levels: The micro-level concerning the logistical Key Processes of the individual company, the meta-level related to the Key Actors, and the macro-level that comprises Routes and Nodes, as part of the physical infrastructure of an economy. The phenomenon is surrounded by influential sectors, divided into two categories, namely Logistics-related conditions on the country level and Drivers of change on the global level. Moreover, respective food safety concepts for each of the identified key categories or levels from inside and outside ABC flows were identified (e.g. Management concerning Processes).

In the following, the results are presented according to the key questions that were used for model development.

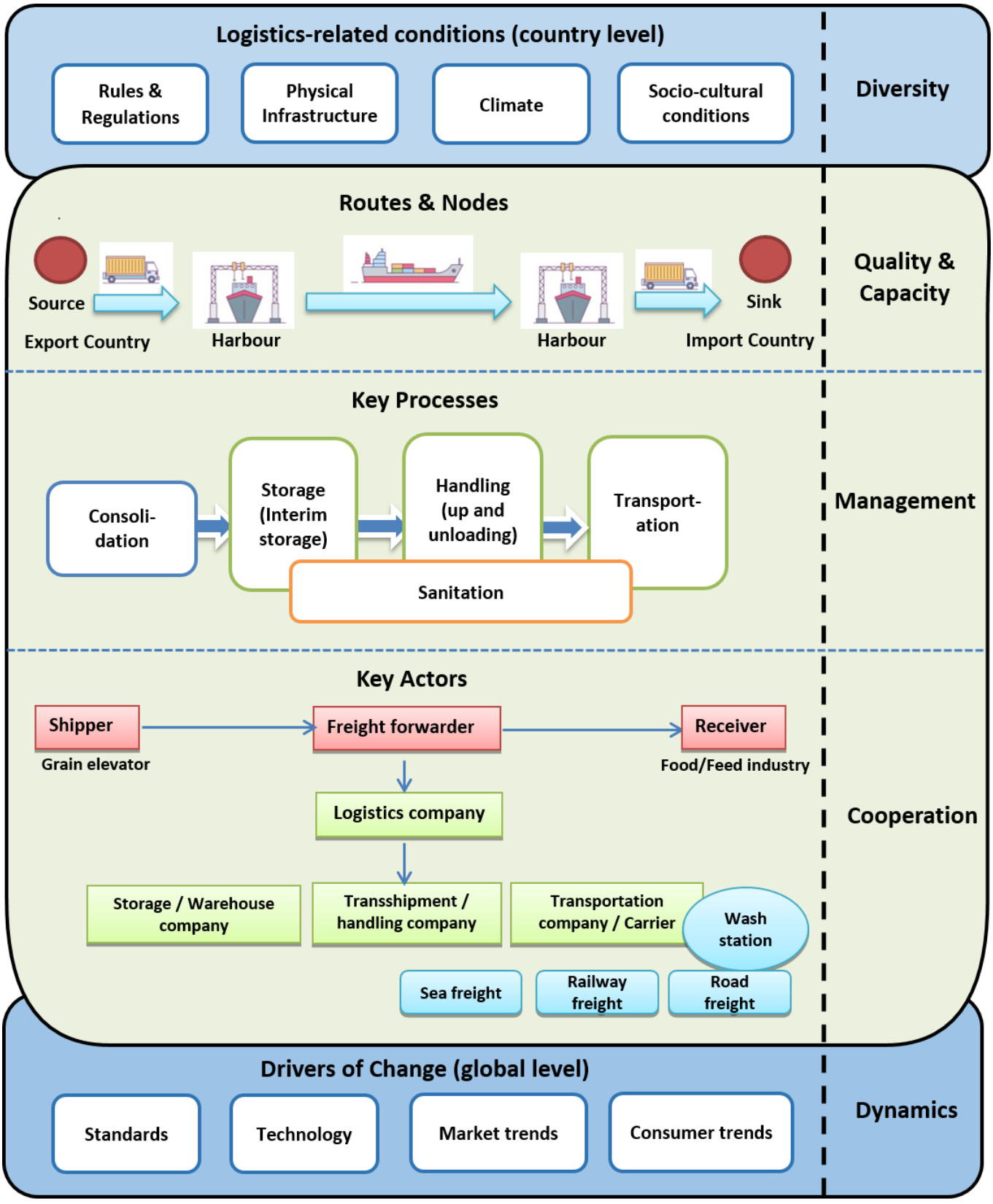

Figure 2.3: Conceptual framework for the identification of critical factors related to food safety in global agri-bulk commodity flows – focusing on the segment of 'Global Sourcing/Procurement' as the first phase of global commodity flows (see Fig. 2.1).

Physical boundaries

ABC flows take place between the delivery point, at which the goods are provided (source), and the receiving point, at which the goods are used (sink). The source might be the procurement warehouse at the production site or a supply warehouse at the export harbour in country A. The sink represents the food or feed industry in country B. In analysing the transportation channels between the source and the sink, two elements of the infrastructure service are identified (Rodrigue *et al.*, 2016; Thakur and Hurburgh, 2009).

- **Routes**: The ABC flows' main route is by sea, followed by the land route.
- **Nodes**: Seaports are the most important logistical nodes that represent links in the network of ABC flows. ABC are temporarily stored or transferred to another route through the network.

This way, ABC is moved through a network of routes and nodes belonging to different economies' infrastructure services/freight transportation systems.

Key processes

The framework is built around the key processes of ABC flows. Key processes in global ABC flows primary serve the transformation of goods in time and space with related facilities and devices. Five core processes defined as a bundle of tasks/activities are identified as relevant for ABC flows:

- **Consolidation:** ABC flows from the same origin with different destinations are consolidated on their route to the node/hub and are combined with ABC flows that have different origins but the same destination. Consolidation refers to segregation and aggregation or rather comingling of different (grain) lots in order to meet buyer specification (Thakur and Hurburgh, 2009).
- **(Interim) Storage**: Storage can take place temporary at nodes when capacities and schedules in the transportation chain of different transportation modes are not coordinated or when ABC have to be organized in terms of volume and weight in order to guarantee full capacity of transportation mode. Storage can also extend over longer periods of time when business objectives and processes require the operation of storage systems (Pfohl, 2018).
- **Handling**: Load and unload operations are carried out by belt conveyor, digger and pneumatic systems at transitions points between transportation modes or between storage and transportation (Pfohl, 2018).

- **Transportation**: External relocation of ABC by waterborne (bulk carrier/vessels and container vessels) or overland transportation (trucks and railway). Transportation starts and ends with handling activities (Schieck, 2008).
- **Sanitation:** Refers to cleansing logistics-related equipment and devices such as transportation means and handling equipment. Sanitation specifications / standards such as time and temperature are established by the carrier or freight forwarder.

Key actors

The core processes relate to the key actors. These are actors directly involved by carrying out the processes and actors who initiate and organize the processes. The identified core group enters into contractual commitments. The following four key actors that coordinate mainly on tactical levels via contracts and specifications were identified:

- **Shipper/Receiver**: Contracts freight forwarder for planning, preparing and post processing of global ABC flows. The shipper can either be the ABC producer or grain elevator in country A or the receiver/buyer from the food or feed industry in country B (Pfohl, 2018).
- **Freight forwarder**: Acts as a bridge between the shipper and the logistics company. Plans and prepares ABC flows and contracts logistics companies for logistics services (Pfohl, 2018).
- **Logistics Company**: As the supplier of logistics services such as transportation, handling and storage, the logistics company takes the leading role in carrying out the physical movement of goods.
- **Wash and maintenance station**: Company in charge of sanitation and maintenance of transportation modes. Contracts between the wash station and the freight forwarder or the carrier regulate sanitation specification/standards (Pfohl, 2018).

Influential sectors

A variety of relevant influential sectors of global commodity flows were identified that can be differentiated in two categories. The first category comprises *Logistics-related conditions* sectors that show country specific differences characterising the diversity of the logistics sector. We identified four influential sectors at the country level that determine the nature of the logistical processes and the behaviour of the key actors:

- **Rules and Regulations**: Dimension of technical related regulations for logistics activities such as dimension of transportation means (from loading unit size to vehicle

size) and food safety regulations and national laws related to the logistics sector (Nuhn and Hesse, 2006).

- **Physical Infrastructure**: Relates to elements of freight transportation service such as routes and nodes and geographical aspects such as topographic conditions (surface form) of a country. Further, it relates to logistics related equipment and devices such as transportation means (Schieck, 2008).
- **Climate**: Includes climate related factors such as weather (e.g. temperature, humidity), climate change, seasonality etc., that affects transportation flow and environmental conditions during logistics activities (Pfohl, 2018; Woitschützke, 2006).
- **Socio-cultural conditions:** Relate to culture and language, as well as to training landscape, technical level capacities and working conditions in the logistics sector of a country (Neumair *et al.*, 2012; Schieck, 2008).

The second category of influential sectors comprises Drivers of change that are related to the process of globalization. Drivers of change relate to changes in global commodity flows and can be categorized into four groups:

- **International Standards**: Refer to public and private standards related to food safety in the logistics sector and are developed by regulatory agencies (e.g. ISO), public organization (e.g. Codex Alimentarius) or industry associations (e.g. FEFAC) (Webb, 2015).
- **Technology**: Relates to progress and innovations within the scope of Industry 4.0 (Abdirad and Krishnan, 2021), including information and communication technology (ICT) such as Internet of Things (IoT) technology in food safety (Bouzembrak *et al.*, 2019) but also new development trends in technical processes, procedures and practices, such as sanitation practices and handling practices and to the equipment and devices, such as size of transportation modes.
- **Market trends**: Relate to (emerging) key market player in the global market of ABC and associated traffic flows/corridors (USDA, 2021); also refers to fuel and commodity availability and corresponding prices as determinant factors of transportation costs (Taghizadeh-Hesary *et al.*, 2019).
- **Consumer trends:** Refer to consumer consumption patterns in different regions such as western countries, emerging countries and developing countries associated to demographic trends and food safety and environmental awareness.

For each of the five identified key categories (Processes, Actors, Routes and Nodes, Logistics-related conditions and Driver of change), respective concepts were identified with a linkage to food safety.

Management

In the context of the EU food safety concept, logistics companies are regarded as food business operator and consequently carry responsibility for food safety. Management covers quality control of both processes and the product. Whereas sanitation, maintenance and traceability of equipment and devices are general elements of process control, product control in terms of safety and quality incorporates dimensions of prevention, mitigation and recovery (Marucheck *et al.*, 2011). Management is estimated to cause up to 85% of quality and food safety problems (Ryan, 2017).

Cooperation

The high number and diversity of participants with conflicting objectives is considered a major challenge for collaboration (Hu *et al.*, 2019; Rodrigue *et al.*, 2016; Singh and Power, 2009; van der Vorst *et al.*, 2009) and thus potentially threatens food safety. Commodity flows usually are not designed in agreement with risk evaluation, and risk assessment as efficiency and effectivity constitute the major targets in coordination and collaboration (Manzini and Accorsi, 2013).

Quality and Capacity of Routes and Nodes

Quality and capacity of port infrastructure include, e.g. facilities, sanitation services, landside connections and sea interface (Bolat *et al.*, 2020; Notteboom and Rodrigue, 2017). Route infrastructure includes, e.g. route and railway network and capacity, road surface conditions and canal widths (El-Wakeel *et al.*, 2018; Jensen *et al.*, 2017). Quality and capacity of routes and nodes determine traffic conditions and consequently affect the transportation flow.

Diversity

Diversity in logistics-related conditions can lead to unpredictable and/or uncertain events that result in disruptions throughout global commodity flows and thus challenging food safety (Narasimhan and Talluri, 2009).

Dynamics

Dynamic shifts of global commodity flows can lead to huge uncertainties in supply and demand, disrupting global supply chains and posing challenges for the international logistics

sector that require a high degree of flexibility (Ahlqvist *et al.*, 2020). Thereby, food safety problems can often be traced back to changes in global food supply chains (Marucheck *et al.*, 2011).

From these concepts, the following application-oriented hypotheses/propositions can be derived that can serve as the basis for further research:

- The type and number of logistical processes and actors involved in global commodity flows can have an influence on food safety.
- The management of logistics service providers, as well as the cooperation between the different actors of global commodity flows can have an influence on food safety.
- The quality and capacity of transport routes and nodes (harbours) can have an influence on food safety.
- Through the interaction with influential sectors, differences in logistics-related conditions at country level and dynamic changes at the global level can have an impact on ABC flows and thus on food safety (e.g. different socio-cultural conditions could influence the quality management of logistics service providers and market fluctuations could influence the choice of cooperation partners).

2.5 Discussion

In the present study, we developed a comprehensive CF by identifying and defining concepts that commonly characterise ABC flows in the context of food safety. The phenomenon "ABC flows" is illustrated by three key categories, namely *Key Processes*, *Key Actors* and *Routes and Nodes*. The context *Influential sectors* is differentiated in two categories, i.e. *Logistics-related conditions* (*Rules and Regulations, Physical Infrastructure, Climate, Socio-cultural conditions*) and *Drivers of change* (*Standards, Technology, Market trends, Consumer trends*) that are linked to the globalisation process. The following food safety concepts related to each of the five key categories were identified: *Management* of logistical processes, *Cooperation* between the key actors, *Quality and capacity* of routes and nodes, *Diversity* of logistics-related conditions and *Dynamics* of drivers of change. The identified concepts were put in context in the graphical representation, and in this way map the research field for a structured and holistic analysis of the impact of global agri-food commodity flows on food safety. While a range of theoretical models of supply chain management aim to minimize the cost of the entire supply chain system (Liao and Widowati, 2021), the herewith developed CF presents a first model for holistically investigating logistics in terms of food safety risks.

2.5.1 The phenomenon: ABC flows

The CF gives an overview over the key actors in ABC commodity flows. Since approximately 70% to 80% of logistics operations are carried out by external actors (Schieck, 2008), it can be assumed that third-party logistics service providers also play a crucial role in global agri-food commodity flows. As companies generally are more interested in working and focusing on their core business, outsourcing logistics activities have enormously enhanced the growth of third-party logistics service providers/companies (Khan *et al.*, 2017). Logistics outsourcing has been widely adopted by organizations as it allows cost reduction and flexibility, which makes companies more competitive on the market (Zhu *et al.*, 2017). Due to the fact that different logistics services are carried out by different subcontractors, the logistics industry can hardly be grasped (Pfohl, 2010). In addition, as the global economy and trade grows, the demand of international logistical services will further increase (Göpfert and Braun, 2013). The economic growth of a country can be both the consequence of the logistics sector development and the stimulator of the logistics sector (Muslija *et al.*, 2021).

The present CF shows the (logistical) processes relevant to researching ABC flows regarding food safety. Transportation, the key factor in logistics activities, is considered one of the most vulnerable links to cross-contamination in the food chain (Ryan, 2017). This seems relevant to ABC as they are shipped in bulk and come in direct contact with the vehicle. Next to transportation, handling is a predominant logistical activity, whose importance increases with the internationalisation of agricultural industry. Handling activities are considered critical in food safety as damage, loss and adulteration can occur (Schieck, 2008). Further, storage processes can lead to port congestions when cargoes reach up to quantities that are more than the port's handling and storage capacity (Bolat *et al.*, 2020), which can have a negative impact on food safety, taking into account time as a determinant factor for food safety. Sanitation, a supplementary service in transportation process, proves to be considerably important, as adulteration and cross-contamination occur in the case of poor quality of sanitation processes (Ryan, 2017).

Corresponding to the high relevance of the transportation process within global commodity flows, the transportation mode deserves particular attention. Sea transportation represents the main run in global ABC flows and is used for longer distance, whereas rail and road transportation are used for regional transportation within the scope of pre- and onward carriage (Schieck, 2008). As part of inland transportation, road transportation is by far the dominant

transportation mode. Hence, the resulting traffic congestion, for example in the EU, leads to envisaged shifts from road freight to rail or to inland waterway transportation, which accounts for a relatively small share in overland transportation (European Commission, 2011). This policy objective faces thereby the trend of decreasing demand for rail freight by bulk shippers (Jonkeren *et al.*, 2019).

Maritime transport plays a pivotal role in international logistics chains and also represents an essential supply chain component in the world food system (Godfray *et al.*, 2011; Lim *et al.*, 2019). In terms of world trade, seaborne trade accounts up to 90% of global trade in terms of volume (tons). With a general increase in international trade, seaborne trade worldwide has grown a lot over the decades, from 500 million tons in 1950 to 10.3 billion tons in 2016 (UNCTAD, 2008, 2017). Therefore, global economic development correlates with growth of seaborne shipments (Berle *et al.*, 2011).

Maritime transport, however, is among the most important sources of uncertainty in global supply chains (Sanchez-Rodrigues *et al.*, 2010). Ports and shipping are exposed to higher risks because of rapidly changing environments (Notteboom and Siu Lee Lam, 2014), which could also have an effect on food safety. Port performance, which is strongly linked to a country's market power/economic development, has a great impact on "smooth" transportation flow (Haralambides, 2017) and can be considered another potential key factor for food safety.

Port performance requires continuous investments in port facilities due to continuous technology development, such as growing ship sizes (Ryan, 2017). Differences in port performance are reflected in port rankings (Jeschke, 2011). Whereas many developing regions are struggling with poor transport infrastructure and service impairing transportation flow (Munim and Schramm, 2018), ports of emerging countries, first of all China, are among the worldwide top 20 seaports (J. Chen *et al.*, 2019; Wahyuni *et al.*, 2020). Nevertheless, if port capacity does not keep pace with trade growth, port congestion affects transportation flow, implicating an increased risk of goods deteriorating (Balliauw *et al.*, 2020; Schieck, 2008; UNCTAD, 2008). Considering transportation routes, infrastructure constraints, such as unfavourable road surface in developing countries, are a potential limiting factor for the transportation flow, especially in connection with challenging weather conditions (C. Chen *et al.*, 2019; Ryan, 2017).

2.5.2 The context: Influential sectors

The present CF takes a holistic view on global commodity flows by integrating influential sectors in order to investigate their direct and/or indirect impact on food safety. In this regard, the present study has identified challenging logistics-related conditions with assorted characteristics and differences at country level. Transportation and food safety related legal and regulatory frameworks are among these challenging conditions. Various legislative frameworks in the transportation system (such as limits for transportation equipment) exist in different countries, making the international logistics sector highly opaque (Jeschke, 2011; Thakur and Hurburgh, 2009; Watanuki, 2015). A lack of international harmonisation of loading units due to different legislative limits for transportation equipment in different countries, for example, may represent a threat to the transportation flow (Jeschke, 2011). Further, differences in the legal framework for food safety in the logistics sector exist across countries, such as in traceability (Thakur and Hurburgh, 2009). Compared to the EU, the USA regulations are less rigorous in the field of food traceability systems and registration of food transportation entities (Ryan, 2017). Apart from that, there is a lack of international harmonisation of safety management practices (Aruoma, 2006; Handford *et al.*, 2015). The great variety of policies between countries is also a challenge for coordination among participants of global commodity flows (Rodrigue, 2017). In this context, also socio-cultural differences, expressed, for instance, by cultural misunderstandings, turn out to be another challenge (Marucheck *et al.*, 2011).

Adverse weather conditions are also critical as they do not only cause potential interruption in global commodity flows affecting the process itself. The importance of weather and climate is revealed in the direct impact on the environmental conditions (e.g. temperature, humidity) in vehicles and warehouses and consequently on food safety. Although the impact might be reduced through available temperature-controlled technique, extreme or unexpected climatic conditions have a negative impact on the supply chain (Manzini and Accorsi, 2013). Further, tropical countries have to face major challenge in this respect than countries of temperate zones. However, impairments of food safety are to be expected when crossing different climate zones, which is unavoidable, especially in maritime shipping along global commodity flows (Evans *et al.*, 2019; Schieck, 2008; Wareing *et al.*, 1993).

Next to logistics-related conditions, the present CF takes into account dynamic developments triggered by globalisation within global commodity flows for investigating ABC flows in the field of food safety. For example, ICT (Industry 4.0) is subject of permanent change and is one

of the most interesting and debated research topics for global supply chains. ICT permits information exchange that is a requirement for collaboration and better coordination and monitoring of agri-food supply chains. However, new technologies related to safety in food supply chains mainly refer to the field of traceability and monitoring of food safety and quality, which has gained considerable importance nowadays (Bouzembrak *et al.*, 2019; Folinas *et al.*, 2006; McKean, 2001; Mirabelli and Solina, 2020). Recurring food safety issues in the past indicated limitations in existing traceability tools and create incentives for constant development, also with regard to public pressure (Fearne *et al.*, 2001; Thakur and Hurburgh, 2009). In the EU food safety regulation for example, traceability is covered by recording trace-back and trace-forward data of the trading unit by all supply chain participants. However, traceability system development goes far beyond this EU obligation that is described as a "short-sighted concept" in literature (Ryan, 2017). Current traceability tools are used to achieve transparency/visibility of global supply chains at various levels. Important traceability components/objects are transportation modes (e.g. location, route), food commodities (e.g. temperature), procedure (e.g. sanitation) and environmental conditions (e.g. temperature, humidity) (Ryan, 2017). Further, information systems are being developed that aim at combining safety, sustainability and efficiency in supply chains that require integrating different data type from different data sources (Manzini and Accorsi, 2013). However, handling and analysing the resulted large-scale databases remains a challenge for most companies (Ryan, 2017).

Further, emerging technologies in terms of faster and (semi-) autonomous transportation modes, especially in road and sea transportation, are being discussed as determining factors shaping future freight transportation systems (Batalden *et al.*, 2017; Csiszár and Földes, 2018). Changing design and size of transportation modes, such as increasing ship sizes and longer and heavier trucks, serve to move larger quantities of goods and are mostly driven by cost reduction (Ryan, 2017; Valentine *et al.*, 2013). These developments mainly represent a challenge for the infrastructure (Jeschke, 2011) and have to be discussed in terms of its potential impact on food safety.

Whereas developments in technology and standards provoke primarily internal changes regarding the design and operations of supply chains (Ahumada and Villalobos, 2009), market and consumer trends additionally create shifts of global commodity flows. Consumer trends relate to consumer demand of food depending on shifts in consumption patterns, which show regional differences. In developed countries, consumers increasingly pay attention to health,

safety and quality aspects as well as sustainability of products (Borsellino *et al.*, 2020). The higher awareness and subsequent ethical requirements of Western consumers is not limited to the production but also comprises the transportation of food. Consequently, the better informed consumer requires ethical behaviour of all supply chain actors (Ahumada and Villalobos, 2009). This clearly shows the power of consumer demand shaping the future of transportation systems. The trend towards sustainable transportation modes that emerges from the environmental awareness of consumers serves as an example. For example, to reduce the port's impact on its carbon footprint, Los Angeles has forced the trucking industry to meet new environmental requirements (Ryan, 2017). Further, the trend towards sustainability leads to an increasing demand on locally produced goods that is stated in literature as "re-regionalization" of trade (Dörrenbächer *et al.*, 2021; Melgar and Burke, 2021). In contrast, the fast growing middle-class in developing and emerging countries, especially in Asia, increases import demand for consumption goods, especially of animal based products (Hansen, 2020).

To sum up, changing consumer consumption patterns manifest themselves in shifts in demand or rather demand variability (Manzini and Accorsi, 2013). Consequently, the resultant shifts in global commodity flows impose challenges and require flexibility from the logistics sector (Jeschke, 2011; Kovács and Kot, 2016). Market trends relate to growing shifts in global economy. These derive from the growing food demand in emerging countries, such as the BRIC countries (Brazil, Russia, India and China) and from an increasing trade between developing countries (South-South-trade) (Jeschke, 2011; Valentine *et al.*, 2013). Trade volumes are shifting towards these markets, implicating the expansion of new trade corridors, as between Brazil and China, and therefore the reorientation of global commodity flows (Lesnic and Crudu, 2019).

Another potential factor co-responsible for imbalances of commodity flows is the variability of transportation costs. Energy/fuel prices are important variables determining transportation costs and, consequently agricultural commodity prices and are characterised by high volatility (Taghizadeh-Hesary *et al.*, 2019). Higher oil prices or shock of energy prices are further discussed as another factor that could reverse globalisation (Rubin and Tal, 2008; Valentine *et al.*, 2013). In addition, fuel price is considered the number one factor defining the future of transportation industry. It has a broad impact on different variables, such as the design of transportation modes, the type of transported goods, selection of routes and transportation modes, which in turn have an impact on food quality and safety (Jeschke, 2011).

2.5.3 Limitations, strengths and implication of the developed CF

Apart from the identification of the main concepts, relations and the discussed current developments in the logistics of the procurement sector of ABC, the limitations of the developed CF also have to be mentioned. It should be underlined that concept identification derives from literature not always specified to ABC or even food due to the limited data availability. Therefore, general literature about international logistics or related to agricultural fresh products such as fruits and vegetables also served as a basis for concept generation. Agricultural fresh produce is treated with much more attention in food logistics literature due to its lower shelf life and the resulting higher vulnerability in food safety comparing to ABC (Manzini and Accorsi, 2013). Consequently, the identified concepts and its importance discussed above have to be reviewed in terms of its actual relevance for ABC flows.

The present CF should not be considered a complete composition of relevant concepts. Financial aspects, for example, such as transactions within the scope of trading in which (logistical) processes are embedded (Schieck, 2008), along with wholesaler, are not part of the investigation field. Along with CF building there is an uncertainty about the scope of the desired conceptual integration of the respective phenomenon. The development of concepts is based on interpretation. Different researchers might have different conceptions of the same phenomenon and may create different CFs, as conceptual analysis requires different type of thinking such as creativity, divergent thinking, comparative reasoning, integrative and logic thinking (Aven, 2018). Also, using different suitable literature and data due to availability may materialize in different results. Therefore, a CF never provides knowledge of hard facts but rather soft interpretations (Jabareen, 2009). However, here also lies the advantage of a CF: It is based on flexible conceptual terms rather than rigid theoretical factors and causal relations. This permits the possibility of modification. As a result of literature that was not available at the time the framework was first developed, the CF can be re-conceptualized and modified accordingly. This also applies to new data gained from the CF application in the field (Jabareen, 2009) and in particular to the influential sectors forming the relevant context of the study. The recording or identification of the influential sectors and respective dimensions prove to be especially difficult since the causality/relevance for both global commodity flows and food safety is hard to identify. Consequently, the concept dimension or characteristics of the influential sectors must be checked in further investigations.

In the present study we developed a CF that illustrate the main concepts regarding ABC flows, allowing to understand the complexity of logistics in the procurement and frame future research about ABC flows in the context of food safety. Generally, it provides a starting point for formulating research questions and serves as a reference for data analysis. The internal structure of the CF enables a systematic procedure: It leads to the selection of methods and helps to structure, focus and limit the collection of data. The CF helps to increase the understanding of the complex phenomenon and its context through a generic and differentiated approach. The differentiation of the phenomenon "ABC flows" and its contexts "influential sectors" in multiple consideration levels help to break up the complexity. The phenomenon "ABC flows" is divided in three aggregation levels, commonly used in logistics literature: The micro-level concerning the logistical *Processes* of the individual company, the meta-level related to the *Cooperation* between key participants and the macro-level that comprises the *Routes and Nodes,* as part of the physical infrastructure of an economy (Pfohl, 2010). Moreover, the differentiation of the influential sectors of ABC flows in two levels reflects the *Diversity* (country-related conditions) and *Dynamics* (drivers of change) and, therefore, captures the complexity of the ABC flows of the global procurement sector. Country specific differences are important subject in literature concerning international logistics (Göpfert and Braun, 2013). The concept *Driver of change* refers to trends and dynamics that are not country-related and have to be considered in the scope of globalisation.

Although the provided concepts and correspondent characteristics or dimensions seem general and abstract, they nevertheless represent a vast narrowing of the relevant data and can be used across different applications (Yin, 2013). The CF was validated through continuous exchange within the research team, by "outsiders" at intra-institutional seminars and by presenting and discussing the CF at an international conference. The next validation step was the empirical application or testing of the CF in a case study which has verified and complemented conceptual knowledge (concepts and application-oriented hypotheses) based on literature with practical/real-world experience from different stakeholders (Zupaniec *et al.*, 2021). The structure or design of the CF and the concept definitions served as a guideline for formulating interview questions used for expert interviews, which are a common method in case studies. However, the CF had to be further developed or even modified during data collection due to the openness of qualitative research. Further, as the CF is very broad/comprehensive and covers a number of elements, it always depends on the feasibility, available time, financial resources

as well as the access to experts if the CF needs to be further narrowed or priorities have to be identified for future investigation.

2.6 Conclusion

By developing a CF, the present study highlights important elements of global commodity flows/logistics in the global procurement of ABC and discusses current developments that could potentially affect food safety and therefore need to be taken into account for the empirical investigation of global commodity flows with regard to food safety. First, the CF illustrates the phenomenon "ABC flows" by differentiating three aggregation levels: *Quality and capacity* of *Routes and nodes*, *Management* of (logistical) *Key Processes* such as interim storage, handling, transportation and sanitation and the *Cooperation* between *Key Actors* such as the shipper/receiver, the freight forwarder, the logistics company and the wash station. Then, the CF underlines the importance of influential sectors of the global sourcing sector of ABC that could have a potential impact on food safety. The identified influential sectors were differentiated and presented in two categories: the *Diversity* of *Logistics-related conditions* at the country level such as *Rules and Regulations, Physical Infrastructure, Climate and Socio-cultural conditions* and the *Dynamics* of *Drivers of change* related to the globalisation process such as *Standards*, *Technology*, *Market trends* and *Consumer trends* were identified as relevant concepts for investigating food safety in ABC flows.

Since logistics - in all its complexity - has been covered only to a very limited extent in food safety research, the CF developed here represents a first conceptual and theoretical basis or reference model for a holistic and empirical investigation. The chosen differentiated perspective not only contributes to a better understanding of the complex field of global commodity flows/logistics where to date, many knowledge gaps in terms of food safety have existed in risk assessment and ERI. It also structures, delimitates and defines this new research area in a holistic manner, providing the basis for the identification of critical factors in terms of food safety in the global sourcing sector beyond the already known critical points (HACCP) in logistical processes such as transportation, handling and interim storage. The developed CF clearly shows the multifaceted nature of global commodity flows providing evidence that future research should focus on studying logistics in its complex context concerning food safety. This way, the developed CF can be seen as a contribution to reducing current uncertainties in risk assessment resulting from the globalisation of agri-food trade, especially in the field of logistics. The CF is designed to assist not only researchers but also practitioners in better understanding

the complexities of the logistics sector in terms of food safety and thus serves as an aid in dealing with complex food safety problems in the context of risk management.

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3 Publication II

Critical factors for food safety in global commodity flows with a focus on logistics – a case study on mycotoxin contamination of agri-bulk commodities

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3.1 Abstract

Logistics as the link between the different stages of the food supply chain can, due to its complexity, provide multiple opportunities for food/feed contamination along global commodity flows. Considering comprehensive international food safety regulations, such as the Regulation (EU) 2019/1381, risk assessment in the field of consumer health protection requires specific approaches determining the impact of logistics on food safety. To identify critical dimensions and corresponding critical factors for food safety in global commodity flows and map complex interactions, we conducted a case study on mycotoxin contamination of agricultural commodities. Accordingly, we interviewed 24 stakeholders directly or indirectly involved in the European and global purchasing and logistics sector of agricultural commodities. Based on the outcome of the interviews, the most relevant dimensions are *Logistical processes, Food safety measures, Human factor, Disruptions and shifts, Logistics related conditions, Cooperation, Main characteristics of the procurement sector* and *Port characteristics*. Food safety risks along global commodity flows are not solely attributable to the logistics sector per se. In particular, *Food safety measures* (e.g. Quality management and Sampling) that are not adapted to the logistics sector, as well as varying *Logistics related conditions* (e.g. Infrastructure and Standards) have proven to be major food safety challenges. By providing an overall picture of global commodity flows, the study contributes to reduce current uncertainties in risk assessment. The identified food safety challenges in the logistics sector need to be addressed holistically throughout the entire supply chain and in cooperation with food safety authorities.

Keywords: *food supply chain, food safety risks, expert interviews, globalisation*

3.2 Introduction

In the age of globalisation and increasing trade volumes, food supply chains have become longer and more complex than ever before, with drastic consequences for food safety. With the multitude and high number of actors, processes, locations and corresponding conditions, global supply chains provide more favourable opportunities for contamination of food and feed (van Asselt *et al.*, 2010). Various severe food safety incidents that have occurred on an international scale in recent decades (e.g. mad cow disease, dioxin, salmonella, E.coli) have demonstrated that contaminated food can spread faster and affect large regions. This has dramatically increased general awareness of food safety (Alemanno, 2015). In this way, globalisation has made food safety a key public health issue and has confronted the international governance of food safety with the issue of how to manage and assess food safety risks. In particular, investigations or clarification of food safety issues that have already occurred, such as E.coli in 2011, have proven challenging due to the complex interplay of many variables both outside and inside global food supply chains (Buchholz *et al.*, 2011). The knowledge gaps and uncertainties uncovered in the process lead to the consequence that health risk assessment to date is often based on incomplete information or poor data availability.

One area where a particularly large number of knowledge gaps have emerged in the context of uncertainty analyses, are the global commodity flows of food and feed and especially the global logistics sector. Consequently, to date the field of logistics is often missing in risk assessment and the question arises as to what role the logistics sector has played in past food safety events. The lack of information and data in this regard is generally reflected in the fact that in the last decades food safety improvements efforts have focused mainly on the food supply chain stages production, processing and retail - while less attention has been paid to the physical flow of goods connecting these stages (Ryan, 2017). However, it can be assumed that the complexity resulting from the high amount of the intervening and interdependent aspects of global logistics (such as involved actors, processes and logistics related conditions) contribute to a greater extent to the general complexity of global food supply chains and consequently may have an adverse effect on food safety.

Hence, the investigation of global commodity flows in terms of food safety requires a more holistic and differentiated approach. The knowledge about the Hazard Analysis Critical Control Point (HACCP) of logistics processes, which are well defined in food safety standards and guidelines in the context of quality management and which are already enough discussed in literature, is no longer sufficient. Against the background of its outstanding role throughout

global food and feed supply chains, its increasing importance with rising global trade and in view of the current knowledge gaps, global commodity flows with the focus on the logistics sector has been identified as a new research field in food safety with the aim of being integrated as an important area of consideration in risk analysis.

Due to a lack of studies, this new research field requires an explorative and pro-active approach that verifies and complements current conceptual knowledge with practical experience from different stakeholders of global commodity flows. Therefore, the goal of the present study is to analyse global logistics from a food safety perspective with the help of a conceptual framework for the identification of food safety risks in global commodity flows (Zupaniec *et al.*, 2020). The following research questions will be used to empirically investigate how the complexity of global commodity flows affects food safety:

- What are the most important critical dimensions for food safety in global commodity flows and how do they interrelate?
- What are potential challenges/weaknesses/difficulties defined as critical factors for food safety within the critical dimensions?
- Which of the identified critical dimensions and critical factors prove to be particularly important for food safety?

To answer these questions we conducted a case study on mycotoxin contamination in agri-bulk commodity flows by interviewing actors/experts directly and indirectly involved in the international logistics or procurement sector of agri-bulk commodities. This way, we aim to draw plausible conclusions about the impact of global commodity flows on food safety by better understanding complex interrelationships and potential causes of food safety risks. The present work makes a contribution to extend the risk assessment practiced so far by analysing and discussing important risk-relevant aspects from the field of global commodity flows.

3.3 Literature Review

Food safety measures in Consumer Health Protection

Against the background of serious food safety incidents, governments and the food industry have been under pressure to develop management, control and enforcement systems at every stage of the supply chain. Since the introduction of the "farm to fork" principle by the European food safety regulation (EC No 178/2002), a variety of public regulations and private sector industry standards have developed over the last 20 years (Webb, 2015). However, outbreaks of food-borne diseases or food safety issues still occur which has made the responsible food safety authorities aware that in times of globalisation, risk analysis must undergo a paradigm shift

from a "from farm to fork" focus to a more holistic view of food supply chains that requires international cooperation and information sharing (Kruse, 2015).

Within the scope of European and international risk management practices, a variety of systems, approaches and methods have been developed for the identification of emerging food safety risks at an early stage (Marvin *et al.*, 2009). On European Level, these systems are developed by the EFSA, and at the global level, by the FAO and others. These systems are based on the general assumption that beyond the critical points for food safety within the food supply chain, influential sectors, such as technology, environment and regulations, also have an impact on food safety and consequently need to be taken into account in the food monitoring process (Noteborn *et al.*, 2005). The aim of such systems is therefore to identify critical factors or drivers of change within and outside the food supply chain that potentially affect food safety and to continuously monitor relevant indicators in order to identify emerging food safety risks at an early stage. Consequently, data collection is based on a “holistic approach” or “horizon scanning” which includes a number of different qualitative methods and data sources such as literature studies, expert consultations and Delphi studies, but also quantitative methods such as analysis tools and simulation models.

Risk assessment has therefore recognized the increasing importance of global supply chains and consequently the need to expand or adapt traditional risk assessment towards new approaches and tools. This is also reflected in the new Regulation (EU) 2019/1381, which complements the general EU food law (EU Regulation No. 178/2002) with the requirement to increase transparency in the EU risk assessment process. In this context, IT-tools have already been developed in order to better analyse food safety risks along global supply chains (Weiser *et al.*, 2016). However, qualitative methods such as integrative or comprehensive concepts and approaches are also needed to support risk assessment in complex food safety cases. Conventionally, risk assessment has been confined to scientific experts with a relatively low formal input from other interested parties or stakeholders and industry in the form of commission meetings (Wentholt *et al.*, 2009). However, the knowledge gaps and uncertainties that have been uncovered call for a more pro-active system involving multiple stakeholders in assessing and clarifying food safety risks along global food supply chains as already practiced in the early risk identification process.

However, knowledge gaps regarding global commodity flows or logistics were also identified in the area of early risk identification: In case studies of mycotoxin contamination in cereal-

based supply chains, logistics as a critical factor was rated relatively high by experts. At the same time, however, it was recognized that due to the poor data situation, further studies are necessary to verify the expert's appraisal (Van der Fels-Klerx *et al.*, 2010).

Logistics in the context of food safety

Most knowledge about food safety risks in logistics exists in various standards and guidelines based on the "farm to fork" approach (e.g. GMP, QS). However, to date, literature lacks data on the impact of complex interrelationships in the logistics sectors within and outside of global commodity flows on food safety. Therefore, a specific conceptual framework based on an extensive literature review was developed in a previous study and is briefly summarized here (Zupaniec *et al.*, 2020).

When considering the logistics sector from a food safety perspective, it is primarily the physical flows of food and feed that are of concern, rather than financial and information flows. In the context of the herewith presented study, global commodity flows are defined as the spatio-temporal transformation of goods through processes such as transportation, up- and unloading. These are carried out by different logistics companies and organized by the procurement and trade sector of the food and feed industry as the customer of logistics processes. The number of parties involved in global commodity flows is continuously increasing between the raw material producer and the compound feed producer and the food industry (Baaken and Lehnen, 2015) . It can be assumed that not only the quality management of logistics service providers, but also the cooperation between the logistics company and the customer can play an important role in food safety (Marucheck *et al.*, 2011; Singh and Power, 2009). Furthermore, global commodity flows are subject to different country-specific conditions such as regulations, infrastructure and cultural conditions (Göpfert and Braun, 2013). In the course of globalisation, global commodity flows are also exposed to global changes such as market and technology development and finally to global competition, which is characterised by optimization efforts of efficiency and cost reduction (Christopher and Holweg, 2011).

3.4 Methodology

To investigate the impact of the complexity of global commodity flows on food safety and to identify the critical dimensions and factors and their interrelationships, we decided to use a case study as a research approach. When there is little literature and knowledge about a contemporary phenomenon, new insights can be gained qualitatively and empirically in the form of case studies. Case studies focus on experiential or practical knowledge in the real life

context, i.e. with special consideration of the influence of its social, political and other contexts, whereby the boundaries between phenomenon and context are not always clearly evident (Yin, 2013). Case studies are emphatic in the sense that despite prior planning, the research design evolves as the research process progresses. Case studies often refer to “how” or “why” research questions and to theoretical assumptions.

3.4.1 Rationale for case study design

We decided to investigate the impact of global commodity flows on food safety with the focus on logistics using the example of mycotoxin contamination of agricultural bulk commodities. The import of wheat, maize and soybeans from third countries into the EU takes place largely in the animal feed sector. In the present study, global commodity flows of agri-bulk were narrowed down in our consideration as follows: The focus is on all (logistical) processes after the production of agri-bulk commodities in the third country, up to the buyer (trader or feed industry) in the EU.

Undesirable substances can be transferred from feed into animal products and therefore pose a health risk to the consumer. A well-known case was feed maize contaminated with aflatoxin from Serbia, which led to maximum levels for aflatoxin in raw milk being exceeded in 2013 in other European countries (Kos *et al.*, 2014). Up to 80 % of the notifications within the framework of Quality Managements (QM) standards such as GMP+ can be traced back to agricultural raw materials. Mycotoxins, on the other hand, represent the second main reason for notification after pesticide residues (Hartog, 2017). As mycotoxins are toxic metabolites produced by certain species of mould under favourable environmental conditions (i.e. temperature and humidity) they represent a common health risk. Due to their international importance, occurrence, spread and persistence at all stages of the food supply chain, they are well suited for a holistic investigation of food safety issues along global supply chains (Van der Fels-Klerx *et al.*, 2009). By investigating global commodity flows, special attention is paid to storage mycotoxins such as aflatoxins, which are formed by certain moulds after harvesting during transport and storage and have a "transfer effect" on the animal product. Aflatoxins represent the most frequent reason for entries in the mycotoxins category in the European rapid alert system RASFF (Pigłowski, 2019).

We chose a single case taking the example of mycotoxin contamination of agri-bulk commodities. Since very little information is available regarding the interacting dimension of global commodity flows, a detailed investigation of only one case seems to be useful. We have

chosen a typical rather general situation as a single case so that conclusions can also be drawn about other comparable situations (Staake, 1994).

As already mentioned, theoretical or research guiding assumptions are necessary for conducting case studies as they form the basis for the case study design/logical plan (Yin, 2013). Their main function is therefore to select appropriate methods and to help to structure, focus and narrow down the data collection. Moreover, data analysis is guided by them. The present study is subject to the following research guiding propositions derived from a conceptual framework for the identification of critical factors in global commodity flows (Zupaniec *et al.*, 2020):

- The type and number of logistical processes and actors involved (1)
- The quality management of logistics service providers, as well as the cooperation between the different actors of global commodity flows (2)
- The quality and capacity of (infrastructure) transport routes and nodes (harbours) (3)
- Differences in country-specific logistics-relevant conditions and dynamic changes within global commodity flows (4)

… all have an influence on potential contamination of agri-bulk commodities with mycotoxins.

3.4.2 Data Collection

We chose in-depth expert interviews as data collection technique since it is the most appropriate method to gain a deep understanding and specific insights of interrelations, backgrounds and context. For this purpose, relevant data cannot be obtained from technical operating documents or archives. Data of interest are real, everyday experiences, as well as individual perceptions/perspectives, motivations and convictions of the experts. The interviewed experts have specific knowledge related to the research interest and are part of the field of action.

The expert sampling was done via deductive sampling, i.e. the selection of experts was derived from prior theoretical knowledge (Zupaniec *et al.*, 2020). Consequently, two selection criteria were used in the sampling procedure. Firstly, the interviewed expert should have knowledge and experience in at least one of the following key areas:

- International logistics in the context of global trade of agri-bulk commodities
- Global trade or procurement of agri-bulk commodities by the food/feed industry
- Food safety guidelines and standards in the area of global food and feed commodity flows

The second requirement was that the experts had basic knowledge and experience in the field of food safety or quality management. Contacting the experts was based to a large extent on the

"snowball principle", in which the first interview partners from the existing network referred other possible interview partners (Patton, 2014).

We chose the guided interview as the interview format, which was based on a semi-standardised questionnaire with about 10 guiding questions. The guided interview offers a flexible use through the possibility to adapt the sequence of questions to the course of the interview and to ask follow-up (ad-hoc) questions (Loosen, 2016). The questions referred to a large extent to challenges, barriers or potential for improvement in the following focus areas based on the research guiding propositions mentioned above: 1. Logistical processes (transport and port activities) 2. Quality management of logistics service providers 3. Cooperation between buyer (trader/feed industry) and logistics service provider and 4. Food safety guidelines, standards and controls. With the help of open questions and targeted "why"- questions, the opinions and experiences of the experts were obtained on the one hand, and on the other hand, this type of question served to learn more about the background or causes of food safety risks and thus the context of global commodity flows.

3.4.3 Conducting the interviews

The experts were first contacted either directly by telephone or by email with a background paper on the study. If accepted, the experts received a consent form, which they signed and handed over on the day of the interview or before. The interviews were recorded with a digital device, transcribed and anonymised (personal names, company names, institutions, location information: country names, city names, river names) afterwards. Further, demographic data and occupational status were surveyed with a short questionnaire, which were also anonymised and summarised for the total sample in Table 3.1. A total of 18 interviews were conducted with 24 experts, of which 14 were individual interviews and the remaining 4 interviews consisted of a conversations with 2-3 experts. All interviews were conducted by the same person from the research team between August 2019 and December 2019 and had an average length of 57 minutes.

Table 3.1: Description of the sample of a total of 24 experts from 18 interviews (n= number of experts). Of the 18 interviews, 14 were conducted face to face on site, 3 by phone and 1 by Skype.

Gender	n	Age (years)	n	Job Experience (years)	n	Position	n	Workplace	n
Female	**5**	*30-39*	**3**	*3-7*	**1**	*Secretary General*	**1**	*Germany*	**11**
Male	**19**	*40-49*	**8**	*7-15*	**6**	*Policy Officer Legislation*	**1**	*Belgium*	**4**
		50-60	**10**	*>15*	**17**	*Managing director*	**8**	*Netherland*	**3**
		>60	**3**			*Middle Management*	**9**	*France*	**2**
						Technical Advisor	**4**	*Spain*	**2**
								Italy	**1**
								South Africa	**1**

The experts were divided into four different groups of actors, which are shown in **Figure 3.1**. The chart shows the number of interviews and experts per stakeholder group and from which sector/area of activity they come. Three different questionnaires were developed with overlapping topics but a different focus (Guideline A = External controls, standards, regulations; B= Logistical processes, port activities; C= Cooperation). As trade and logistics are closely linked, representatives of these sectors/actors groups have received the same questionnaire.

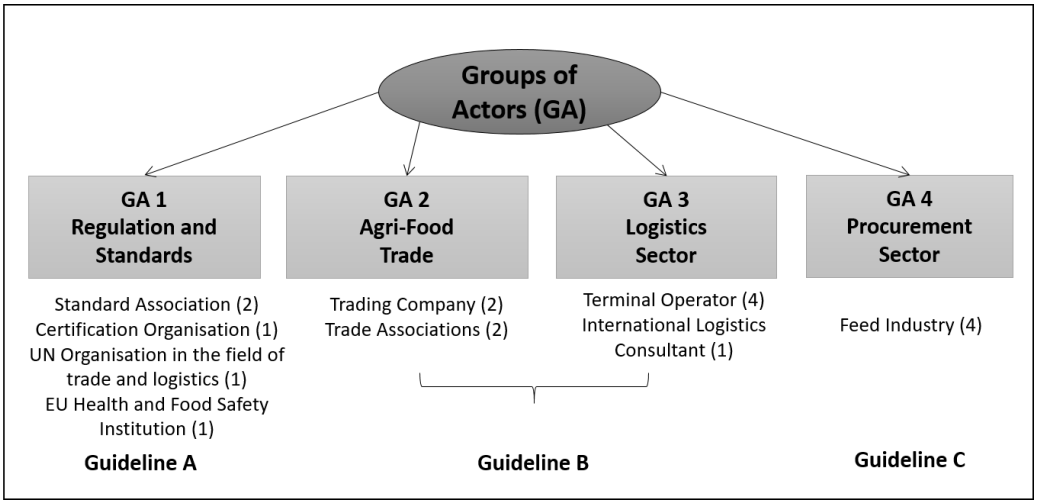

Figure 3.1: Segregation of the experts into four groups of actors (GA), job affiliation and number of interviews (n)

3.4.4 Data Analysis

The interviews were analysed by one person of the research team by Qualitative content analysis, which involves the coding of the transcribed interviews. Parts of the text are thus ordered according to certain criteria and described by categories (Mayring, 2004). The development of such a category system is aimed at reducing the complexity of the material. The data point in the same direction, i.e. no complete matching or consistency of data is required

within a category. For example, parts of the text were coded to the same category if they contained a relevant aspect, which a.) has been explained, b.) has been related to another relevant aspect, c.) has been critically evaluated in the food safety context. The coding unit (the smallest text segment that can be coded) represented a statement/sentence. The formation of categories followed both a deductive and inductive process. This means that the categorisation was based on the above mentioned theoretical assumptions and at the same time a lot of new information collected through the open questions led to new assumptions and corresponding categories.

The logic used to link the data collected to the propositions or research questions was based on pattern matching. Pattern matching consists of comparing empirically based patterns in the collected data with a predicted pattern or propositions in order to confirm or disprove the assumption and develop additional new assumptions. Further, rival explanations were used as criteria for interpretation. This implies that the systematic search for alternative, plausible explanations/interpretation/views by a different organisation/categorisation of the data determines the way in which knowledge is gained. Both pattern matching and rival explanations strengthens internal validity as important quality criteria for case studies (Yin, 2013).

We used *MAXQDA* as Computer-Assisted/Aided Qualitative Data Analysis software (CAQDAS) to support category building and data analysis. The transcribed and anonymised interviews and audio files were stored in an interview database. In addition to the raw data, MAXQDA was able to store interview protocols and maintain a continuous research diary ("memo writing"). With the help of *MAXQDA*, the collected data could be well organised and the entire research process documented, so that the chain of evidence can be traced from the research questions to the present case study report, which increases the reliability of the present study (Yin, 2013).

3.5 Results

Based on the outcome of the expert interviews, eight key dimensions of global commodity flows were found to be the most relevant for mycotoxin contamination/food safety: *Logistical processes, Food safety measures, Human factor, Disruptions and shifts, Logistics related conditions, Cooperation, Main characteristics of the procurement sector* and *Port characteristics*. Further, we identified critical factors for mycotoxin contamination/food safety

for each dimension. While all identified critical factors are summarised in an overview table (see Appendix, Table 3.2), the most relevant are addressed in this section.

By using the "Code Co-occurrence Model" in MAXQDA, which records and visualizes the overlapping or common occurrence of codes, the identified key dimensions were put into context. The graphical outcome of the relative impact relationships between the key dimensions is presented in Figure 3.2. It shows the complex interaction between all identified dimensions, its different relationships (different line thickness) as well as the code frequency for each critical dimension. According to the code frequency, data analysis revealed some critical dimensions and factors to be more relevant in the present case study**.** In the following, the most important dimensions will be addressed by looking closer at the identified factors and related relationships.

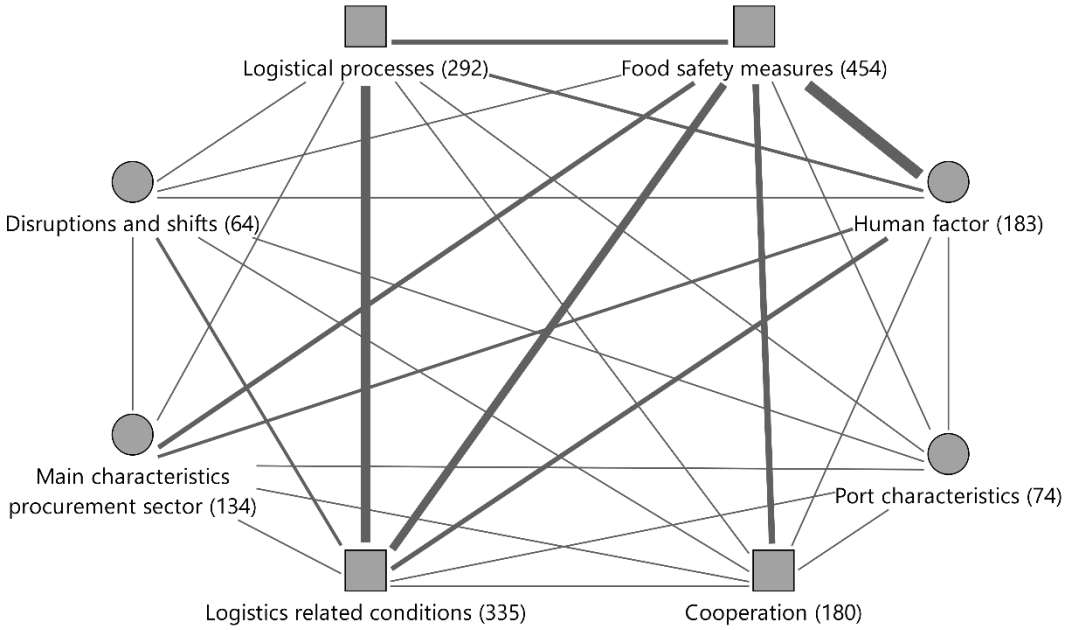

Figure 3.2: Graphical representation of the relative influence relationships between the identified critical dimensions. Thickness of the lines is proportional to the influence of the dimension considered, e.g. the strong correlation between Human factor and Food safety measures indicates that for example Human factors (e.g. mentality and diligence) have a great impact on the implementation of food safety measures (e.g. QM Management). Frequency of coded segments of each dimension is indicated in the parenthesis (n).

3.5.1 Food Safety Measures

Food safety measures show the most frequent mention of critical factors (Figure 3.2). This implies that the interviewed experts consider the food safety measures *Quality Management (QM) of Logistics companies, Sampling and Analysis*, *External Controls* and *Traceability* (see Annex, Table 3.2) required by EU food safety policy and applied along global agri-bulk commodity as critical for food safety due to their current weaknesses. Figure 3.3 shows that

among these critical food safety measures, the *QM of Logistics company* represents the biggest challenge for ensuring food safety. Although the EU "farm to fork"-principle states that logistics companies – as part of the food supply chain – are obliged to carry out their own controls within the scope of a quality management system, the present study revealed that in practice – and especially in a global context – whether a logistics company can establish a QM system depends on a number of factors.

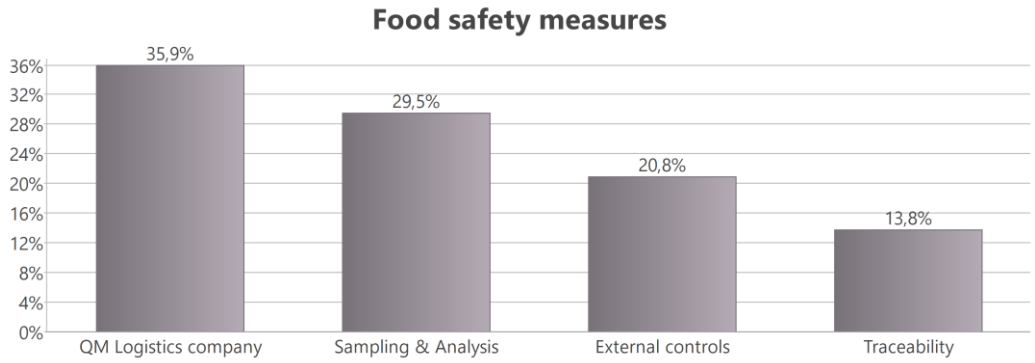

Figure 3.3: Share of the mention (=coded segments; total code frequency n=454) of sub areas within the dimension "Food Safety Measures" by the interviewed experts.

These factors are to a large extent mutually dependent: whether a QM system is introduced or a trained quality manager or even a quality department is in place depends on the financial and human resources, which are often related to the size of the company and consequently on the degree of internationalisation (see Annex, Table 3.2). However, many experts state that the way in which QM is implemented is more important for food safety than whether or not a QM system is in place. Here the human aspect comes into play *(→Human factor)*. Figure 3.4 shows the division of the dimension *Human factor* into the identified critical factors (see Annex, Table 3.2). The number of mentions of the critical factors by the interviewees reflects both their relevance for food safety and their relevance for the different actors involved, such as logistics companies, the feed industry, authorities and inspection bodies. In this context, especially the high mention of *Mentality* and *Diligence* (which are mutually dependent) with regard to logistics companies, indicates their respective influence on the quality level of the implemented QM of logistics companies. The lack of integrity of logistics companies can be mainly attributed to the economic pressures and lack of incentives. On the other hand, the lack of knowledge and awareness for food safety as well as experience are rather related to the low attractiveness in the sector due to difficult working conditions and low payment resulting in high labour turnover and relatively lower education level *(→ Main characteristics of procurement sector)*.

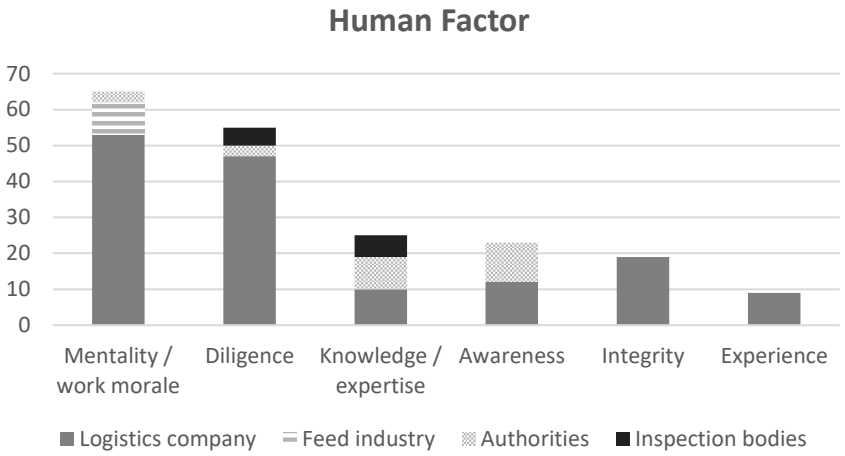

Figure 3.4: Number of mention (=coded segments; total code frequency n=183) of critical factors in the dimension "Human Factor" by the interviewed experts and respective relevance for different actors

However, the results show that socio-cultural conditions have a great influence on the human factor, so there are major country-specific differences here *(→ Logistics related conditions)*. Furthermore, Figure 3.3 illustrates that *Sampling* of agri-bulk commodities during logistical processes and the *Analysis* of samples assigned by the owner or buyer of the goods (here: trader or feed industry) represent the next major challenge for ensuring food safety along global commodity flows according to the experts (see Annex, Table 3.2). At first the sampling frequency of a trading unit has to be considered critically as it determines to a large extent whether and how much contamination is found. The sampling plan is based on a risk assessment which however, poses a challenge to the buyer as it relies on the access of background information of a country, such as crop production and storage conditions (e.g. weather) and analytical results of goods originating from the respective country. In addition, against the background of low margins in the trade/procurement sector of bulk agricultural commodities, high sampling costs can have a reducing effect on sampling frequency *(→ Main characteristic of procurement sector)*.

However, variations of analytical results of a trading unit due to different analytical methods between North-west European countries and supplier countries have not only a disconcerting effect on the participants, but must be viewed critically in view of the low margins due to the costs of multiple testing. Further, long wait for the analysis results and the lack of quick tests (e.g. ergot alkaloids) are considered by the experts as not compatible with the overall time pressure that characterises global commodity flows, especially at ports. In the worst case, waiting for analysis results can lead to two extreme events: It can obstruct or even stop processes, such as a vessel having to wait several days under favourable conditions for

mycotoxins at the export port before it can leave *(→ Disruptions and shifts*). On the other hand, due to scheduled delivery times that must be met, the analysis results are available when the goods have already been processed in the feed industry or even fed to livestock. Furthermore, demanding and different infrastructural conditions (such as large flat stores, silos and bulk carriers, different handling systems) make a correct and representative sampling of mycotoxins, which are a challenge due to hotspot building, even more difficult *(→ Logistics related conditions: Infrastructure*).

External controls carried out by authorities or private control bodies also show weaknesses according to the experts. With regard to authority controls, different types of official border control (from no controls, to risk-oriented, to overall controls), different control frequencies and costs within the EU are seen as an impeding factor for commodity flows, as well as the differences in handling food safety issue and corresponding consequences for the actors involved even within a country. On the other hand, the lack of understanding/awareness of the authorities (see Figure 3.4 *Human factor*) regarding the role of logistics in food safety is reflected in the control gaps for example in terms of sanitation of discharging facilities and truck compartments. With regard to inspection bodies, the results show that the biggest challenge is to find accredited or certified inspection bodies around the world.

Finally, the greatest weakness in traceability, as the last critical food safety measure identified in this study, is the current gaps along global agri-bulk commodity. In a low-margin sector, for reasons of efficiency, consolidation (mixing) of agri-bulk commodities from different countries in the export port and commingled storage in the EU port takes place, with the result that traceability back to the producer of the agri-bulk goods or even to the country of origin cannot be guaranteed neither in third countries nor in the EU *(→ Main characteristics of procurement sector)*.

3.5.2 Logistics related conditions

Global commodity flows are embedded in *Logistics related conditions* that represent one of the most important critical dimension for food safety/mycotoxin contamination (Figure 3.2). Figure 3.5 shows the breakdown of *Logistics related conditions* into eight identified influential areas in terms of their importance for food safety. Here we can differentiate between Influential areas that show country or world region-specific differences, such as *Infrastructure, Regulations, Weather, Socio-cultural conditions*, and *Political conditions* as well as influential

areas that can be interpreted as global drivers such as *Market conditions*, *Technology* and *Standards*.

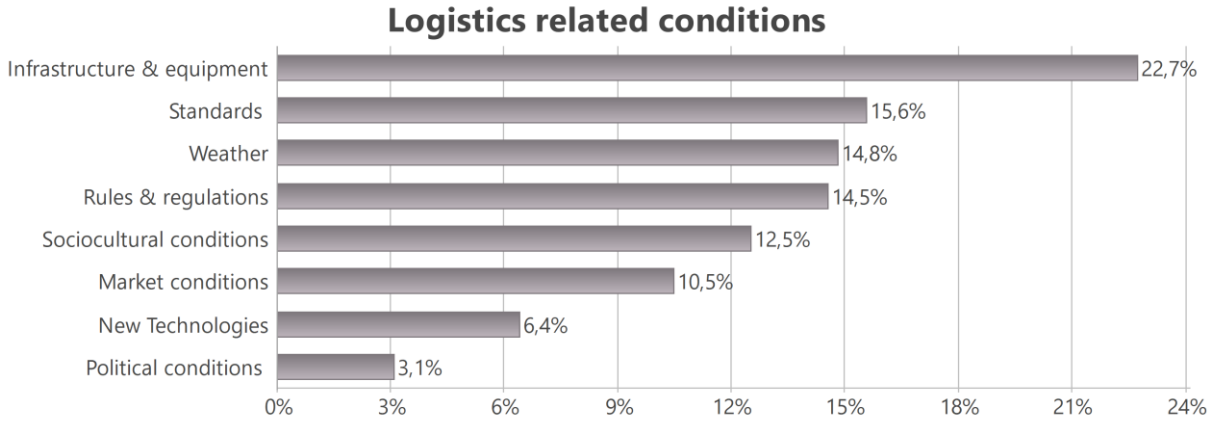

Figure 3.5: Share of the mention (=coded segments; total code frequency n=335) of the sub-areas (influential areas in the dimension „Logistic related conditions“) by the interviewed experts.

Although infrastructure proves to be the most critical Influential area, *Rules and regulations* (14,5%) and *Standards* (15,6%), which together make up the international food safety regulatory framework, are even the most important influential area. Here, the stated lack of harmonisation manifests itself in the diversity of food safety regulations (such as different Maximum Limits (ML) for mycotoxins), as well as the variety and high amount of standards, even within the EU. According to the experts, this constitutes a major barrier to international trade that creates uncertainty among the actors involved and consequently can have a disruptive effect on global commodity flows. In addition to diversity, we identified gaps or inaccuracies in food safety standards and regulations regarding important aspects such as sanitation of transportation modes and handling equipment, that are however relevant for food safety. This is reflected in control gaps of food safety authorities, for instance in the field of preload in trucks or cleanness of handling equipment. On the other hand, inaccuracies in standards regarding sanitation of truck compartments triggers uncertainty among the participants and leads to the fact that “*everyone can do what they want*” (E2). This weakness is related to the limited efficiency of standards. Hence, many experts consider that they do not cover or influence one of the most important factors in QM, such as the way in which QM is implemented, which is directly linked to the mentality and behaviour of logistics companies, as mentioned above.

With regard to the second most important area of influence, *Infrastructure and equipment*, the results indicate that a wide range of types and qualities of logistics infrastructure are used in global commodity flows, which can vary from region to region, from country to country, but also within a country. The type and quality level of infrastructure mainly affects the logistics

processes having a decisive influence on important mycotoxin-relevant parameters: The type of handling equipment (elevators/ enclosed conveyor belts vs trucks) for instance, has an effect on the duration (discharging rate) of the handling processes and on the environmental conditions. The type of storage facilities (flat storage vs. silos) has an impact on bird infestation and weather related environmental conditions. Furthermore, holes/leakages in truck compartments and bulk carriers (water tightness hatches of sea vessels) can lead to rain/water infiltration that favours mould contamination. Further, there are huge differences between the quality of ventilation systems of sea vessels/bulk carriers: from modern ventilation systems to no ventilation at all during sea transportation. Finally, the factor of availability of an adequate and sufficient infrastructure along global commodity flows must be considered. Especially in the event of market fluctuations or dynamic shifts of commodity flows that lead to an increased demand in a certain supplier country, logistical bottlenecks can occur. This can include having to use storages that do not meet minimum standards or time delays due to insufficient roads.

Weather does not only play a decisive role for mycotoxin contamination during logistical processes, but it is closely linked to market conditions or fluctuations that are responsible for shifts of global commodity flows. Climate determines to a large extent harvest quantity/conditions that control market prices and consequently worldwide demand or flows of agri-bulk commodities. Changing *Political climate* (such as the election of a new president, export restrictions) or even trade wars/conflicts between countries also impacts the international flow of agri-bulk commodities. Dynamic shifts not only affects the availability of infrastructure, but also the storage time of agri-bulk commodities at the port and the behaviour of logistics companies and buyers. While the changing origins of agri-bulk may pose challenges for buyers in their risk assessment of new supplier countries and partners/suppliers, the QM of logistics companies suffers from too much stress or too little work. Apart from that, the results show that there are huge country- or word region- specific differences in the way QM is implemented by logistics companies. Here, different *Socio-cultural conditions*, especially cultural differences that are reflected in the mentality, play the most important role.

Finally, the relatively low mention of *Technology* (6,4%) reflects the opinion of many experts, that there is still a very limited use of new technologies in the logistics sector that could enhance food safety. In practice, new technologies, such as block chain technology and its improving effect on traceability, sampling innovations (e.g. near-infrared, real-time data) and innovations in the field of monitoring of environmental conditions during storage and transportation (e.g. early warning sensors) do not yet play a role in the broad application.

3.5.3 Logistical Processes

Logistical processes include the sub-areas *Interim storage at ports*, *Up- and unloading* and *Transportation* (road and sea transportation). As data analysis revealed the multiple mention of critical factors in the different logistical processes, the most important critical factors are presented in an aggregated form in Figure 3.6. Accordingly, *Time* or the duration of logistical processes was the most frequently cited critical factor related to mycotoxin contamination of agri-bulk commodities, although it was mentioned in large part in combination with the critical factors *Weather and Infrastructure (→ Logistics related conditions*).

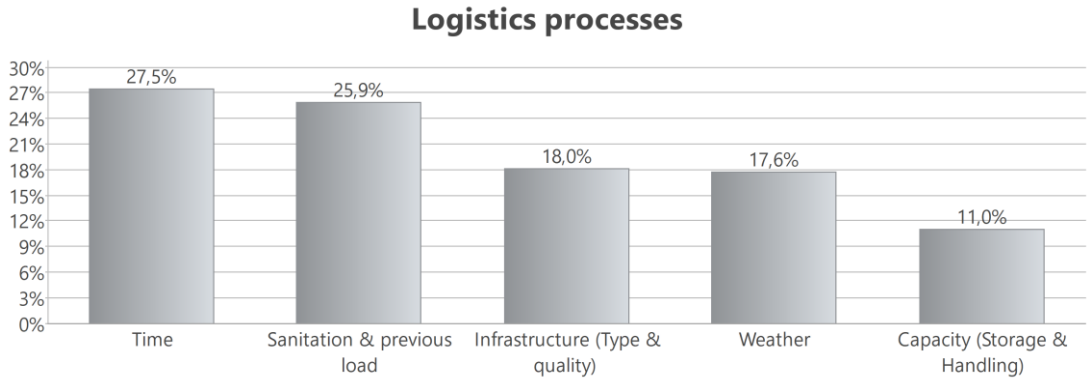

Figure 3.6: Share of the mention (=coded segments; total code frequency n=292) of aggregated critical factors in the dimension „Logistics processes" by the interviewed experts.

Firstly, this applies in particular to sea transportation. Most experts agree that mycotoxin contamination may occur during sea transportation as the duration of regular transportation in combination with comparatively unfavourable environmental conditions inside the bulk vessel due to poor infrastructure (e.g. shortcomings in the ventilation, leakages of hatches) and varying conditions outside (e.g. change of climate, storms) can lead to condensation inside the bulk carrier which promotes mould contamination. Further, as the business interest of terminal operators is a high rotation of handled goods, ports are generally not prepared for longer storage periods in terms of equipment and expertise. Consequently, the time of interim storage at ports is considered critical in two respects: when the goods are unloaded in rainy conditions or delivered already humid from sea transportation and additionally are unloaded by trucks than by covered conveyor belts. The duration of handling processes is also of importance concerning mycotoxin contamination: the faster the up-/unloading process, depending on technical equipment and the volume quantity, the shorter the goods stay in unfavourable conditions of the bulk carrier. Accordingly, large volumes in combination with poor handling equipment, have a negative effect on time and thus promote on mycotoxin contamination. However, in

practice especially rainy conditions may be responsible for the fact that the handling processes has to be delayed in the absence of closed handling systems to the disadvantage of food safety. Next, *Sanitation* of handling equipment and transportation modes as an important element of a logistics company's QM is proving to be a one of the major challenge in practice according to the frequent mention of this critical factor by the experts. This applies in particular to the inadequate cleaning of truck compartments in accordance with the preload that may lead to unhygienic conditions and increase the risk of to cross-contamination. Finally, the *Handling and storage capacity* of a port is also evaluated as critical for food safety by the experts. In times of high demand, when storage capacity is limited due to the spatial limitations of ports, different goods/products can be stored without separation for reasons of efficiency, with negative effects on traceability (→ *Foods safety measures*) and with the risk of cross-contamination. On the other hand, a high import rate combined with a low handling capacity can lead to goods staying longer in bulk carriers under unfavourable conditions, if either long queues of bulk carriers exist in front of the port or seagoing vessels are used as a flexible storage facility.

3.5.4 Cooperation

Finally, the results show that *Cooperation* between the buyer (here: trader or feed industry) and the logistics company must also be considered a critical dimension in terms of food safety in global commodity flows. Figure 3.7 illustrates the outstanding role of the buyer that determines the *Power balance* between the buyer and the logistics company with potential consequences for food safety. First of all, as the owner of the goods, the buyer carries responsibility for the safety of the product and that all actors downstream comply with EU food safety regulations, which requires corresponding measures. With regard to food safety, the buyer determines quality and safety specification, draws up a sampling plan within the framework of its HACCP plan, arranges for samples to be taken at the place of origin and along global agri-bulk commodity flows by inspection bodies and in case of the feed industry, takes reserve samples during the acceptance check.

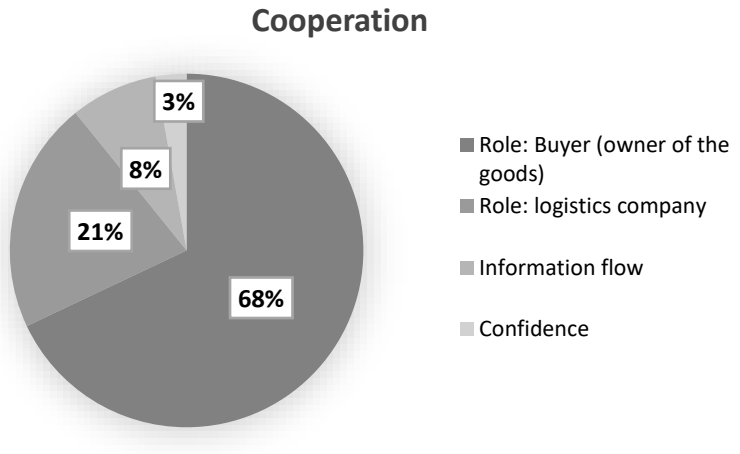

Figure 3.7: Proportion/share of the mention (=coded segments; total frequency n=180) by the interviewees for the sub- areas of the dimension „Cooperation“ illustrating the dominant role of the buyer that is relatively more relevant for food safety than the issues of “information flow” and “confidence”.

Consequently, the buyer, as the owner of the goods, is in a position to redirect commodity flows or knock the goods, if for example they exceed the allowed Maximum Limit (ML) for contamination. On the other hand, the buyer checks his suppliers/logistics service providers through his own and commissioned audits by inspection bodies and carries out supplier evaluations. In summary, the buyer's task is to assess the risks associated with the product and the supplier/service provider as part of their HACCP plan and at the same time to promote the QM of logistics service providers, e.g. through training or strict requirements. Secondly, as a customer the buyer decides not only on the type (type of transport means, type of storage facilities), but also on the quality of logistics service. Theoretically this means that the buyer has the possibility to choose between a bandwidth of logistics providers in terms of their QM. In practice, it depends on the buyer’s willingness to pay more, their financial resources, market prices of agri-bulk commodities and ultimately on the availability of logistics companies with good QM that is not always guaranteed in the event of dynamic shifts of global commodity flows. Similarly, the buyer can choose to work with the “right” inspection body, but here too it is a challenge to find accredited/certified inspection body around the world. Finally, the cargo owner decides on the conditions during the logistic processes that are relevant for a potential mycotoxin contamination. The buyer determines for example the storage conditions and takes the key decision whether to unload a bulk vessel in rainy conditions or not. Finally, the cargo owner decides how long the goods will be temporarily stored at the port, which also depends on the market conditions.

In contrast, logistics companies carry out the buyer's instructions. Their main task is to keep the goods from A to B in the same quality which includes keeping the agreed storage and transport

conditions by control measures within the framework of their QM. Product control is limited to visual inspection only. This illustrates that the logistics company who is closest to the goods and therefore can directly uncover discrepancies regarding food safety, is strongly limited in his actions by the existing power balance to the buyer. In summary, the results clearly show that the performance of the logistics company with regard to food safety always depends to a considerable extent on the buyer's attitude and actions.

3.6 Discussion

By investigating the case of potential mycotoxin contamination of agri-bulk commodities along global commodity flows, we were able to identify eight critical dimensions for food safety (*Food safety Measures, Logistical processes, Human factor, Disruptions and shifts, Logistics related conditions, Cooperation, Main characteristics of the procurement sector and Port characteristics*) and corresponding critical factors inside and outside global commodity flows. Furthermore, we have identified and visualised interrelationships between these dimensions and shown which dimensions and critical factors tend to be more important in the context of food safety. The close and complex interconnectedness of the different dimensions of global commodity flows shows very clearly that potential food safety threats and risks along global commodity flows are not solely attributable to the logistics sector *per se* and the associated actors and processes involved. Rather, the *Food safety measures* and *Logistics related conditions* that vary from country to country as well as the *Cooperation* between the buyer and logistics company have proven to be a major challenge for food safety along global commodity flows.

Among the *Food safety measures* that have to be applied along the global commodity flows according to the EU food safety regulation, we have found that QM of logistics companies is one of the biggest challenges. This is not striking against the background of the general assessment that the management factor causes up to 85% of quality and food safety issues or concerns (Ryan, 2017). The CODEX Alimentarius Commission CAC highlights that the implementation of HACCP food safety management system and an overall risk-based management of food safety /quality remains very challenging along the whole food chain (Codex Alimentarius Commission, 2016). In the present study, we have found plausible explanations for the logistical part of global agri-bulk commodity flows. Global commodity flows, which largely consist of logistics and trade, are generally characterised by strong competition (Christopher and Holweg, 2011). As a low margin sector, this applies in particular to the procurement of agri-bulk commodities as exemplified by one of the experts: *"When we*

are talking about huge globally traded commodities such as wheat, corn, soybean meals, and so forth - then we are talking about mass markets where margins are generally always very low and eventually even not existing" (E.7). Consequently, efficiency and effectivity constitute the major targets in the cooperation between trading partners and the coordination of logistical processes with the result that commodity flows as part of global supply chains are as a matter of principle not designed in agreement with risk evaluation and risk assessment (Manzini and Accorsi, 2013).

In addition to economic pressures, time pressure and spatial capacity limits also encourage the pursuit of efficiency in this sector. In this context, ports, as the most important hubs, are the focus of attention. Here, the efficiency factor can affect food safety in two ways: If port capacity does not keep pace with trade growth or export-import rates due to lack of efficiency, ports may become congested, leading to an increased risk of deterioration in the quality and safety of goods (Schieck, 2008). In this case, the transportation flow is impaired, which may result in agri-bulk having to remain in the bulk ship under unfavourable conditions for a longer period, as this study has confirmed. On the other hand, for efficiency reasons, the separation of different qualities and risk categories at the import harbour remains a challenge due to the general spatial limitations in ports. Therefore, extended port storage must be viewed critically for food safety. The situation is similar at the export port at the beginning of global agri-bulk commodity flows: In order to reduce transport costs and maximise profit, it is also necessary to combine/mix agricultural goods of different origin and different quality before sea transportation.

In general, global competition forces traders and procurers from the feed and food industry to buy at low prices on the world market, taking risks or trying to manage them through risk assessments when sourcing from distant countries. For the same reason, traders or procurers often do not choose the "safest option" when selecting logistics companies. On the contrary, savings are often made at the logistics company, the last link in the chain, especially during "crisis conditions" such as high market fluctuations. Additional services and more transparency in terms of quality and safety, which are associated with additional expenses for the logistics provider, are therefore less in demand and accordingly not honoured by the customer. In this regard, the claim expressed by one of the experts that *"logistics companies who are transparent should be rewarded by the industry for their transparency, for their openness"*(E.2) seems justified. Consequently, due to the low demand/orders, additional services with regard to food safety are even accompanied by potential economic losses for the logistics company. This transfer of economic pressure from the trader or procurer to the logistics company often leads

to the logistics company limiting his QM in order to make any profit at all. These prevailing economic circumstances have a direct impact on the attitude and behaviour of logistics providers with regard to food safety. The statement *"I think the biggest risk [for food safety] is the human factor"* (E.5) confirms the finding of the present study identifying the *Human factor* as an important critical dimension for food safety.

This reflects the importance of the way the QM is implemented. According to the GMP standard, a reliable QM system requires pro-active action, which is expressed in a series of preventive measures (Hartog, 2017). The lack of incentives for prevention can be seen as a reason why, despite the various QM and certification systems already in place, logistics processes remain a challenge in terms of quality assurance. However, the present study also shows that there are considerable differences between countries in terms of QM implementation, which is related to a different understanding of quality in the individual countries. This should be a particular focus of attention in international trade (Baaken and Lehnen, 2015) . On the other hand, the economically challenging conditions often lead to the fact that especially small logistics companies that do not meet the requirements and drop out or that not all participants in the chain are certified. With a high number of actors, as is often the case with global commodity flows, the latter can quickly lead to a lack of transparency or chain fragmentation. In terms of food safety, this is seen as a challenge, as "*the whole chain is as strong as the weakest link*" (E.1).

However, in the course of globalisation there is a trend towards chain integration as an opposing development with respect to chain fragmentation. The focus here is on global corporations that may own an entire supply chain and, according to the experts, dispose of a very good QM systems. Moreover, they are generally better positioned in terms of infrastructure and technology and transfer such capacities, as well as the understanding of quality, to emerging and developing countries as *"the more integrated the chain is, the more important the quality becomes"* (E.10). Nevertheless, as competition intensifies, the need for companies to use supply chain integration practices will increase, requiring a flexible organizational structure (Porter, 2019). In general however, there is a common lethargy in the logistics sector with regard to investments in the latest technologies that are relevant for food safety (e.g. block chain technology, sampling technology). The low relevance of technology is reflected in the low frequency of mentioning in this study. The fact that new technologies, in particular of the Industry 4.0 (e.g. block chain) require financial resources that a large part of the logistics industry does not have, once again illustrates the economic pressure on the logistics sector. In

addition to the cost factor, the lack of initiative from top management, the unwillingness of stakeholders to accept change and to share data, and insufficient interoperability between partner systems may be other reasons why the use of these technologies is scant (de Vass et al., 2021).

The explanations demonstrate very well that under the current system the logistics sector can neither be held solely responsible for food safety risks nor is it capable of independently ensuring the socially desired level of food safety. Besides the economic pressure, this is also reflected by the power balance between buyer and logistics companies. Statements like "*This can only be solved as a whole sector*" (E.13) and "*we need to work and team up together*" (E.16) illustrate that the problem can only be solved integratively as an entire supply chain/industry. It should be considered whether the value of food safety as a co-determining element for pricing could provide incentives to invest more in corresponding measures and technology. In this context, a higher willingness of consumers to pay more for the product would have a positive effect regarding food safety on the entire chain.

Furthermore, it is the international food safety governance and the resulting food safety measures applied along global agri-bulk commodity flows themselves which, due to current weaknesses, pose an indirect threat to food safety (or mycotoxin contamination). This is supported by the results to the extent that, *Regulations* and *Standards* in the dimension *Logistics related Conditions* represent a greater challenge for food safety according to the code frequency than, for example, *Infrastructure* or *Weather*. In particular, the frequently cited great variety and quantity of regulations and standards play a key role, which in the literature is also referred to as the "fragmentation of the multilateral international food safety regime" (Alemanno, 2015). Since 2000 with the paradigm shift in European food safety regulations, the standards for food safety and quality have grown immensely, with the result of a great variety of safety management practices (Aruoma, 2006). Besides the multilateral organizations like FAO, WHO and OIE, the private setting industry and plenty of NGOs have dedicated themselves to the field of food safety standards. On the other hand, the lack of harmonisation at the level of national regulations is shown by the fact that mycotoxins, especially aflatoxins, are differently regulated in approximately 100 countries in terms of the maximum levels (ML) (van Egmond and Jonker, 2004).

The different sets of rules and standards as well as the amount of standards beyond food safety, such as sustainability and GMO-free standards, pose a challenge for the coordination between

the participants in global commodity flows (van der Vorst *et al.*, 2009). The consequences are far-reaching and can manifest themselves by interruptions of commodity flows and an increased uncertainty of comprehension among participants. This may explain a certain weariness by some experts: *"But they all have their own level and they all want to be unique. It would be good if there were a few less [standards] that would save a lot of cost […] I think it would also reduce the risk, if something goes wrong. [..] by so many schemes, a lot of time is wasted on understanding where the differences are"* (E.16). Even in the literature it is mentioned that the current lack of harmonisation of a global international food system can be blamed for food safety accidents (Alemanno, 2015). This has triggered an ongoing debate over the establishment of a global food safety regime in order to overcome the current institutional fragmentation. In addition to the fragmentation, it is also stated that the current global food safety system appears to be incomplete and presents several gaps (Alemanno, 2015). The present study confirmed current gaps for instance in the field of sanitation/cleaning of truck compartments, where inaccuracies lead to the fact that "*everyone can do what he wants because no one is also off the mark, because nothing is defined"*(E.2).

In this context, the study has shown that there are no uniform and precisely defined food safety practices in the logistics sector required by standards or regulations, neither globally, EU-wide nor nationally. Consequently, it is up to the client of logistics services that *"ultimately determines what happens and what does not happen"* (E.18), e.g. the feed industry, to enforce precise quality and safety requirements at the logistics company they work with, which is perceived as burdensome task by some experts. Consequently, the present study emphasizes the importance of harmonizing regulations and standards in order to avoid disruptions in global commodity flows that could affect food safety and has uncovered gaps and inaccuracies in food safety standards and regulations related to the logistics sector, which are however relevant to food safety. In the long term, it would therefore be advisable not only to revise the standards with a view to harmonisation, but also to fill in the gaps with greater precision in order to achieve greater clarity and certainty for participants on the one hand and greater transparency in the food safety practice (e.g. sanitation) on the other.

Furthermore, the study has revealed that *Food safety measures* and corresponding requirements in their current form are not adapted to the complexities of global agri-bulk commodity flows, which poses a challenge to the participants and thus indirectly a risk to food safety. According to the results, it is above all the area of *Sampling and Analysis*, which represents one of the greater concerns in terms of mycotoxin contamination/food safety. It is well known that the

heterogeneous distribution or hot-spot formation of mycotoxin production makes representative sampling a major challenge, which is further complicated by the large quantities of agri-bulk and by the difficult and varying infrastructural conditions at harbours and in bulk vessels. In addition to this heterogeneity, the study showed that different analysis methods applied along global commodity flows can also lead to a variability of the analysis results within a lot and at different stages of the commodity flow. In this context, the WHO confirms that laboratory capacities outside Europe are less advanced and surveillance systems less developed (World Health Organization WHO, 2015). Against this background, it proves difficult to meet the desired requirement to transport and store uniform agri-bulk regarding its risk category which is based on analytical results. In fact, due to the challenges mentioned above, different qualities are often mixed together at the export port and sampled afterwards.

Finally, the high sampling costs in a sector with very low margins can lead to a lower sampling frequency, which can also have a negative impact on food safety. However, the frequency with which the factor *Sampling and Analysis* is mentioned in connection with global commodity flows indicates that further studies should take a closer look at this. At the institutional level, the problem of different analytical methods has already been recognised. Efforts are being made by food safety authorities to improve the comparability of the analysis methods and their results, with the aim of further harmonisation. There is also a need to understand and quantify sampling uncertainties under varying conditions of mycotoxin contamination in cereal shipment (Bourgeois and Lyman, 2012). For the practice in global commodity flows research, advances in sampling and analysis could mean less sampling costs, more precise sample plans, more security when mixing agri-bulk from different origins to certain risk categories at the export harbour as well as better adaptation of suitable transportation conditions on the bulk vessels.

Another frequently mentioned food safety measure that is not adapted to the real conditions of global agri-bulk commodity flows is *Traceability*, which as an EU obligation requires recording of trace-back and trace-forward data of the trading unit by all supply chain participants. However, the study demonstrates that traceability is difficult to implement especially in two points of global commodity flows: at consolidation at the export harbour and at commingled storage in the import harbour. In order to maximise profit, grain storage bins for instance can contain grain from many different sources with the consequence that the identity of the lot is not preserved (Thakur and Hurburgh, 2009). In this context, efforts in the field of analysing the authenticity/origin of feed stuff by fingerprint technology especially in the field of agri-bulk commodities, can be very useful (Achten *et al.*, 2019). Apart from this, traceability as covered

by EU food safety regulation has been evaluated in literature as a short-sighted concept (Ryan, 2017). Therefore, in addition to the traceability of the trading unit, other important aspects would have to be traced. Current development of traceability tools move in the direction to achieve transparency/visibility of global supply chains at various levels such as transportation modes (e.g. location, route), parameters of food commodities (e.g. temperature), procedures (e.g. sanitation) and environmental conditions during logistical processes (e.g. temperature, humidity) (Ryan, 2017). Moreover, information systems are being developed that aim at combining safety, sustainability and efficiency in supply chains that require integrating different data type from different data sources (Manzini and Accorsi, 2013). In general, in the area of traceability, blockchain seems to be the most promising and applicable technology. But other potential applications are also seen in standards compliance and supply chain integration (Batwa and Norrman, 2020).

Further, the study revealed weaknesses in official authority controls in the logistics sector reflecting the gaps identified in food safety regulations mentioned above. As a result, in practice there are fewer authority controls in logistical areas important for food safety, such as the type of sanitation or the quality condition of transportation modes. These control gaps lead to the assumption that food safety authorities often have a lack of understanding of the importance of logistics for food safety. The reason can be seen in an expert's statement that logistics "*is, or always has been, a very opaque industry*" (E.2). The lack of knowledge and understanding is also reflected in new regulations and respective requirements, e.g. in the field of modified mycotoxins. On the one hand, modified or "masked" mycotoxins represent an emerging issue which needs to be addressed as they can lead to underestimation of the mycotoxin content of commodities due to analytical overlooking (Nakagawa, 2016). On the other hand, rapid and affordable tests for masked mycotoxins are still lacking, which many experts consider impractical as it can hinder the flow of agricultural commodities and also increases economic pressure in the industry. This highlights the problem all the more that new requirements are decided on by authorities where little knowledge of real-life practice prevails. The challenge is therefore to establish new regulations and corresponding requirements that can be linked to practice without creating an additional "burden" for the participants.

In summary, it is important to question and adapt current food safety measures and requirements with regard to their practicability, so that they do not impede global commodity flows and significantly reduce efficiency. Consequently, this would increase the acceptance and willingness of the stakeholders involved to take food safety measures. For this purpose,

feedback from the economic operators is important, i.e. food safety authorities must cooperate more closely with the trade and logistics industry, especially when new regulations are imposed. As long as there are no fundamental changes in this regard, the question arises whether the identified weaknesses in the area of regulations and standards and resulting food safety measures, which are also seen as a risk to food safety, need to be integrated into current systems of risk assessment or early risk identification. However, more studies are needed in this area to verify these results.

Limitations of the study

The sample size of 18 interviews with 24 experts is rather limited for generalizability or representativity. The aim of the study was therefore to show tendencies and plausible causal relationships and explanations. However, the study has revealed differences in perception and even contradictions between the experts. The different roles of the interviewed experts have an influence on the perception and depending on the point in the flow of goods from which they act, they see the weak points somewhere else. This shows how important it is to survey different groups of actors in a complex sector such as logistics and trade. Further actors of interest could be customs or independent inspection bodies as well as further logistics actors such as transportation companies (e.g. road transportation, sea vessels). The sometimes large discrepancy in perception or the lack of consensus among the experts can be seen both as a legitimisation for the research field and as an argument for further research.

The qualitatively determined risk for food safety along global commodity flows in the present case study must be evaluated under two caveats. First, the influence of global commodity flows, especially logistics, on mycotoxin contamination of agri-bulk commodities must be considered in relation to the other supply chain stages, such as primary production and processing, in order to counteract a distorted perception of risk. Much research on the development of management or prevention tools for mycotoxin contamination is conducted in the area of crop production and post-harvest techniques / storage; however limited research was conducted in the field of the logistics sector to date.

Another caveat regarding the interpretation of the results refers to the fact that several experts hold additional knowledge and experience in food sector areas other than agri-bulk commodities, e.g. fruits and vegetable and not all experts consulted, especially from the field of logistics, had sound knowledge about mycotoxins. Therefore, the questions had to be asked

in a general food safety context and, finally, the identified critical factors may not be limited to the case of mycotoxin contamination of agri-bulk commodities.

Further, the identified context factors (such as cooperation, main characteristics of procurement sector) have a general influence on food safety and not only on mycotoxins. In addition, based on the expertise and experience of some experts in the food sector, the actual relevance of the identified critical factors for mycotoxins and agri-bulk for feed use should be verified in further studies. Moreover, it would also be advisable to narrow down the topic in further studies to focus on individual aspects.

3.7 Conclusion

A first explorative or empirical look into the complex and opaque area of logistics within global commodity flows from a food safety perspective has been conducted by interviewing various experts from the European and global procurement and logistics sector of agri-bulk commodities that include actors form trade, logistics, the feed industry as well as from the field of regulations and standards on the case of mycotoxin contamination of agricultural raw materials. The present study uncovered trends for relevant critical dimensions and factors for mycotoxin contamination and food safety risks in general along global commodity flows and provide plausible correlations and explanations or backgrounds for this. In this way, the study has demonstrated that, due to the close interconnection of logistics with the trade and the feed industry (2) as well as with its different environments, logistics cannot be considered separately in terms of food safety.

In addition to the already assumed critical factors for food safety in logistics processes, it is above all the food safety measures (such as *Quality Management* of the logistics company, *Sampling and analysis*, *External controls* and *Traceability*) not adapted to practice and varying *Logistics related conditions* in global commodity flows that pose a challenge to food safety (4). Further, we have found that the conditions prevailing in the trade and logistics sector, such as competitive pressure, time pressure and low margins, are in conflict with food safety requirements, which not only cost time and money (e.g., sampling), but also fail to deliver the expected efficiency due to a number of gaps (e.g., sanitation and traceability) and irregularities (e.g., diverse analytical methods and regulations). In particular, economic pressure combined with difficult working conditions resulting in a high fluctuation of workers in the logistics sector as well as varying socio-cultural conditions influence human factors such as mentality and diligence which can have a negative impact on the implementation of QM. The strong economic

pressure further leads to a general inertia in the logistics and trade sector to invest in the latest technologies (e.g., Block chain) that could influence food safety in a positive way. Furthermore, the interaction with complex logistics related conditions, which are characterised by a great variety of regulations, standards and of the type and quality of infrastructure on the one hand and dynamics, especially market fluctuations, on the other, can have a disruptive effect on global commodity flows (3, 4).

The fact that the sector is highly fragmented and complex can be seen not only in the diversity of the logistics related conditions, but also in the divergent statements of the experts regarding the certification and level of QM of logistics service providers. The case study therefore makes no claim as for the representativeness of the data or even an evaluation/ranking of the critical dimensions and factors determined. Instead, it highlights the importance to improve knowledge in this field of research. The case study will support further studies by providing potential relevant dimensions and factors critical for food safety along global commodity flows. The frequency and variance of the data should be interpreted as an indication that individual dimensions or critical factors should be investigated and further verified inclusive of quantitative studies. In the long term, current approaches to risk assessment and early risk identification, including innovative models and tools that analyse complex supply chains are to be supplemented by elements from the area of global commodity flows. In conclusion, the study can be seen as a pioneering work since the topic still has a lot of undiscovered research potential.

3.8 Acknowledgment

One of the major plus point of the case study was the great willingness of the experts to cooperate, their competence, openness, time and wealth of experience. In addition, the output could be increased enormously by an open and friendly discussion atmosphere and the possibility to conduct the majority of the interviews personally on site. Special thanks are due to the organizations COCERAL, UNISTOCK EUROPE, FEFAC and ENFIT, who contributed to a large extent to the success of the study through their helpfulness, their expertise and their mediation to experts.

3.9 Annex

Table 3.2: Identified critical dimensions, sub-areas and factors for mycotoxin contamination and food safety risks in global agri-bulk commodity flows with the focus on logistics.

Sub areas of Critical Dimension	Critical Factor
Logistical Processes	
Interim Storage at ports	• **Storage time:** Ports are generally not specialised (equipment, expertise) for longer storage periods • **Storage capacity:** Due to spatial limitations, problematic in time of big demands • **Type of storage facilities:** Flat storage (warehouse) has to face more challenges (animals, leakages) than vertical storage (silo). • **Monitoring / control:** Critical especially at longer storage • **Commingled storage:** No separation of different products may take place for efficiency reasons. • **Ventilation**: Not always guaranteed and critical at longer storage
Up – and unloading	• **Time:** In extended cases, goods remain in sea vessel under unfavourable conditions. • **Discharging facilities**: Covered belt systems are better than trucks concerning moisture damage. • **Weather:** Rainy conditions delay loading and cause damage of the goods by moisture. • **Hatches (open/closed)**: Speed at which the ship's hatches close under rainy conditions is relevant for preventing moisture damage. • **Different products**: In busy times, the same equipment can be used for different products. • **Speed of grain falling** correlates with the height of the handling cranes and may lead to grain damage • **Infrastructure of handling systems**: Open handling systems rely on weather • **Sanitation:** Using same discharging facilities for different products without sanitation • **Pier un-/ uploading:** Ground contact over the pier (footbridge)
Transportation - Truck	• **Sanitation:** Critical if not carried out according to the preload (cross-contamination) • **Driver:** Critical in terms of behaviour, education and food safety awareness • **Registrations**: No official registrations of truck companies (esp. food industry) • **Cover of the trucks:** No covering of the trucks under rainy conditions (esp. third countries) • **Time:** Critical when transportation takes longer than three days due to bigger distances (esp. third countries) • **Poor maintenance**: Moisture ingress in case of leakage (e.g. through cracks)
Transportation – Sea vessels	• **Time:** Critical at several weeks if not ventilated • **Poor maintenance of hatches:** Water entering the holds due to leakages • **Weather and climatic changes** increase risk of condensation inside bulk carriers. • **Ventilation**: Poor ventilation systems up to no ventilation • **Sanitation**: Proper cleaning of sea vessels is challenging due to infrastructure. • **Training**: Good training of the crew, e.g. in terms of proper ventilation • **Monitoring**: Challenge in controlling environmental conditions (e.g. temperature)
Food Safety Measures	
Sampling & Analysis	• **Sampling frequency**: Sampling plan depending on a country's risk category and sampling costs • **Analytical methods**: Diversity of analytical methods and high incertitude • **Availability of accredited labs**: Challenge in finding accredited labs all over the world • **Analytical results**: Duration and variation of analytical results • **Quick tests:** Lack of reliable quick tests (e.g. Ergot alkaloids, masked mycotoxins) • **Analysis at origin:** Important to gain information on quality/safety of the product to adjust transportation conditions and to mix goods of similar quality • **Representative sampling**: Problematic due to the mass of goods, challenging infrastructure (silos, flat stores, bulk carriers) and the heterogeneous distribution of mycotoxins (nest formation)
QM Logistics Company	• **Company size**: The smaller a company, the fewer resources it normally has. • **Internationalisation** correlates with the company size, i.e. international companies are more flexible due to more resources. • **Training and updates:** Proper Training and regular updates on changes in standards, regulations

	• **Investments**: Lack of investments, e.g. in technology (traceability), transportation mode • **Quality manager:** Quality manager / department at place often correlates with company size.
Traceability	• **Gaps**: No identification of the country of origin nor the raw material producer • **Consolidation:** Mixing goods of different qualities and origins at the export harbour • **Commingled storage:** Mixing of goods of different qualities and origins at the import harbour • **High flow rate** in silos • **Technology**: Lack of technological support, e.g. integrated systems • **Certification:** Traceability is linked to certification. Not all actors involved are certified. • **Costs:** Accurate and complete traceability of agricultural commodities increase costs. • **Time**: Traceability is only possible within a certain period of time.
External Controls	***Inspection body*** • **Availability:** Challenge in worldwide availability of accredited/certified IBs • **Gatekeeper:** Challenges in ensuring food safety by a gatekeeper in third countries without a QM system in place ***Authorities*** • **Differences** in management of food/feed safety risks within a country, type of control, in control frequency and in control costs
Human Factor	
	• **Mentality**: Work morale of actors directly (buyer, logistics company) and indirectly (control authorities) involved • **Behaviour**: Diligent behaviour by actors directly (logistics company) or indirectly (e.g. inspectors/control authorities) involved • **Expertise**: Technical knowledge of actors directly (logistics company) and indirectly (control authorities) involved • **Awareness** of the relevance of logistics processes in the context of food safety of actors directly (logistics company) and indirectly (control authorities) involved • **Integrity:** Non-transparent behaviour of logistics companies, usually economically motivated • **Lack of experience:** Experience is needed for a careful implementation of the high quality/safety requirements in the logistics sector.
Disruptions and shifts	
	• Shifts in commodity flows, i.e. change in the country of origin are associated with new risks and require a high degree of flexibility and adaptability of the actors involved. • Disruptions in global commodity flows can lead to uncertainties among the actors involved and time delays or break of chains (e.g. port congestions).
Logistics related conditions	
Infrastructure and equipment	• **Varying type and quality level** of infrastructure (e.g. port infrastructure, means of transport, facilities) depending on factors such as maintenance and resources • **Varying availability** of infrastructure (e.g. means of transport, roads (esp. in third Countries), storage facilities)
Rules and regulations	• **Lack of harmonization** in food safety regulations (e.g. Maximum limits for contaminants (ML) or GMOs) • **Impracticability:** Difficult implementation of food safety requirements (e.g. in the field of new ML, masked mycotoxins) • **Imprecision/gaps:** Inaccuracies (e.g. type of sanitation) and/or lack of consideration of logistics in EU food safety laws/regulations • **Lack of food safety regulations**: In certain regions of the world, resulting in a lack of controls, also in trade and logistics
Weather	• **Rainy conditions:** During logistical processes (storage, up-/unloading, transportation) in connection with poor infrastructure and / or maintenance • **Climate change** leads to shifts in production regions and consequently to shifts in global commodity flows. • **Weather conditions** influence product temperature during loading.
Standards	• **Diversity and amount:** Diversity of quality/safety standards and amount of additional standards (e.g. sustainability) • **Imprecision/gaps:** Inaccuracies (e.g. sanitation) and/or lack of consideration of important aspects of logistics, e.g. logistics activities in export countries • **Lack of effectiveness/reliability:** Food safety standards do not cover / influence day-to-day business, e.g. way of working.

Market conditions	• **Market fluctuations**: Depending on regional harvest conditions (quality/quantity); can affect the course of commodity flows and the behaviour of logistics companies (e.g. less attention to food safety due to stress situation) and trader (e.g. choice of logistics companies). • **Consumer trends**: Divergent /dynamic trends (veganism / sustainability vs. increase in world population and meat demand) lead to uncertainties and disruptions.
(New) Technologies	• **Block chain**: Low use of Block chain to improve traceability or information flow through faster processing of "big data" • **Sampling**: Low use of sampling innovations (e.g. near-infrared, real-time) • **Monitoring**: Low use of innovations in the field of monitoring of temperature and humidity (e.g. early warning sensors)
Sociocultural conditions	• **Cultural differences** in mentality between countries affect the behaviour of the (logistics) actors involved (e.g. diligent handling of port infrastructure). • **Education:** Differences in the education of logistics companies between countries due to different training landscape; lower education level in logistics compared to other sectors • **Language**: Lack of language skills of the logistics companies (e.g. truck driver) can lead to problems in complying with national regulations.
Political conditions	• **Political climate:** Political instability, new policies (e.g. new president), BREXIT can lead to shifts in trade and logistics sector (e.g. export tariffs/restrictions). • **Trade war:** Conflicts between trading partners on market price developments resulting in shifts of commodity flows and changes in logistical demand/availability
Cooperation	
	• **Information flows:** Challenge in transparent communication and data interchange in terms of food safety, such as variation of analytical results; logistical and organisational challenge in the transfer of analytical certificate and ownership. • **Confidence:** Long term relationships between supplier and buyer result in more confidence and less control. **Role of the buyer** • **Power balance** in favour of the buyer gives him great influence: e.g. quality / safety specification, conditions of logistical processes, storage time, redirection of commodity flows and logistics options (ports, logistics company). • **Responsibility** for food quality/safety and corresponding measures: e.g. sampling (plan), handling of contaminated products, risk assessment (supplier/origin evaluation), and controls/audits: e.g. acceptance check by feed industry. **Role of the Logistics Company** • **Responsibility** for maintenance of agreed storage and transportation conditions through control measures (e.g. sanitation, preload) in the scope of QM • **No food safety control / decision:** Responsibility in terms of food safety is limited to visual checks. No power concerning decision taking in challenging conditions during logistical processes (e.g. discharging by rain) • **Lack of knowledge**: Little or no knowledge about the conditions of the goods in the exporting country (quality, handling, storage)
Main characteristics of the procurement sector	
	• **Chain fragmentation**: Complexity and lack of transparency due to a large number of actors, not all certified and due to different practices • **Negative image:** Low attractiveness of the logistics sector due to difficult working conditions resulting in high labour turnover, lack of junior staff, low education level • **Competitive pressure**: Choosing the safest option in terms of logistics often means no longer being competitive on the market as trader / feed industry. • **Low margins** in the procurement/trading of agricultural raw materials conflict with costly food safety requirements. • **Lack of economic incentive** for logistics companies to invest more in the quality and safety of logistics processes. • **Economic pressure:** Cost reduction/effectivity is necessary for survival in the logistics sector; saving money is more important than quality/safety assurance.
Port characteristics	
	• **Time pressure**: As berthing of bulk carriers at ports is associated with high costs, a speedy handling of port processes is desirable but may produce stress situations. • **Port animals:** Due to the proximity to the sea, ports are home to more animals (mainly birds) which can be a source of contamination. • **Port / handling capacity**: Direct effect on the speed of handling. Port congestion usually results in queues of ships where goods stay longer under unfavourable conditions for food safety.

	• **Hygienic condition:** Varying hygiene conditions of port areas depending on street cleaning in a country • **Investments** in port infrastructure depends on factors such as political, economic and social climate in a country as well as on port administration. • **Availability of stevedores:** Limited number of workers when fast handling of port processes is required • **Port competition / image**: Certain features of a port can lead to a port being called at or not, which has a direct impact on the flow of goods. • **Transhipment:** Direct/short loading from a large to a smaller vessel with less contact points; no interim storage. Not possible in every port. • **Administration** plays an important role for a smooth and rapid handling of port processes. • **Distribution network**: If there is not enough storage capacity, goods have to be transported directly after handling which requires a good distribution network (e.g. channels, railway).

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4 Discussion

The present study demonstrated that an investigation of logistics in terms of food safety should not be limited to the process level (HACCP), as it is embedded in a complex and interdependent environment that can influence food safety in different ways. First, a conceptual framework (CF) for identifying critical factors in global commodity flows of agricultural commodities was developed based on a comprehensive literature review. With the help of the differentiation of the phenomenon "global commodity flows" into different levels of aggregation and the identification of concepts, the complexity was broken down, and thus, the research field was defined. Likewise, application-oriented theories were derived from the CF regarding possible interaction and interrelationships. Together with the concepts, these formed the basis for implementing a case study. With the case study on mycotoxin contamination in agri-bulk commodity flows, it was possible to identify critical dimensions and corresponding factors, recognise complex interrelationships and uncover background factors that have a decisive influence on food safety in the logistics sector.

We have found that food safety-relevant interactions or (inter-) dependencies take place not only - as already assumed in the CF - with a.) logistics-relevant conditions, which vary from country to country and are subject to dynamic developments, but also b.) within the supply chain in the form of dependencies on the customer and strong competitive pressure and c.) with the requirements/food safety measures posed by food safety authorities. This way, the present thesis contributed to filling the knowledge gaps regarding the interactions and dynamics within logistics and its surroundings and its influence on food safety.

4.1 Interactions between logistics with its complex environment

Against the background of the complexity of logistics and the resulting need for a holistic approach, a CF was developed that considers and illustrates logistics in its complex environment. Its context was differentiated into contextual factors, such as dynamic global drivers as well as country-specific conditions. However, due to the poor data situation/lack of literature, it was not clear what significance the context has for food safety, i.e. whether and to what extent the respective context factors influence food safety in the logistics sector. While the CF allowed us to make assumptions about possible effects or interrelations, the expert study - based on the CF - enabled us to gain new insights and identify trends (by frequency of mention) in which contextual factors of the logistics sector play a more significant and which a lesser role in food safety.

In this regard, the frequent mention of food safety standards and regulations demonstrated their particular role in the logistics sector for food safety. According to the experts, the great variety and quantity of food safety standards and regulations create uncertainty among the actors involved. Consequently, they can have a disruptive effect on global commodity flows and a negative impact on food safety. This can also be interpreted as a confirmation of what has been already described in the literature: the current lack of harmonisation of food safety standards and regulations can even be "blamed" for food safety accidents (Alemanno, 2015). In addition, the case study revealed that standards are often incomplete or imprecise, especially in one of the most critical areas for food safety, namely sanitation. The scope for interpretation resulting from the gaps often leads to a lack of transparency in the logistics industry or undesirable behaviour of logistics service providers in their QM. Therefore, the case study results could not only confirm the ongoing international debate over the establishment of a global food safety regime to overcome the current institutional fragmentation. The study also showed the importance of filling the existing gaps with greater precision to achieve more clarity and certainty for participants on the one hand and more transparency in food safety practices (e.g. sanitation) on the other.

Apart from that, the number and diversity of standards beyond food safety pose an additional challenge for the coordination between the participants in global commodity flows (van der Vorst *et al.*, 2009). For example, sustainability and GMO-free standards have also become increasingly important in recent years to which players in the food industry must operate. From the importance and attention that standards and regulations have received in the case study and literature, it is evident that private standards are highly influential as they cover large parts of the respective industry. Although private standards and corresponding certification are voluntary, they have become indispensable in supplying the food and feed industry (Theuvsen, 2010).

Another important finding of the study is that the global infrastructural framework has to be considered when investigating logistics in terms of food safety (which was first identified in the CF in the present study). With the help of the case study, we have found that there are considerable differences in the type, quality and availability of the global logistics infrastructure (e.g. port infrastructure, means of transport, handling and storage facilities) that influence food safety along global commodity flows. Here, differences between Western countries and developing or even emerging countries become apparent, e.g., the availability of roads and quality of storage facilities (e.g. lack of ventilation) and transport modes (e.g. covering of the

trucks). In the transport sector, we can refer to "performance" in this context, which is hugely different on the continents due to very different natural (climate, surface form, water network) as well as economic development of the states (Göpfert and Braun, 2013; Woitschützke, 2006). However, the study also clearly showed that there are differences not only between world regions but also from country to country and even within a country. Especially in the case of strong demand, logistical bottlenecks can occur in any country, even economically highly developed ones, with the consequence that facilities have to be used (e.g. storage in bulk vessels) that do not meet food safety requirements.

Despite the still firm heterogeneity in infrastructural conditions, globalisation is at the same time leading to a gradual worldwide adjustment or unification of the quality of infrastructure, which can be seen as a favourable development in terms of food safety. First, this is achieved in the course of global trade by adapting standards, specifications and regulatory guidelines in infrastructure to Western standards. Second, by expanding global corporations that dispose of advanced infrastructure and strict QM systems and transfer them to emerging and developing countries. Third, Chinese investments in infrastructure in developing countries are playing an increasingly important role. Africa is a particular target for Chinese investment (Yang *et al.*, 2020). They have not only modernised the port facility in Mombasa and upgraded 500 kilometres of road to Nairobi. In northern Kenya, with the help of the state-owned China Communication Construction Company, they are also planning Africa's largest port and an exposed Southeast African infrastructure project (Ombaba *et al.*, 2012).

Another important finding of the case study is that technology was given low importance in terms of food safety. While the literature in the field of logistics/supply chain management is very much concerned with the latest technology developments (Industry 4.0: e.g. Blockchain, Big Data Analytics, Internet of Things IoT), the case study has shown that these currently play hardly any or subordinate role in practice for agricultural commodities and consequently for food safety. Whereas mainly large corporations have access to the latest technology due to their financial capacities, the largest share of the logistics sector is denied access to this kind of technology. The minor importance of technology was reflected in the low frequency of mentioning by the experts. However, in combination with the HACCP system, blockchain technology, for example, would lead to real-time food tracing and build up a safety control system (Tian, 2018). However, this would be of great importance, especially in the case of agricultural bulk commodities mixed from different sources at the port, so that traceability back to the origin is no longer possible. Consequently, the challenge described in the literature,

handling and analysing large-scale databases, often related to the latest technologies (Ryan, 2017), is less relevant in the agricultural commodities' logistics/trading sector. The striking discrepancy between the exorbitant share of technology in the supply chain/logistics literature and its actual importance in practice in the agricultural commodity sector has several reasons, which are explained in more detail below.

Another interesting learning is that - contrary to expectations - disruptions and shifts in global commodity flows caused by market fluctuations, for example, do not pose a major challenge to ensuring food safety in the agricultural commodity sector in practice. In this context, however, it is important to mention that the interviews were conducted from August to December 2019, i.e. shortly before the outbreak of the global Covid-19 pandemic. According to the German Farmers' Association DBV, due to the economic consequences of the Corona pandemic, EU exports have plummeted by 11% and EU imports in the agricultural and food sector by 13% (DBV, 2021). The Covid-19 pandemic has therefore created massive disruptions in the food system, from farm to fork. At the logistical level, the disruption of global commodity flows has taken place through ports and border closures, resulting in food security risks in Asia and the Pacific (Kim *et al.*, 2020). One consequence of port closures was seen, for example, in prolonged storage of agricultural products in unfavourable conditions (e.g., in ships), which ultimately leads to deterioration/waste of agricultural products (Oelofse, 2020). The importance of ports is also reflected in the case study results, where ports and their characteristics were identified as one of the most important critical dimensions for food safety. Administration, availability of stevedores and handling capacities are critical factors in ports that play a crucial role in the smooth and rapid handling of port processes, which become even more critical during a pandemic.

The present thesis has shown that considering the context or environment of logistics is indispensable in investigating food safety since the logistics sector is exposed to much more different and dynamic conditions due to cross-border activities compared to the production and processing sector. Furthermore, through the empirical investigation in the case study, it was also possible to establish tendencies in which conditions play a greater role in practice, which can be seen as a significant advance in knowledge. However, the Covid-19 pandemic has shown that the respective importance of each contextual factor may vary depending on global developments or events. It has also demonstrated how important it will be in the future to deal with global commodity flows, especially with ports as critical infrastructure, not only from a food safety but also from a food security perspective. Therefore, it is of enormous importance

to have sufficient knowledge of vulnerabilities and critical factors in global commodity flows to be able to act more quickly in such an event, thus minimising food waste and ensuring the supply of sufficient and safe food.

However, the tendencies discovered in the case study through frequency mentions should not be equated with an evaluation of the experts. Due to the high amount of identified critical factors, the next step should consist of a ranking procedure performed by an expert group using defined criteria to identify the most important critical factors by using a weighting system. The subsequent identification of related indicators and information sources for the selected critical factors in monitoring purposes is a common practice in developed approaches for ERI in the food sector (Marvin *et al.*, 2009; van Asselt *et al.*, 2010). However, this kind of approach bears several limitations which would also apply to the logistics sector: Especially the quality and accessibility of information sources seem problematic as experience showed that sometimes the necessary information on a crucial indicator might be confidential and not open for public use (van der Fels-Klerx *et al.*, 2008). It is further criticised that such procedures are time and resource consuming concerning data collection and interpretation as no automated approach is yet in place with the consequence that a consistent weighting or ranking of critical factors or indicators is not applied (EFSA *et al.*, 2018b; FAO, 2013a; Marvin *et al.*, 2009).

4.2 Interactions between supply chain actors and influence of competitive pressure on food safety in the logistics sector

The second important advance in knowledge is that the dependency of the customer (trade or feed industry) and the exposure to competitive pressure may have a negative effect on ensuring food safety in the logistics sector. In developing the CF, it was already assumed that the cooperation between actors along the supply chain must play an essential role in food safety. The case study has concluded that the power relation favouring the cargo owner (trader/feed industry) in particular has a significant influence on whether and to what extent the logistics company implements food safety measures. The cargo owner also decides on the conditions during the logistic processes; for example, he takes the key decision whether to unload a bulk vessel in rainy conditions or not. This means that the logistics service provider's hands are often tied, even though he is closest to the product and could better assess the consequences for food safety. Since the logistics company is not the deciding but the executing force, it is not held accountable for food safety incidents. This could be one reason why logistics has not yet been in the spotlight in international food safety issues, with the result that the area of logistics has

been "forgotten" in food safety research or generally given less consideration in the inspections/work of food safety authorities, which will be discussed later.

Further, this study was able to show that in a low-margin sector such as agricultural commodity sourcing, the societal value of food safety is actually at odds with the economic value of competition. In order to make any profit at all, traders and procurers try to save money, especially on the logistics service provider. The situation even worsens under crisis conditions, e.g. strong market fluctuations. This means that there are no incentives for logistics service providers to offer additional services in terms of quality and safety associated with additional costs for the customer/buyer, as this is simply not required and accordingly not rewarded. On the contrary, the study showed that the strong economic pressure is transferred by the trader or the food/feed industry to the logistics industry, forcing many logistics service providers to cut corners on QM to make their profits. In practice, due to financial constraints, many predominantly small logistics companies have no QM and are not certified, accordingly. On the one hand, this contributes to the feeling that the logistics sector is non-transparent; on the other hand, it also poses a risk to food safety, as implementing the HACCP concept and traceability cannot be guaranteed.

In addition, the low wages and poor working conditions prevalent in the logistics sector contribute to a high turnover of workers, which has a negative impact on food safety behaviour and awareness. In addition to financial constraints, one of the main barriers to effective implementation of food safety management systems is limited human resources, such as insufficient knowledge, awareness and skills (Fotopoulos *et al.*, 2009; Panisello and Quantick, 2001). Accordingly, the case study results confirm that the *Human factor*, which was identified as one of eight critical dimensions, plays a decisive role in whether and how food safety measures are implemented in the logistics sector. The study was thus able to prove that, as in other areas of research and life, the human factor appears to be the most crucial factor in food safety (Marušić, 2011).

However, the challenges posed by globalisation and increasing social pressure are placing demands on the logistics sector that many logistics companies can no longer meet. In addition to product safety, high demands are placed on the logistics industry in terms of increased efficiency, which is to be achieved, for example, through the use of new technologies. Moreover, greater sustainability is to be reflected in fair wages and lower CO2 emissions concerning climate change (McKinnon *et al.*, 2015). The uncertainties caused by the dynamic

developments in global agricultural trade also demand a high degree of flexibility from logistics service providers, which large companies, in particular, can meet. The further integration of the global and European market and the associated demand for cross-border transport services is another reason why the logistics sector is undergoing a progressive concentration on a few (larger) logistics service providers (Pfohl, 2010). On the one hand, this makes the logistics sector more manageable. It can be assumed that the value of food safety is better implemented by larger companies with more resources, according to the experts surveyed. On the other hand, the crowding out of small companies contradicts the value of sustainability, which shows that not all social values can be achieved equally.

The identification of correlations, backgrounds and future developments regarding food safety in the logistics sector could only be uncovered with the help of practical experience in the form of a case study and represents one of the crucial findings of the present study. We have found why well-intentioned food safety measures such as QM are difficult to implement in practice and which adjusting screws should be turned in order to achieve an improvement: Since there is intense competitive pressure in a low-margin sector such as agricultural commodities, and the logistics company is highly dependent on the customer regarding food safety, the problem can only be solved integratively as an entire supply chain/industry. On a political level, more incentives could be created, for example, to increase the attractiveness of the logistics sector through better pay/minimum wage and/or to build up and expand the technical know-how in the logistics sector in terms of food safety in cooperation with stakeholders from research, industry, and the public sector (Schodl and Eitler, 2020). However, due to the global interconnectedness in the logistics sector, it is not enough for this to be implemented only in individual or a few countries. Instead, the necessary changes in the logistics sector need to take place at the international level, which has only gradually been initiated by the globalisation process and its actors.

4.3 Interactions of logistics with food safety measures

Finally, the biggest revelation of the study is that food safety measures - elaborated at the level of food safety authorities - in their current form are not adapted to the complexities of global agri-bulk commodity flows, which causes uncertainties among the participants and thus indirectly a risk to food safety. It is a general challenge for governments to ensure that the food safety measures applied effectively assure food quality and safety at all levels of the food chain (Orriss and Whitehead, 2000). Here we have shown that this claim for the effectiveness of food safety measures cannot be met in practice in the case of agri-bulk commodity flows. This is the

most remarkable insight gained in the present study since no assumptions could be made in this context through the literature review and subsequent CF development. Therefore, this knowledge could only be gained from real-life experiences through the case study.

According to the EU Basic Regulation, logistics operators are considered food companies, as they are involved in the food and feed supply chain. Therefore, logistics companies are also obliged to implement the HACCP concept as part of their QM. In the developed conceptual framework, QM was identified as a food safety concept at the level of logistical processes. As described above, plausible explanations were found through the case study as to why difficulties in the implementation of QM occur in the logistics industry. In addition to the economic losses associated with food safety services for logistics companies, for example, there are critical voices in the literature confirming that the HACCP system - although a valuable tool for improving food safety, especially in the food processing industry - will not by itself solve the problems associated with food quality and safety in trade. The reason is seen in the fact that the application of the HACCP system does not alone address deficiencies in basic hygienic practices that are primarily responsible for food safety issues (Orriss and Whitehead, 2000). Therefore, the HACCP system only serves as an effective tool to enhance food safety when adequately applied as part of an overall quality assurance system based on the CODEX General Principles of Food Hygiene (Orriss and Whitehead, 2000). This could be another reason why logistics processes remain a challenge in quality and safety assurance on a global scale.

A further important insight gained from the case study is that the current process for sampling agri-bulk commodities during logistical processes and the analysis of samples along global commodity flows in terms of their contamination have weaknesses that could negatively impact food safety. In general, representative sampling in the form commonly practised today is challenging due to different infrastructural conditions and large quantities. In addition, the current differences in analysis methods around the world lead to different analysis results within a defined lot of agricultural commodities or at various stages of the supply chain. Subsequently, this increases uncertainty among stakeholders to classify the commodity to a particular risk category during transportation in a bulk ship or storage at a port. High sampling costs ultimately contribute to fewer samplings being taken, which can have a negative impact on food safety given the uncertainties that exist. Comparability of global analytical methods and corresponding results as sought by national and international organisations (Poms, 2012) and research in quantifying/estimating sampling uncertainties under varying conditions (Bourgeois and Lyman, 2012) would be helpful to reduce uncertainty among stakeholders in this respect.

With regard to traceability - an essential pillar of the basic principles of the EU Basic Regulation - the case study confirmed the criticism known from the literature research for the CF: the "trace-back and trace-forward data of the trading unit by all supply chain participants" required by the EU Basic Regulation is too short-sighted and does not lead to the desired goal in the case of agricultural commodities. Furthermore, the case study found that traceability back to origin is not possible due to the mixture of goods of different origins at the export port in the third country. This is due to the need to reduce transportation costs resulting from economic pressures in the procurement sector. This illustrates very well that the market alone does not provide the socially desired level of food safety (Fricke, 2015b) and that incentives must be created on the part of policy-makers so that traceability can be achieved in practice.

The study also concluded that public and private controls in the logistics sector represent another weakness, reflecting existing gaps in food safety regulations and standards. The criticism regarding public inspections is that less attention is paid to areas relevant to food safety, such as the type of cleaning or the quality of the means of transport. The study has shown that the reasons for these control gaps in the logistics sector are mainly due to the lack of expertise of the controllers. In this context, further problems are seen in the insufficient personnel and financial resources of the official food control (Theuvsen, 2010). However, it is the task of the government to integrate legislation and food quality assurance systems, including HACCP, throughout the food chain and to eliminate any gaps or weaknesses in the corresponding controls (Orriss and Whitehead, 2000).

According to the case study results, the situation is often no different for private controls. Here, the experts also criticised a lack of knowledge, motivation and diligence. In addition, there is often the problem of the availability of independent, third parties who are accredited and well trained to take the sample in (different) ports in each country. However, a lack of independence of the auditors and a low risk orientation of the audits – similar to public audits - are also seen as a problem in this regard (Theuvsen, 2010). Since certification systems depend primarily on trust, improving certification and audit procedures is necessary. Given a large number of certification systems in the food industry, it is surprising that there have been few research approaches to the efficiency of certification systems to date (Jahn *et al.*, 2005). Furthermore, it is also suggested that the general lack of coordination between private and public controls hinders the realisation of risk orientation, which is an important principle of the EU Basic Regulation (Theuvsen, 2010). However, more exchange and communication would be urgently

needed, especially in the logistics and trade sector, which appears confusing or opaque even to the players themselves.

The study revealed the necessity for essential changes on the institutional level of food safety authorities and new research regarding the effectiveness of food safety measures intended for the logistics sector. Since logistics is not tied to a specific location but is embedded in diverse, dynamic and challenging conditions and is subject to strong competitive pressure, the existing (HACCP, sampling, traceability and standards) and new requirements would have to be reviewed for their effectiveness and better adapted to practice. Furthermore, it is indispensable to deepen the knowledge of the processes and critical factors in the logistics sector at the authority level to improve the performance of auditors and to ensure the supply of sufficient and safe food in times of crisis such as a pandemic. Both the adaptation of food safety measures and the knowledge of vulnerabilities can only be achieved through more cooperation, communication and transparency between the supply chain sector and food safety authorities and between private and public controls.

4.4 Limitations of the study

The present study has limitations which are discussed in the following. First, it must be pointed out that through the practical application of the CF in the field using the case study, a validation of the CF has taken place. According to the case study results, the CF would have to be revised/modified and supplemented by further concepts, especially in the area of food safety measures (e.g. sampling, controls) and characteristics of the logistics and trade sector, e.g. competitive pressure. In this context, the critical role of the trader or buyer would need to be emphasised more to show the unequal power relationship regarding food safety. Further, the newly identified relations and backgrounds would need to be integrated into the CF. Due to the openness of qualitative research, the CF may be further developed accordingly once new data is gained from further studies or from new literature that was not available when the CF was first developed (Jabareen, 2009).

As already mentioned, the CF provided the basis for the case study. An attempt was made to examine all aspects of the CF through the case study. However, the variety and amount of data that could be obtained in this way through the case study proved to be very extensive and demanding, requiring a great deal of time to be spent on data processing and analysis. On the other hand, many valuable results could not be included in the publication, such as the revealed differences in perception and even contradictions between experts regarding certification and

traceability. Therefore, it would be advisable to focus on a single or few aspects in similar or further studies. For example, it would be interesting to look more closely at the case study data with the greatest frequency (e.g. sampling) and variance (e.g. traceability). In any case, feasibility, available time and financial resources need to be better estimated in further studies.

Due to the lack of representativeness (sample size of 18 interviews with 24 experts), it is not possible to draw any general conclusions from the case study about the risk posed by logistics concerning food safety. Furthermore, the logistics sector was considered separately in the present study, which can lead to a distorted perception of risk. It would be helpful to determine the relative risk of logistics compared to the other stages of the supply chain, such as production and processing, to assess the actual risk. Most experts who participated in the case study believe that the influence of crop cultivation (especially climate and weather), post-harvest and storage conditions at the production site are more relevant to food safety risks (e.g. mycotoxin contamination) than the weaknesses of global commodity flows. This may also reflect the general perception of low risk posed by logistics, shown in the research priorities on mycotoxin contamination along global supply chains. In crop production, research focuses, for example, on the development of tools for the management or prevention of mycotoxin contamination through the creation of predictive models based on environmental monitoring (meteorological data) (Battilani and Leggieri, 2015; De Wolf *et al.*, 2003). Further, post-harvest techniques such as monitoring the storage environment and processing technologies such as innovative milling to minimise mycotoxin content in cereals are also being developed in the food and feed industry (Garcia-Cela *et al.*, 2019; Schaarschmidt and Fauhl-Hassek, 2021).

However, the experts' statements are based not only on extensive professional experience but also on subjective perceptions and feelings. Thus, as long as not enough studies are conducted in this area to prove the experts' opinion of a lower risk posed by logistics compared to other supply chain stages, the mentioned research foci remain scientifically unfounded. Therefore, the development of integrative research approaches to identify the relative risk posed by logistics would be very beneficial in this context. Ultimately, the study showed through the variance in the data that the experts' risk perception depends very much on the point in the commodity flow they are related to. Therefore, to make the picture more complete, it would be useful to interview further actors/stakeholders such as transportation companies (e.g. road or maritime transportation) and independent inspection bodies.

Finally, attention must be drawn to the subjectivity or scope for interpretation inherent in qualitative research. In the case of the CF, its development was accompanied by uncertainty about the extent of the desired conceptual integration of the phenomenon "global commodity flows". Different researchers might have different conceptions of the same phenomenon and may create different CFs, as a conceptual analysis requires different types of thinking such as creativity, integrative and divergent thinking (Aven, 2018).

With respect to the case study, the scope for interpretation is characterised, for example, by the fact that terms were used differently or synonymously by experts depending on the context. For example, the term "supplier" can mean producer, logistics service provider, forwarder, and trader. The term "standards" can refer to the standards developed by private institutions (e.g. GMP, QS) or to a country's standard in terms of technology or infrastructure. The term "infrastructure" was also used differently by the experts. Some understand it to mean means of transport, others to port infrastructure, while others understand it to mean the national transport infrastructure. This makes the evaluation and interpretation of the data partly a challenge, showing that the topic's complexity is also reflected in the language. At the same time, it demonstrates the importance of a common wording in literature and practice, e.g., a CF or glossary, which would contribute to a better understanding of the topic.

Another limitation of the study is that in interpreting the experts' statements, factors influencing the expert opinion such as motivation/interest, knowledge about food safety/mycotoxins, practical experience and professional position/responsibility were not considered due to the scope of the study. In this respect the terminal operators, for example, as the executing force of the logistical activities, who are less responsible for food safety due to the described balance of power but have the most practical experience, tend to be more critical than the feed industry. As a logistics customer, the feed industry is further removed from logistical processes but is primarily responsible for food safety, which is why it has been most affected by image damage in recent food safety scandals. For further studies of this type, it would be worth considering using these factors to evaluate and interpret the data.

Against the background of the complexity of the topic and the many interpretations that come with qualitative research, great emphasis was placed on "reliability" as an essential quality criterion of case studies. This includes precise documentation of the whole research process (research diary/audit trail) and an interview database to make the study inter-subjectively comprehensible. Besides, the present study is characterised by pursuing "internal validity" as a

further quality criterion. Thus, peer debriefing made it possible to uncover potential bias, and a prolonged engagement helped prove and substantiate causal relationships.

5 Conclusion

The present dissertation was the first step to shed more light on a highly important topic that suffers from a substantial gap in RA and supply chain research concerning food safety. Developing a conceptual framework and its practical application in a case study allowed a deeper and more detailed look at global commodity flows. In this way, the study contributed to a better overall picture of global commodity flows. Furthermore, it could fill essential knowledge gaps concerning food safety by identifying critical dimensions and factors and especially relevant interactions within the logistics sector and its environment.

The study confirmed that the logistics industry is highly fragmented and complex and thus contributes greatly to the overall complexity of global food supply chains and, consequently, food safety risks. Thus, it has become evident that the contribution of logistics to increased food safety risks within global supply chains has been underestimated so far by food safety authorities. The use of qualitative research approaches has proven to be correct and ground-breaking: The conceptual framework developed, with its different levels of consideration and concepts, served as the basis for the case study, which helped to capture both the diverse and dynamic conditions and the complex interactions inside and outside of the logistics sector and to understand their potential impact on food safety.

The identified critical dimensions and factors and the plausible causal relationships can now be transferred to the knowledge base of the focus area "Global supply chains" in RA. The knowledge can be used as a basis for similar or even quantitative studies to verify the results presented here (due to the lack of representativeness). Here, the focus of consideration could be on the data that showed a high frequency or variance in the naming of experts. In this context, it would also be helpful to examine the disagreements among different groups of stakeholders and to involve other stakeholders in this type of research. Furthermore, expert rankings such as Delphi studies could be used to assess the critical dimensions and factors identified here in terms of their relevance for food safety. Finally, it would also be interesting to examine logistics in direct comparison with the other supply chain stages to better assess the actual risk ratio or counteract a distorted risk perception.

The overall goal is to constantly update and expand the knowledge gained through similar and further studies and integrate it into existing and new tools for supply chain analysis, which can be used, e.g., to clarify and analyse transnational food safety issues. In addition, indicators and corresponding data sources for the identified critical factors can be defined for potential monitoring purposes in the context of emerging risks identification. This way, developed systems for emerging risks identification by the EFSA and FAO could be supplemented by the element of logistics.

The study further demonstrated that the prevailing conditions in the logistics sector, such as competitive and time pressures, make it difficult for logistics service providers to meet food safety requirements. The unequal power relationship between logistics companies and buyers (traders/feed industry) or the dependence on buyers in food safety has also shown that the logistics sector - as the last link in the chain - can neither be held solely responsible for food safety risks. Nor is it capable of independently ensuring the socially desired level of food safety. Careful implementation of a quality management system seems to be one of the biggest challenges in this context. The economic pressure combined with challenging working conditions resulting in a high fluctuation of workers as well as varying socio-cultural conditions influence human factors such as mentality and diligence, which can have a negative impact on the implementation of QM. Furthermore, the strong economic pressure leads to general inertia in the logistics sector to invest in the latest technologies (e.g. blockchain) that could positively influence food safety.

While the study emphasises the need for integrative and sustainable solutions that require the cooperation of all economic players, it also shows that it will be difficult for the market alone to achieve the socially desired level of food safety. Therefore, incentives for more transparency and diligence in QM and investment in new technologies could be discussed on a political level. On the other hand, it has become clear that the logistics sector is increasingly under pressure due to globalisation and that mainly small logistics companies who do not meet the various demands (efficiency, sustainability, food safety etc.) could gradually be squeezed out of the market. The logistics sector could thus become more manageable.

However, the biggest surprise and, at the same time, the most important finding of the present study is that many food safety measures are not adapted to the complex and challenging conditions of the logistics sector. Thus, they pose a potential risk to food safety. As the international agricultural trade growth continues, effective food safety measures become

increasingly important to ensure food safety along global supply chains. This underlines the vital role of food safety authorities and the need for a paradigm shift in the future. Both holistic, multidisciplinary approaches and ongoing stakeholder involvement in the work of food safety agencies must become more important strategic priorities in an increasingly complex and uncertain world such as that of logistics and trade.

An intensified engagement with the topic of logistics on the level of food safety authorities is not only essential to make measures more practicable and thus more effective in terms of food safety (e.g. harmonisation and specification of standards). It is also important to continuously update and expand knowledge about critical factors as well as dynamics and developments in the logistics sector. With regard to the latter, the main challenge is to systematically investigate, evaluate and, in the best case, continuously monitor the dynamic development and its influence on food safety using approved scientific methods.

The present thesis demonstrates the strategic and conceptual vulnerability of the international food safety governance in relation to the logistics sector. Therefore, due to the global reach of logistics, it ultimately calls for further multi-sectoral investigation and analysis, both at the EU (EFSA) and at the international level (CODEX Alimentarius Commission).

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7 Summary

In the era of globalization and increasing agricultural trade volumes - due to population growth, urbanization and changing consumption patterns - food supply chains have become more complex, with far-reaching consequences for food safety. A high number and diversity of entities, processes and locations can create food safety risks and vulnerabilities at all stages of global food supply chains. Various severe food safety incidents that have occurred on an international scale have confronted food safety authorities with the challenge of how to manage and assess food safety risks, focusing so far on the supply chain stages "production", "processing" and "retail". However, investigations of food safety issues that have already occurred have revealed essential knowledge gaps and uncertainties concerning the role that logistics has played in food safety incidents in the past.

Logistics plays a crucial role in global commodity flows by connecting the individual stages of the supply chain. There is a broad knowledge about critical points for food safety (HACCP) during transport, storage and handling in the context of hazard analysis in quality management. However, less is known about how the complex interactions within logistics and its varying environment throughout global supply chains affect food safety. This is where to date, the traditional risk analysis approach reaches its limits and where action is needed to meet the demand for more transparency in the EU risk assessment process under the new Regulation (EU) 2019/1381. Therefore, the research question underlying the dissertation is "How does the complexity of logistics contribute to potential food safety risks along global agri-food supply chains?"

Due to a lack of studies resulting in poor data situations and rudimentary knowledge, the research field is largely exploratory. As a first step, we have developed a conceptual framework exemplified by agri-bulk commodities to define and delineate the phenomenon of global commodity flows as a new field of investigation in risk assessment. We systematically reviewed multidisciplinary literature concerning logistics using qualitative text analysis, adapted from the Grounded Theory approach. In a second step, the conceptual framework served as a basis for an empirical investigation of mycotoxin contamination in agri-bulk commodity flows in the form of a case study. For this purpose, expert interviews were conducted with 24 actors directly or indirectly involved in the international logistics, trade and procurement (feed industry) of agri-bulk commodities and in the field of respective regulations and standards.

By developing the conceptual framework, we determined and illustrated different levels of the main concepts inside and outside of agri-bulk commodity flows relevant to the investigation of logistics in terms of food safety. The main internal concepts are *Logistics processes* and *Management* (micro-level), *Key actors* and *Cooperation* (meta-level), as well as *Routes and Nodes* and their *Quality and Capacity* (macro-level). The external concepts can be divided into *Country-related conditions* related to *Diversity*, as well as *Global drivers* associated with the *Dynamics* of globalization. Furthermore, we formulated application-oriented theories that serve as research guiding propositions. By conducting the case study, we identified eight critical dimensions for food safety: *Food Safety Measures*, *Logistical Processes, Human Factor, Disruptions and Shifts, Logistics related conditions, Cooperation, Main characteristics of the procurement sector* and *Port characteristic*s. Furthermore, we have identified corresponding critical factors for each dimension, and we have visualised interrelationships between these

dimensions and shown which dimensions and critical factors tend to be more important for food safety.

Since logistics - in all its complexity - has been covered only to a very limited extent in food safety research, the conceptual framework developed represents a first theoretical basis and the reference model for a holistic and empirical investigation. Revealing the multifaceted nature of global commodity flows and its presumed effects on food safety provides evidence that relevant research in the future should focus on studying logistics in its complex context. The case study results confirm that potential food safety threats and risks along global commodity flows are not solely attributable to the logistics sector per se and the associated actors and processes involved. Rather, major challenges for food safety are Food safety measures (e.g. sampling, external controls, traceability) that are not adapted to the conditions in the logistics sector, logistics-related conditions (e.g. infrastructure, standards, regulations) that vary from country to country, as well as the unequal power relationship between logistics companies and buyers (traders/feed industry). Further, the prevailing conditions, such as competitive and time pressures, challenging working conditions, high fluctuations of workers and varying socio-cultural conditions make it partly very difficult for the logistics companies to meet food safety requirements. The human factor is thus becoming one of the most important critical dimensions for food safety in the logistics sector.

The present dissertation contributes to a better overall picture of global commodity flows. It closes essential knowledge gaps by providing plausible correlations and explanations for food safety risks in the logistics sector. However, due to the lack of representativeness of the case study and the dynamics of the sector, it is crucial to constantly update and expand the knowledge gained. For this purpose, the newly generated data can be used as a basis for further studies, e.g. to further verify the results and to focus on data that showed high frequency and variance in the case study by, e.g. involving additional relevant stakeholders. Additionally, expert rankings such as Delphi studies could be used to assess the critical dimensions and factors identified in terms of their relevance for food safety. The overall aim is to integrate the knowledge gained into existing and new tools for supply chain analysis, which can be used to clarify international food safety issues or in the field of early risk identification.

The dissertation shows the need for integrative and sustainable solutions that require the cooperation of all economic players. However, it also demonstrates that it would be difficult for the market alone to achieve the socially desired level of food safety. Therefore, incentives for more transparency and diligence in quality management and investment in new technologies (e.g. blockchain) should be discussed on a political level. Furthermore, the finding that many food safety measures are not adapted to the challenging conditions of the logistics sector and thus themselves pose a potential risk to food safety underlines the critical role played by food safety authorities and the need for a paradigm shift. Both holistic, multidisciplinary approaches and ongoing stakeholder involvement in the work of food safety agencies must become important strategic priorities to make measures more practicable and thus more effective in terms of food safety (e.g. harmonization and specification of standards). The main challenge is to systematically investigate, evaluate and, in the best case, continuously monitor the dynamic development of the complex and uncertain world of logistics and its influence on food safety using approved scientific methods. This calls for further multi-sectoral investigation and analysis, both at the EU (EFSA) and at the international level (CODEX Alimentarius Commission), to fulfil the task of consumer protection in times of globalization.

8 Zusammenfassung

Im Zeitalter der Globalisierung und des zunehmenden Agrarhandels - bedingt durch Bevölkerungswachstum, Urbanisierung und veränderte Konsummuster - werden Agrar lieferketten immer komplexer, was weitreichende Folgen für die Lebensmittelsicherheit mit sich bringt. Eine große Anzahl und Vielfalt von Unternehmen, Prozessen und Standorten kann auf allen Stufen der globalen Warenketten zu Risiken in der Lebensmittelsicherheit führen. Verschiedene schwerwiegende Vorfälle im Bereich der Lebensmittelsicherheit, die sich auf internationaler Ebene ereignet haben, stellen die zuständigen Behörden vor die Herausforderung, Risiken zu managen und zu bewerten. Dabei lag der Fokus der Bemühungen bisher auf den Stufen "Produktion", "Verarbeitung" und "Einzelhandel" der Lieferkette. Die Analyse bereits aufgetretener Lebensmittelsicherheitsprobleme hat jedoch erhebliche Wissenslücken und Unsicherheiten hinsichtlich der Rolle der Logistik bei diesen Vorfällen aufgedeckt.

Die Logistik spielt eine Schlüsselrolle in den globalen Warenströmen, indem sie die einzelnen Stufen der Lieferkette miteinander verbindet. Im Rahmen der Gefahrenanalyse gibt es bereits ein umfassendes Wissen über kritische Punkte für die Lebensmittelsicherheit (HACCP) bei Transport, Lagerung und Handhabung als Teil des Qualitätsmanagements. Weniger erforscht ist jedoch, wie sich die komplexen Wechselwirkungen innerhalb der Logistik und ihre unterschiedlichen Rahmenbedingungen in den globalen Lieferketten auf die Lebensmittel-sicherheit auswirken. Hier stößt der traditionelle Ansatz der Risikoanalyse bisher an seine Grenzen und es besteht somit Handlungsbedarf, um der Forderung nach mehr Transparenz im EU-Risikobewertungsprozess im Rahmen der neuen Verordnung (EU) 2019/1381 nachkommen zu können. Die der Dissertation zugrunde liegende Forschungsfrage lautet daher: "Wie trägt die Komplexität der Logistik zu potenziellen Risiken für die Lebensmittelsicherheit entlang globaler Agrarlieferketten bei?"

Aufgrund des Mangels an Studien und der daraus resultierenden unzureichenden Datenlage und rudimentären Kenntnisse, ist dieser Forschungsbereich weitgehend explorativ. In einem ersten Schritt haben wir einen konzeptionellen Bezugsrahmen am Beispiel von Agrarrohstoffen entwickelt, um das Phänomen der globalen Warenströme als neues Untersuchungsfeld der Risikobewertung zu definieren und abzugrenzen. Wir haben multidisziplinäre Literatur zur Logistik systematisch anhand einer qualitativen Textanalyse überprüft, die sich am Ansatz der Grounded Theory orientiert. In einem zweiten Schritt diente der konzeptionellen Bezugsrahmen als Grundlage für eine Fallstudie zur empirischen Untersuchung der potentiellen Kontamination von Agrarrohstoffen mit Mykotoxinen entlang globaler Warenströme. Dazu wurden Experteninterviews mit 24 Akteuren geführt, die direkt oder indirekt an der internationalen Logistik, am Handel und an der Beschaffung (Futtermittelindustrie) von Agrarrohstoffen beteiligt oder im Bereich der entsprechenden Richtlinien und Standards tätig sind.

Bei der Entwicklung des konzeptionellen Bezugsrahmens haben wir verschiedene Ebenen der wichtigsten Konzepte innerhalb und außerhalb der Agrarrohstoffströme bestimmt. Dementsprechend wurden die Konzepte, die für Untersuchung der Logistik im Hinblick auf die Lebensmittelsicherheit besonders relevant sind, veranschaulicht. Die wichtigsten internen Konzepte sind *Logistikprozesse* und *Management* (Mikroebene), *Hauptakteure* und *Zusammenarbei*t (Metaebene), sowie *Routen und Knotenpunkte* und deren *Qualität und Kapazität* (Makroebene). Externe Konzepte lassen sich in *Länderspezifische*

Rahmenbedingungen, die mit *Diversität* und in *Globale Driver*, die wiederum mit *Dynamik* der Globalisierung assoziiert werden, unterteilen. Darüber hinaus haben wir anwendungsorientierte Theorien formuliert, die als forschungsleitende Thesen dienen. Mit Hilfe der Fallstudie konnten wir acht kritische Dimensionen für die Lebensmittelsicherheit identifizieren: *Maßnahmen zur Lebensmittelsicherheit*, *logistische Prozesse*, *menschlicher Faktor, Störungen und Verschiebungen, Logistikrelevante Rahmenbedingungen, Zusammenarbeit, Hauptmerkmale des Beschaffungssektors* und *Hafenmerkmale*. Des Weiteren haben wir für jede Dimension entsprechende kritische Faktoren ermittelt, die Wechselbeziehungen zwischen diesen Dimensionen visualisiert und gezeigt, welche Dimensionen und kritischen Faktoren für die Lebensmittelsicherheit tendenziell wichtiger sind.

Da die Logistik in ihrer ganzen Komplexität in der Forschung im Bereich der Lebensmittelsicherheit bisher nur in sehr geringem Umfang behandelt wurde, stellt der entwickelte konzeptionelle Bezugsrahmen eine erste theoretische Grundlage und das Referenzmodell für eine ganzheitliche und empirische Untersuchung dar. Die Offenlegung der vielschichtigen Natur globaler Warenströme und die Ableitung ihrer mutmaßlichen Auswirkungen auf die Lebensmittelsicherheit zeigen, dass sich die entsprechende Forschung künftig auf die Untersuchung der Logistik in ihrem komplexen Kontext konzentrieren sollte. Die Erkenntnisse aus der Fallstudie bestätigen zudem, dass potenzielle Gefahren und Risiken für die Lebensmittelsicherheit entlang der globalen Warenströme nicht allein auf den Logistiksektor und die damit verbundenen Akteure und Prozesse zurückzuführen sind. Die größten Herausforderungen für die Lebensmittelsicherheit sind vielmehr: Lebensmittelsicherheitsmaßnahmen (z.B. Probenahme, externe Kontrollen, Rückverfolgbarkeit), die nicht an die Bedingungen im Logistiksektor angepasst sind, von Land zu Land unterschiedliche logistische Rahmenbedingungen (z.B. Infrastruktur, Standards, Richtlinien) sowie das ungleiche Machtverhältnis zwischen Logistikunternehmen und Abnehmern (Händler/ Futtermittelindustrie). Darüber hinaus machen es die vorherrschenden Bedingungen wie Wettbewerbs- und Zeitdruck, schwierige Arbeitsbedingungen, hohe Fluktuation der Arbeitskräfte sowie unterschiedliche soziokulturelle Bedingungen den Logistikunternehmen teilweise schwer, die Anforderungen an die Lebensmittelsicherheit zu erfüllen. Der Faktor Mensch wird damit zu einer der wichtigsten kritischen Dimensionen für die Lebensmittelsicherheit im Logistiksektor.

Die vorliegende Dissertation trägt zu einem besseren Gesamtbild der globalen Warenströme von Agrarrohstoffen bei. Durch plausible Zusammenhänge und Erklärungen für Lebensmittelsicherheitsrisiken in der Logistikbranche konnten wesentliche Wissenslücken geschlossen werden. Aufgrund der mangelnden Repräsentativität der Fallstudie und der Dynamik des Sektors ist es jedoch wichtig, die gewonnenen Erkenntnisse ständig zu aktualisieren und zu erweitern. Zu diesem Zweck können die neu generierten Daten als Grundlage für weitere Studien dienen, z. B. um die Ergebnisse weiter zu verifizieren und sich auf Daten zu konzentrieren, die bei der Fallstudie eine hohe Häufigkeit und Varianz aufgewiesen haben. Hierzu könnten zum Beispiel zusätzliche relevante Interessensgruppen einbezogen werden. Darüber hinaus könnten Experten-Rankings wie Delphi-Studien genutzt werden, um die ermittelten kritischen Dimensionen und Faktoren hinsichtlich ihrer Bedeutung für die Lebensmittelsicherheit zu bewerten. Übergeordnetes Ziel sollte die Integration der gewonnenen Erkenntnisse in bestehende und neue Instrumente zur Analyse von Agrarlieferketten sein, die zur Klärung internationaler Vorfälle der Lebensmittel-sicherheit oder im Bereich der Risikofrüherkennung eingesetzt werden können.

Die Dissertation zeigt die Notwendigkeit integrativer und nachhaltiger Lösungen, die die Zusammenarbeit aller Wirtschaftsakteure erfordern. Sie zeigt aber auch, dass es für den Markt allein schwierig ist, das gesellschaftlich gewünschte hohe Niveau der Lebensmittelsicherheit zu erreichen. Daher sollten Anreize auch auf politischer Ebene diskutiert werden, um mehr Transparenz und Sorgfalt im Qualitätsmanagement als auch Investitionen in neue Technologien (z. B. Blockchain) im Logistiksektor zu erreichen. Die Erkenntnis, dass viele Maßnahmen zur Lebensmittelsicherheit nicht an die schwierigen Bedingungen des Logistiksektors angepasst sind und somit selbst ein potenzielles Risiko für die Lebensmittelsicherheit darstellen, unterstreicht die entscheidende Rolle der zuständigen Behörden und die Notwendigkeit eines Paradigmenwechsels. Sowohl holistische, multidisziplinäre Ansätze als auch die kontinuierliche Einbindung von Stakeholdern in die Arbeit von Behörden im Bereich der Lebensmittelsicherheit müssen zu wichtigen strategischen Prioritäten werden, um Maßnahmen praktikabler und damit effektiver im Sinne der Lebensmittelsicherheit zu gestalten (z.B. Harmonisierung und Präzisierung von Standards). Die größte Herausforderung besteht darin, die dynamische Entwicklung der komplexen und unsicheren Welt der Logistik und ihren Einfluss auf die Lebensmittelsicherheit mit anerkannten wissenschaftlichen Methoden systematisch zu untersuchen, zu bewerten und im besten Fall kontinuierlich zu überwachen. Dies erfordert weitere sektorübergreifende Untersuchungen und Analysen, sowohl auf EU-Ebene (EFSA) als auch auf internationaler Ebene (CODEX Alimentarius Commission), um der Aufgabe des Verbraucherschutzes in Zeiten der Globalisierung gerecht zu werden.

9 Appendix

9.1 Interview Guidelines for the case study

Guideline A: Group of Actors 1 "Regulation and Standards"

Topic 1: Weak points in external control related to food safety

- External controls related to food/feed safety take place along the entire supply chain. What are the specific challenges in the logistics sector?
- What are the challenges of current control procedures during logistical processes in the field of mycotoxins?
    - And why are there these challenges/weak points?
- Logistics-related conditions such as infrastructure and environment can influence external controls. Which conditions prove to be particularly obstructive for the external controls?
    - Are there any country-specific differences in logistics-related conditions that play a role in external controls?
    - Are there any global factors/drivers that play a role in external controls?

Topic 2: Weak points in the internal QM of logistics companies related to food safety

- How would you estimate the Quality Management of logistics companies in general?
- What are the challenges in ensuring the safety of agricultural products during logistical processes?
    - What weaknesses do you see concerning traceability during logistical processes?
    - What role do prevention concepts, such as HACCP, play in practice?
- Which conditions make the implementation of food/feed safety measures more difficult?
    - Are there any country-specific differences in logistics-related conditions that play a role in the QM of the logistics company?
        - Is the influence positive or negative?
    - Are there any global factors/drivers that play a role in the QM of the logistics company?
        - Is the influence positive or negative?

Guideline B: Group of Actors 2 "Agri-Food Trade" and 3 "Logistics Sector"

Topic 1: Critical factors in logistical processes concerning food safety

- Which logistic activities have the greatest influence on mould contamination/food safety of agricultural commodities and why?
- To what extent food safety is taken into account in logistical decisions?

Topic 2: Weak points in the QM of logistics companies

- How would you estimate the Quality Management of logistics companies in general?
- What challenges can arise in the scope of the implementation of food safety measures?
    - What role do prevention concepts, such as HACCP, play in practice?
    - What weaknesses do you see concerning traceability during logistical processes?
    - Which conditions make the implementation of food/feed safety measures more difficult?
        - Are there any country-specific differences in logistics-related conditions that play a role in the QM of the logistics company?
            - Is the influence positive or negative?
        - Are there any global factors/drivers that play a role in the QM of the logistics company?
            - Is the influence positive or negative?

Topic 3. Critical factors at the port concerning food safety

Conditions such as environmental and hygiene conditions are relevant for the contamination of agricultural products with moulds.

- Which factors in the port have an influence on these food safety conditions?
    - Are there any country-specific differences?
        - What about emerging countries, such as BRICS?
        - What about developing countries?
    - Are there any global factors/drivers that play a role in a port's food safety conditions?
        - Is this influence positive or negative?

Time plays a huge role in the contamination of agricultural commodities with moulds.

- Which factors at the port have an influence on the duration of logistics activities, such as transhipment/loading and unloading/ intermediate storage?
    - Are there any country-specific differences?
        - What about emerging countries, such as BRICS?
        - What about developing countries?
    - Are there any global factors/drivers that play a role in the duration of logistics activities in a port?
        - Is this influence positive or negative?

Topic 4: Critical factors on the transportation route

- Which factors on **sea transportation** favour the contamination of agricultural commodities with mycotoxins?
    - Are there any country-specific differences in logistics-related conditions that play a role in the mould contamination of agricultural commodities during sea transportation?
        - Is this influence positive or negative?
    - Are there any global factors/drivers that play a role in the mould contamination of agricultural commodities during sea transportation?
        - Is this influence positive or negative?

- Which factors on **the road transport** favour the contamination of agricultural commodities with mycotoxins?
    - Are there any country-specific differences in logistics-related conditions that play a role in the mould contamination of agricultural commodities during road transportation?
        - Is this influence positive or negative?
    - Are there any global factors/drivers that play a role in the mould contamination of agricultural commodities during road transportation?
        - Is this influence positive or negative?

Guideline C: Group of Actors 4 "Procurement Sector"

Topic 1: Difficulties/barriers in cooperation with logistics service providers

- What challenges did you face when working with logistics service providers over the course of your professional experience that led to problems in product safety?
    - Why?
    - What problems did you encounter when receiving goods? What are they due to?

- Country-specific differences in the logistics-related conditions can influence cooperation with logistics service providers. Which conditions make cooperation more difficult, especially concerning food safety?
    - Is this influence positive or negative?
- Global factors/drivers also have an impact on cooperation with logistics service providers. Which global factors have an influence on cooperation, especially concerning food safety?
    - Is this influence positive or negative?

Topic 2: Role of food safety in cooperation with logistics service providers

- What role does food safety play in cooperation with logistics service providers?
    - Why?
- What are the challenges in regulating food safety in contracts and specifications?
- What potential for improvement do you see in current traceability systems in the supply chain/logistics sector?
- How do you generally assess the QM of logistics service providers?
    - What challenges do you see in the area of food safety?
    - How do you assess the awareness of logistics service providers concerning food safety?
    - Which logistic activity has the greatest influence on food safety, and in particular on mycotoxins?

Topic 3: Weak points in external controls concerning food safety

- What are the challenges for official controls concerning food safety in the logistics sector?
- What potential for improvement exists in standards/certificatation concerning food safety in the logistics sector?

Additional question:

Where do you see the greatest challenge for the logistics sector in the future?

9.2 Acknowledgement

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9.3 Declaration on oath

I hereby declare that I completed the doctoral thesis independently based on the stated resources and aids. I have not applied for a doctoral degree elsewhere and do not have a corresponding doctoral degree. I have not submitted the doctoral thesis, or parts of it, to another academic institution and the thesis has not been accepted or rejected.
I declare that I have acknowledged the Doctoral Degree Regulations which underlie the procedure of the Faculty of Life Sciences of Humboldt-Universität zu Berlin, as amended on 5th March 2015. Furthermore, I declare that no collaboration with commercial doctoral degree supervisors took place, and that the principles of Humboldt-Universität zu Berlin for ensuring good academic practice were abided by.

Selbbständigkeitserklärung:
Hiermit erkläre ich, die Dissertation selbstständig und nur unter Verwendung der angegebenen Hilfen und Hilfsmittel angefertigt zu haben. Ich habe mich anderwärts nicht um einen Doktorgrad beworben und besitze keinen entsprechenden Doktorgrad.
Ich erkläre, dass ich die Dissertation oder Teile davon nicht bereits bei einer anderen wissenschaftlichen Einrichtung eingereicht habe und dass sie dort weder angenommen noch abgelehnt wurde. Ich erkläre die Kenntnisnahme der dem Verfahren zugrunde liegenden Promotionsordnung der Lebenswissenschaftlichen Fakultät der Humboldt-Universität zu Berlin vom 5. März 2015. Weiterhin erkläre ich, dass keine Zusammenarbeit mit gewerblichen Promotionsbearbeiterinnen/Promotionsberatern stattgefunden hat und dass die Grundsätze der Humboldt-Universität zu Berlin zur Sicherung guter wissenschaftlicher Praxis eingehalten wurden.

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