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Framework for early assessment of food safety hazards in the transition to a more sustainable food system: three case studies in the Vietnamese Mekong Delta

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ABSTRACT

Food production in delta areas such as the Vietnamese Mekong Delta (VMD) faces pressures from climate change effects, primarily salinity intrusion and drought. This urges a transition towards a more sustainable food system, which is better able to deal with the pressure factors. Multiple transition pathways are considered, including implementing adaptation strategies at the primary production stage. However, these changes may affect food safety. This study applied a qualitative framework to investigate changes in the occurrence of food safety hazards resulting from adopting adaptation strategies at primary production. We selected three case studies (CS) in the VMD: (1) adaptation in the usage and application of water sources for agricultural production, (2) shifting from monoculture rice, duck, and fish to an integrated crop-livestock farming, and (3) introduction of a new crop (i.e., quinoa). Potential microbiological and chemical hazards were assessed based on a literature study and expert input, and their likelihood of occurrence in each future scenario was compared to the current situation. The simplified approach was considered functional given the limited data for future scenarios. Our theoretical analysis showed that applying different types of fresh water resulted in different hazards (CS 1). Similarly, hazards in integrated farming (CS 2) would differ from those in separate farming. Quinoa production (CS 3) might result in similar or reduced hazards compared to rice. Regardless, building awareness on quinoa safety as a new commodity is crucial. The results of this analysis can inform policymakers and stakeholders to prioritize food safety hazards for mitigation and monitoring, and ultimately facilitate the joint efforts towards a "safe-by-design" food system transition.

1. Introduction

Salinity intrusion and drought are two examples of major stressors that pressure food production systems worldwide. Especially in delta areas, these stressors affect not only the availability of fresh water but also disrupt primary production, resulting in crop losses and affecting livestock health Rahman et al. [1]. The increasing pressures in delta areas urge a food system transition from the current to a future situation that aims for a more sustainable food system [2]. Taking into account the different needs of stakeholders in the food system, multiple transition pathways can be proposed. For agricultural production (i.e., the primary production stage), transition pathways include the adoption of adaptation strategies implemented by farmers. Some examples include reusing water for irrigation, diversifying crops, and considering innovative farming systems. However, such changes may affect food safety [3,4]. For example, when (waste)water is recycled for irrigation, the

Abbreviations: AMR, Antimicrobial resistance; AMU, Antimicrobials use; GAP, Good Agricultural Practices; GFSA, Generic Food Safety Assessment; HPAI, Highly Pathogenic Avian Influenza; HM(s), Heavy metal(s); OTA, Ochratoxin A; PAHs, Polycyclic aromatic hydrocarbons; PCBs, Polychlorinated biphenyls; PFASs, Per- and polyfluoroalkyl substances; PFOA, Perfluorooctanoic acid; PFOS, Perfluorooctane sulfonic acid; RASFF, Rapid Alert System for Food and Feed; VMD, Vietnamese Mekong Delta; WHO, World Health Organization; ZEN, zearalenone.

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recycled water can be of low quality and may contain chemical and microbial contaminants that can be (re)introduced into the food system. Likewise, applying manure or other residual streams as crop fertilizer that possibly contain heavy metals (HMs), pathogens, or antibiotic residues could pose a similar risk. In both cases, besides the nutrients, certain food safety hazards are also introduced in the food system [3,5]. To ensure or improve food safety of a changing food production system in delta areas, its potential impact on food safety must be evaluated beforehand, which also aligns with the safe-by-design approach [6].

One of the low-lying delta areas facing increasing pressures from climate change is the Vietnamese Mekong Delta (VMD). The VMD is known as Vietnam's largest agriculture and aquaculture production area with rice, fruits, vegetables, and aquaculture products as its main commodities [7]. Besides, VMD is the most important area for food production in Vietnam as well as the main exporter of food products [8, 9]. Simultaneously, the VMD region is the world's third-largest delta and is greatly affected by climate change and saline water intrusion [10]. Salinity intrusion and drought make the VMD vulnerable [9] and are threatening current food production systems in the VMD, necessitating adaptation strategies for a more resilient food system [11].

Food systems are complex entities involving a wide range of stakeholders and interconnected activities across multiple domains. Approaches to further develop food systems must thus address many issues simultaneously. Besides efforts that are technical or organisational, aspects such as food safety are equally important, though not yet universally considered [2,12]. Therefore, this study aimed to investigate the impacts of selected adaptation strategies in the primary production system in the VMD region on food safety. The results of the suggested approach will give insight into potential increases or decreases of chemical and microbial hazards (Fig. 1). The VMD was selected to evaluate the applicability of the food safety framework to potential adaptations in the context of food systems transition in delta areas, as part of the Deltas Under Pressure project [2]. Other delta areas, such as deltas in Bangladesh and the Netherlands, are dealing with similar pressures. The possibility of applying this approach to these delta areas is briefly discussed as well.

2. Methodology

2.1. Food safety assessment framework

This study aimed to evaluate changes in potential food safety hazards that may arise as a result of implementing adaptation strategies in primary production systems. This study focused on the primary production stage as a starting point in safeguarding food safety along the supply chain [13]. The methodology employed in this study was based on the Generic Food Safety Assessment (GFSA), a theoretical framework designed to help farmers evaluate and control food safety hazards emerging from changes in their production system [3]. This qualitative, hazard-based approach was selected over a quantitative, risk-based approach. Given the general nature of the innovations examined, we assumed that specific data required for a quantitative risk-based approach would be lacking (i.e., the concentration or level of certain food safety hazards in crops or foods of animal origin in the scenarios under investigation, and the severity of the hazards).

The GFSA consists of five steps (i.e., identify changes, identify potential hazards, establish control measures, implement changes, and evaluate), and the output is valuable to improve food safety management at the farm level. The present study, however, aims to evaluate potential consequences on food safety from certain changes in primary production at a higher spatial level (e.g., community or region). Given the scope of this study, changes in operational activities at the farm level were not investigated, and steps 1 and 2 of the GFSA were followed with some adjustments as elaborated below. Steps 3–5 were out of the scope of this study and were not followed as they require thorough knowledge of the operational activities and actual implementation by farmers. The output of this analysis can serve as a starting point for food safety analysis of certain adaptation strategies involving changes in primary production at a higher spatial level. Relevant stakeholders in the food system domain (e.g., farmers, local government, researchers, businesses) can use the outputs of this study when considering such changes. If the considered change is applied by a farmer, a full application of the GFSA can be performed to refine the analysis and provide a more thorough in-depth analysis conducted on the case at hand.

Step 1: Define the current and future scenarios and identify potential changes in primary production.

Current and future scenarios of primary production systems were identified (see below in Section 2.2 for examples). In this study, only the general aspects of a change in a primary production system were considered. Whereas specific, operational changes that may occur at individual farm level were not investigated.

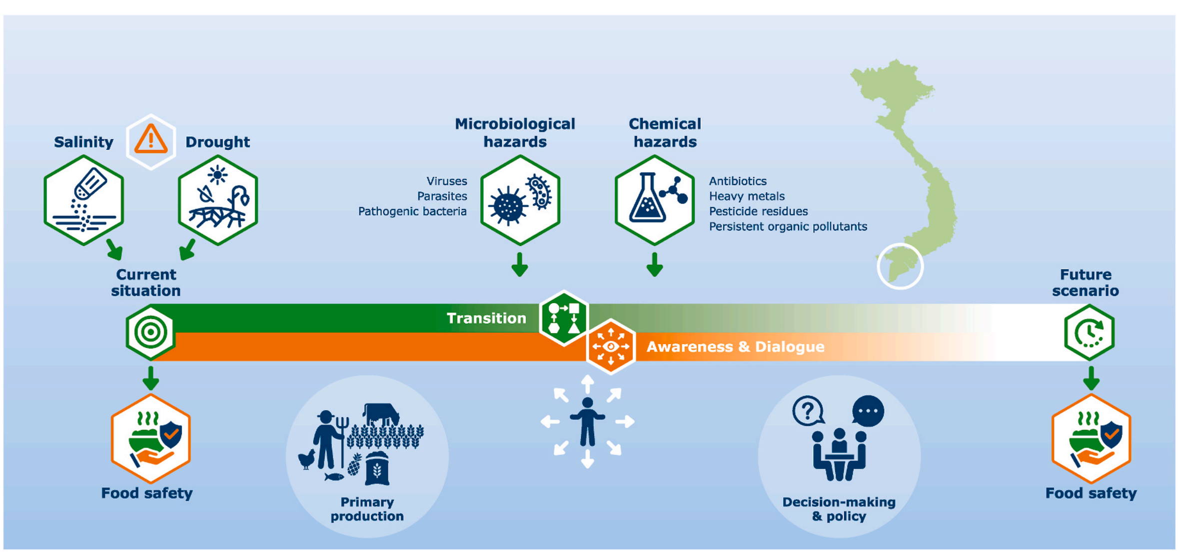

Fig. 1. Visualisation of the application of the Generic Food Safety Framework to assess potential changes in food safety hazards when considering food system transitions (case studies in the Vietnamese Mekong Delta). Visual: ©Communication Services, Wageningen University & Research.

Step 2: Identify potential hazards in the current and future scenarios.

For both current and future scenarios, the likelihood of occurrence of potential microbiological and chemical hazards was identified based on available data from peer-reviewed studies and expert input. Additionally, the Rapid Alert System for Food and Feed (RASFF) database was consulted to elicit data on the occurrence of food safety hazards in certain food commodities, where applicable. Finally, grey literature, relevant legislations (e.g., Vietnamese and the European Union food safety legislations), CODEX guidelines, and good agricultural practices (GAP) were consulted as well.

The likelihood of occurrence of each potential hazard in the future scenario was compared to that of the current system. It was qualitatively expressed as 'new', 'eliminated', 'increased', or 'decreased'. A new hazard refers to a hazard that can be expected to occur in the future system but is not likely to be present in the current system. In contrast, an eliminated hazard refers to a hazard that occurs in the current system but is not expected to occur in the future system. Likewise, increased and decreased hazards refer to hazards that are expected to occur at higher and lower levels in the future system as compared to the current system, respectively [4].

2.2. Selection of case studies within the VMD

Literature study, a field visit, and expert interviews were performed to gain a comprehensive understanding of the current situation and expected changes or possible adaptation strategies in the primary food production system in the VMD. Interviews involved several experts from Wageningen University & Research, and a set of questions was used as a guideline during the interviews. These experts were selected based on their current or previous experiences regarding food systems and/or food safety-related research in delta areas, including the VMD. Further details on the experts involved and questions asked are available in (**Supplementary Materials -** Appendix A**)**. A field visit to the VMD in December 2023 facilitated conversations on the primary production system and food safety with farmers, local authorities, and researchers based in the VMD. Based on the literature study, the expert opinions, and the field visit, an inventory of ongoing and expected adaptation strategies in primary production systems that are occurring or may occur in the VMD was summarized in **Supplementary Materials** (Appendix B – Table B1). Based on this output, three case studies that reflected some of the most important adaptation strategies and represented major primary production systems in the VMD were selected. Case study 1 (using alternative water sources) was selected because water availability and quality are major factors that severely affect agricultural production in the VMD in general. One of the current changes in the transition process is to switch to available water sources other than the usual ones. Case study 2 represents a major challenge due to drought and salinity intrusion, namely rice production which is one of the most important agricultural production systems in the VMD. Shifting from growing rice in monoculture to an integrated rice-livestock farming system is considered an adaptation strategy to better cope with the expected longer periods of drought. Case study 3 considers the introduction of quinoa as a drought and salt-tolerant crop in the VMD. Case studies 1 and 2 represent ongoing and upcoming adaptation strategies, while case study 3 pertains to a possible future scenario. Each selected case study is further described below and visualized in Fig. 2.

2.2.1. Case study 1 - water: adaptation in the usage and application of water sources for agricultural production

Fresh water in the VMD is expected to become even more scarce due to the impacts of climate change, salinity intrusion, and drought, among other pressures [10]. Agricultural practices such as rice farming and aquaculture also drive (fresh) water use competition in the VMD [14]. To cope with fresh water scarcity, one of the expected adaptation strategies is to explore various other fresh water sources. Surface water was identified as one of the most important water sources in the VMD [15]. Surface water can originate from rivers and primary canals, as well as smaller canals (secondary and tertiary canals). Other water sources are groundwater (home-drilled wells) and domestically collected rainwater (e.g., collected rainwater stored in a pond). Since the likelihood of microbial and chemical hazards occurring varies between these sources, changes in water source usage potentially impact food safety. The water-food nexus emphasizes the significance of fresh water availability to achieve food security, of which food safety is an integral part [16]. Due to possible differences in food safety hazards in the river water versus the smaller canals, surface water was evaluated in two sub-categories, i.e., river and primary canal, and secondary and tertiary canals. Thus, this case study evaluated the use of four types of fresh water sources for crop cultivation and as drinking water for livestock: (1) surface water from rivers and primary canals, (2) surface water from secondary and tertiary canals, (3) groundwater, and (4) domestically collected rainwater.

2.2.2. Case study 2 - farming system: from a monoculture to an integrated crop-livestock farming system

Rice (*Oryza sativa* L.) is a major agricultural product in Vietnam, and rice production in the VMD accounts for more than half of Vietnam's total rice production [17]. However, intensive rice production uses a significant amount of fresh water and depletes soil nutrients rapidly. Next to that, agrochemicals (pesticides, fertilizers) are repeatedly (overly) applied. Additionally, water scarcity and salinity intrusion are challenging the need for fresh irrigation water for rice production in the dry season [18]. Integrated crop-livestock farming (also known as mixed crop-livestock farming) is a common agricultural production system in some Asian countries that has been practiced for years [19,20] and is considered a promising strategy to cope with current challenges. In this case study, the production of rice, duck, and freshwater fish in monoculture systems represents the current system. The future system refers

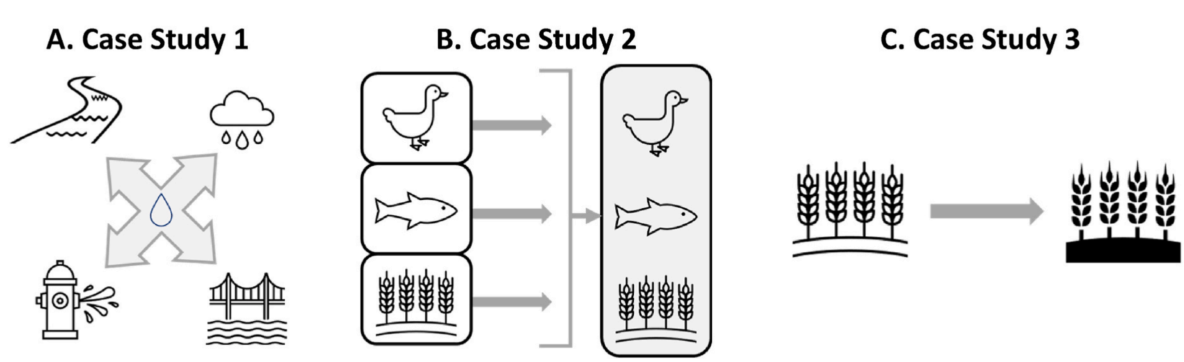

Fig. 2. Schematic figure of the three case studies. A Case study 1: Water: adaptation in the usage and application of water sources for agricultural production; B Case study 2: Farming system: from a monoculture to an integrated crop-livestock farming system; C Case study 3Quinoa: introduction of a new crop.

to the integration of crop (i.e., rice) and livestock (i.e., duck and fish). Representing the majority of the farms in the VMD, small-scale agricultural production was considered. Characteristics of the selected current and future systems are summarized in Table 1.

2.2.3. Case study 3 - quinoa: introduction of a new crop

The third case study focused on the introduction of a new crop as the future scenario, which was compared to the production of rice as the current crop. Intensive rice production requires a large amount of water. To cope with water scarcity and increased salinity levels in the VMD, other crops that are more tolerant to drought and salinity can be considered. Kaveney et al. [21] explored a range of salt- and drought-tolerant crops as alternative crops to grow in the VMD. Among the considered crops was quinoa (*Chenopodium quinoa* Willd.). As quinoa is a new crop species in the VMD, its potential food safety hazards should be evaluated in advance.

3. Results

The framework was applied to the three selected case studies. Based on available literature and experts' knowledge, qualitative evaluation was performed on the likelihood of occurrence of food safety hazards in the future scenarios compared to the current system. Using a descriptive reporting approach, results for each case study are elaborated below. These should not be seen as an exhaustive list of possible hazards associated to the current and future scenarios evaluated but rather to showcase the applicability of the framework.

3.1. Case study 1 – water: adaptation in the usage and application of water sources for agricultural production

The possible usage of four different fresh water sources for irrigation and livestock drinking water were compared for their occurrence of food safety hazards. These water sources were (1) surface water: river or primary canal, (2) surface water: secondary or tertiary canal, (3) groundwater: home-drilled well, and (4) rainwater: domestically collected rainwater. In the current situation, all water sources are used, with surface water being one of the important sources. In the future, the balance in the use of water sources could shift since surface water is likely to become brackish, at least temporarily. The possible impact of using different water source on the described hazards, and whether their occurrence is likely to become prominent, is summarized below and depicted in Fig. 3.

Table 1
Characteristics of the current and future scenario in case study 2.

Commodity	Current	Future
Rice	Monoculture rice, e.g., rice cultivated in flooded field 2–3 times per year.[a]	• Integrated farming where rice, fish and duck are grown simultaneously in rice fields (outdoors). • Ducks and fish feed on weeds and pests (insects, snails). • Rice benefits from the droppings of duck and fish as an organic fertilizer.
Duck	• Local feeds such as water plants, kitchen waste, broken rice, and rice by-products are used.[b] • Ducks can forage in backyards, nearby ditches, and ponds.[b]	
Fish	• Fish are grown in ponds, cage culture in river, at a small scale.[c] • Agricultural by-products, homemade feed and commercial feed are used.[c]	

[a] Kaveney et al. [21], Kim Dang et al. [22].
[b] FAO [23].
[c] Tri et al. [24].

3.1.1. Microbiological hazards

Foodborne pathogens, parasites, and viruses. Water can be a source of pathogenic bacteria, such as *Escherichia coli*, *Salmonella* spp., and *Listeria monocytogenes* [25,26]. Only a limited number of papers indicated actual levels of specific pathogenic bacteria in the different water sources in the VMD. Therefore, total coliform counts were used as an indicator. Most surface waters in the VMD exceeded the Vietnamese standards for surface water quality for coliform contamination [27]. Also, domestically collected rainwater was often contaminated, as 92 % of the collected rainwater samples collected in a study performed in the VMD showed bacterial contamination [28]. In general, total coliform counts in surface water were roughly 10-fold higher than in domestically collected rainwater. Finally, groundwater contaminated with faecal matter is ubiquitous in the VMD. In a study assessing groundwater quality at 64 sampling sites in the VMD, 81 % of the samples were found to be contaminated with coliforms [29]. Nevertheless, levels in groundwater were considerably lower than in rainwater or surface water (about 50- and 500-fold lower, respectively). Overall, most pathogens are expected to occur in surface water, followed by rainwater and groundwater.

Apart from pathogenic bacteria, water is a common way of transmission of parasites such as *Giardia*, *Cryptosporidium*, and *Cyclospora* [25] whereby particularly fresh produce can become contaminated. Cattle and pigs were reported to be a source of the parasite *Cryptosporidium parvum* [30]. No data on the occurrence of *Giardia* or *Cryptosporidium* in water sources in the VMD were found in literature. However, surface water from Northern Vietnam was reported not to be contaminated with *Giardia* or *Cryptosporidium*. Meanwhile, contamination with both parasitic species was reported in sewage canals and vegetable samples from that area [31]. Overall, no conclusion can be drawn regarding the effect of applying a certain water source in the VMD on the possible occurrence of parasites.

Certain environmentally stable viruses may also be transferred via water to food products. More specifically, viruses that can be transferred via the faecal-oral route, such as norovirus or hepatitis, can be relevant hazards for transfer via irrigated crops [32,33]. No data related to viral contamination in water sources in the VMD were found in the literature. Since faecal contamination is the most likely source of viral contamination in water sources, the hazard pattern for viral contamination was thus assumed to follow that of bacterial hazards, since faecal contamination was also the most likely source of bacterial water contamination (Fig. 3). The occurrence of food-borne viruses was therefore evaluated as being most likely in surface water, followed by domestically collected rainwater, and least probable in groundwater.

Besides the intended use of water, extreme weather events such as floodings, which are increasingly occurring in the VMD due to climate change, can result in water contaminations in the primary production system. Especially diarrheal diseases were reported to correlate with such events, although no causal relationships were established [34]. Another study, however, detected human enteric virus Rotavirus A in floodwater in Can Tho, located in the VMD. Levels of these microorganisms were in the range of those in sewer water, indicating a potential human health risk [35].

3.1.2. Chemical hazards

Different groups of chemical hazards can be present in water sources. The following chemical hazards were considered relevant for water sources in the VMD.

Natural toxins. Natural toxins may be present in water, such as cyanotoxins produced by algae blooms. There are various forms of cyanotoxins, whereby the hepatotoxic microcystins which are associated with liver cancer, are of main concern. Microcystins were reported to be found in various water sources in Vietnam, as well as in the VMD [36]. High levels were particularly reported in duck and fishponds, and in water reservoirs. Additionally, algae blooming in a canal sample was detected, but with a low microcystin concentration compared to the

Current situation	Food safety hazard	Future scenario: Surface water: river or primary canal	Future scenario: Surface water: secondary or tertiary canal	Future scenario: Ground-water	Future scenario: Rainwater
Surface water: river or primary canal	Foodborne pathogenic bacteria	n.a.	?	-	-
	Parasites	n.a.	?	?	?
	Viruses	n.a.	?	-	-
	Cyanotoxins	n.a.	+	-	-
	Heavy metals	n.a.	≈	+	+
	Pesticides	n.a.	≈	-	-
	Other contaminants: PFASs, microplastics, etc.	n.a.	≈	-	-
Surface water: secondary or tertiary canal	Pathogenic bacteria	?	n.a.	-	-
	Parasites	?	n.a.	?	?
	Viruses	?	n.a.	-	-
	Cyanotoxins	-	n.a.	-	≈
	Heavy metals	≈	n.a.	+	+
	Pesticides	≈	n.a.	-	-
	Other contaminants: PFASs, microplastics, etc.	≈	n.a.	-	-
Ground-water	Pathogenic bacteria	+	+	n.a.	+
	Parasites	?	?	n.a.	?
	Viruses	+	+	n.a.	+
	Cyanotoxins	-	+	n.a.	+
	Heavy metals	-	-	n.a.	-
	Pesticides	+	+	n.a.	+
	Other contaminants: PFASs, microplastics, etc.	+	+	n.a.	?
Rainwater	Pathogenic bacteria	+	+	-	n.a.
	Parasites	?	?	?	n.a.
	Viruses	+	+	-	n.a.
	Cyanotoxins	+	≈	-	n.a.
	Heavy metals	-	-	+	n.a.
	Pesticides	+	+	-	n.a.
	Other contaminants: PFASs, microplastics, etc.	+	+	?	n.a.

Fig. 3. Expected changes in the likelihood of occurrence of food safety hazards in changing from one water source in the current situation to another water source as a future scenario. n.a. not applicable, + increased (in orange), - decreased (in green), ≈ similar (in yellow), ? unknown (in grey). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

other samples [36].

Heavy metals. The main sources for HM contamination of water sources are geological sources and industrial pollution. In the VMD, arsenic pollution of geological origin is a relevant food safety hazard [36]. Reported concentrations of arsenic in the Mekong River water were low with concentrations ranging between 0.1 and 0.3 μg/L [37], while groundwater samples contained higher amounts of arsenic. Over 75 % of the studied groundwater samples reported arsenic concentrations that exceeded the limit of 10 μg/L as set by the WHO [38], and all groundwater samples from 16 shallow tube wells for agricultural use had elevated arsenic concentrations of 60–900 μg/L of arsenic [37]. In addition, agricultural fields irrigated with groundwater had higher levels of arsenic than fields irrigated with river water [37]. Domestically collected rainwater was reported to contain traces of various HMs. In particular, lead contamination was frequently (17 %) reported at concentrations exceeding both the WHO and Vietnamese drinking water standards of 0.01 mg/L, while arsenic was reported not to be present in concentrations exceeding these standards in domestically collected rainwater samples [28]. Furthermore, it was reported that increased drought in combination with acid sulphate soil used for food production can pollute surface water as well as shallow groundwater by amongst other HMs [14].

Pesticide residues. Pesticide residues are reported to widely contaminate (drinking) water sources throughout Vietnam, although the level of contamination and the types of detected pesticides vary per water source, sampling location, and throughout the year. A study from Chau et al. [39] in the VMD compared pesticide contamination in various water sources and reported that surface waters were the most heavily contaminated. Also, all analysed harvested rainwater samples were found to be contaminated with pesticide residues, possibly as a result of spray drift, whereby residues ended up on rooftops, and subsequently flushed in with the domestically collected rainwater. Finally, 5 out of 22 samples of groundwater from home-drilled wells were found to contain pesticide residues, though their concentrations were lower than in the analysed surface and rainwater samples [39].

Other chemical contaminants. Water may be contaminated by a range of (environmentally relevant) chemicals. These contaminants can originate from anthropogenic activities like mining, industrial and agricultural activities, including improper agricultural waste management such as burning or burying plastic mulch and residuals, and packaging of fertilizers and pesticides. A wide variety of chemical contaminants, such as per- and polyfluoroalkyl substances (PFASs), can subsequently pollute soil and water [40]. A baseline study on PFASs in Vietnamese river ecosystems reported that perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) were consistently detected in surface water, which included the Mekong River, and their levels were particularly high in surface water from a channel that received wastewater treatment plant discharges [41], illustrating the connection with industrial activities. Furthermore, Vietnam is one of the biggest plastic material consumers and a top contributor to plastic waste; consequently, microplastic pollution can be expected in the aquatic environment [42]. A baseline study on microplastics in Vietnam observed that microplastic concentrations in surface waters in the VMD exceeded concentrations of microplastics in other rivers in Vietnam

[43].

3.2. Case study 2 – farming system: from a monoculture to an integrated crop-livestock system

Relevant microbiological and chemical food safety hazards that might occur in an integrated crop-livestock system were identified and compared to their occurrence in the monoculture system as elaborated in the following section and summarized in Fig. 4.

3.2.1. Microbiological hazards

Foodborne pathogens, parasites, and viruses. Microbiological hazards are considered existing hazards in rice, duck and fish. Some foodborne pathogens are specifically related to a certain food product. For example, rice is commonly associated with *Bacillus cereus* contamination, a spore-forming foodborne pathogenic bacterium [44]. With regards to ducks, limited studies reported that foodborne pathogens frequently detected in ducks were *Staphylococcus aureus, Campylobacter* spp. and *Salmonella* spp. [45–47]. Ducks raised (partly) outdoors are also prone to infectious avian diseases, including highly pathogenic avian influenza (HPAI) [48]. HPAI is a major concern for poultry health, however, there is no evidence that this virus could be transmitted to humans through the consumption of contaminated poultry products [49]. Freshwater fish are also prone to contamination with bacterial pathogens, especially to those linked to the aquatic environment such as *Vibrio* spp., *Listeria monocytogenes*, and *Yersinia* spp. [50]. Novoslavskij et al. [50] reported that *V. parahaemolyticus* was detected in 50 % of fish samples collected from Vietnam, mainly in marine fish but also in freshwater fish. Furthermore, FAO reported on multiple outbreaks in Southeast Asian countries involving Group B *Streptococcus* (also referred to as *Streptococcus agalactiae*), that were linked to the consumption of freshwater fish such as tilapia [51]. A wide variety of helminth species (parasitic worms) were also detected in freshwater fish in Vietnam, both from farmed and wild-caught fish [52]. Rearing multiple species (in this case duck and fish) at the same location might affect parasites infection as this condition provides an increased potential for the completion of the life cycle of the parasite. These parasites can possibly be transmitted to humans if meats are not cooked properly. For example, fish is the second intermediate host for *Gnathostoma* spp. (nematode), while poultry, including duck, is a paratenic host [53]. Overall, studies on the occurrence of microbiological hazards in crop-livestock systems are lacking, and it is therefore difficult to estimate how such a farming system would affect hazards compared to monocultures.

	Food safety hazards	Future scenario Integrated rice, duck, fish farming: Rice	Duck	Fish
Current situation Farming rice, duck, fish farming separately	Foodborne pathogenic bacteria	?	?	?
	Parasites	n.a.	+	+
	Antimicrobial resistance	?	?	?
	Mycotoxins	≈	-	-
	Pesticide residues	-	-	new
	Veterinary drugs residue	new	-	-
	Heavy metals	?	?	?
	Other chemical contaminants (dioxins, DDT, PFASs, etc.)	≈	≈	?

Fig. 4. Expected changes in the likelihood of occurrence of food safety hazards in a future scenario of integrated farming of rice, duck, and fish compared to the current system (i.e., separate farming system for rice, duck, and fish). n.a. not applicable, + increased (in orange), - decreased (in green), ≈ similar (in yellow), ? unknown (in grey), new (in blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Antimicrobial resistance. The application of veterinary drugs, including antimicrobial use (AMU), is common in Vietnamese livestock production and considered a major driver in the development of antimicrobial resistance (AMR) in the country [54]. The quantity of antimicrobial active ingredients used per kilogram of animal biomass in Vietnam was estimated to be 1.5 times higher than in EU countries [55], with prophylactics being the most widely used antimicrobial [56]. Specific data on AMU in duck and freshwater fish in the VMD are lacking. In integrated fish/livestock farms, higher AMR in fish was observed as compared to fish monoculture and this was contributed to the shedding of livestock faeces (e.g. duck, chicken, pig) in the water [57,58]. The same studies reported that AMR in livestock faeces has been related to the respective AMU during livestock production. With regards to the rice-duck-fish farming system, it remains uncertain whether the application of antimicrobials and other veterinary drugs (e.g., antiparasitic agents, coccidiostats) will be affected compared to monoculture farming and how it will affect AMR in the products thereof.

3.2.2. Chemical hazards

Natural toxins. Rice can be contaminated by naturally produced toxins such as cyanotoxins (e.g. microcystins) and mycotoxins. For example, microcystins were detected in rice, although at a very low level that was not considered a concern for humans [59]. Microcystins were also found in fish and duck samples from the VMD [36]. The occurrence of cyanotoxins such as microcystins would be more likely to be influenced by the water quality (as elaborated in case study 1) than by shifting to an integrated crop-livestock system. Like other cereals, rice is vulnerable to mycotoxin contamination, i.e., toxic metabolites of certain fungal species. Several mycotoxins have been commonly associated with rice including aflatoxins, citrinin, fumonisins, zearalenone (ZEN), and ochratoxin A (OTA) [60]. Phan et al. [61] also reported that rice produced in the VMD was often contaminated by aflatoxins and fumonisins. However, it remains uncertain whether growing rice in an integrated rice-livestock system could affect fungal infection and subsequently mycotoxin concentrations in rice. In rice monoculture, pesticide application is a common practice to control pests. In an integrated farming system, ducks and fish may also help reduce insects that can subsequently contribute to fungal spread, next to or instead of pesticide application. Considering this information, mycotoxin levels in rice in a rice-livestock system might not be significantly affected as compared to rice production in monoculture, as pests are controlled in both systems through different mechanisms.

Mycotoxins and their metabolites can also be found in food of animal origin (including fish and poultry meat) due to exposure to mycotoxin-contaminated feed [62]. In an integrated farming system, this might be less concerning as both duck and fish will receive less animal feed and largely feed on insects, plankton, and weeds (i.e., naturally available feed sources). It is also assumed that the animals will not feed on rice grains. In this case, the likelihood of the animals being exposed to mycotoxins via contaminated feed might be reduced.

Pesticide and veterinary drug residues. Pesticides are commonly applied in rice cultivation to control a range of pests such as insects, weeds, and fungal and bacterial pathogens [63]. Pesticide application can result in residues in rice grains, especially in the case of excessive use driven by various factors, such as high pest occurrence or lack of knowledge, or safety awareness by farmers [64]. The same study also reported that pesticide residues were higher in permanent rice systems than in alternating rice-shrimp systems.

Integrating duck-fish into rice farming serves as weed and pest control to rice plants [20,65,66]. This interaction might lead to reduced pesticide application in rice cultivation compared to monoculture rice as also observed in previous studies [67,68]. Consequently, it can be hypothesized that the level of pesticide residues in rice could be lower when cultivated in an integrated farming system. Pesticide residues in ducks could be considered an existing hazard as in both current and future scenarios ducks forage in the rice field; however, the exposure might be reduced due to the lower pesticide application in the integrated farming system. Finally, Braun et al. [64] reported that alternating rice-shrimp farming could be vulnerable to cross-contamination of hazards. For example, pesticides residues from rice could be found in shrimp, while antibiotics from shrimps may end up in rice. In our case study, pesticide residues from rice fields could be considered a new hazard in fish as compared to pond farming.

Heavy metals. HMs and trace elements are widely present in the environment, particularly copper, zinc, lead, cadmium, arsenic, and chromium [69]. Rice plants can contain a range of these toxic elements by accumulating these elements from the environment, especially from the soil [70–72]. Arsenic and cadmium are considered the main toxic metals in rice [70,73].

In an integrated rice-duck-fish system, multiple farming practices can be applied, which all may affect HM deposition in the resulting edible plant or animal parts. For example, fertilizers and pesticides may contain substantial amounts of HMs and their application could lead to HMs uptake by plants and animals [74,75]. Some feed supplements may contain essential elements such as iron, copper, and zinc as well as toxic elements such as lead, cadmium, and nickel [76,77]. Chanpiwat et al. [78] reported that HMs in fish are influenced by farming practices, specifically due to the use of chemicals (e.g., feed formulation, fish health management, etc.). The same study reported that traditional fish farming practices in the VMD characterized by feeding with traditional feed (mixed rice bran, broken rice, etc.) and regular pond draining could reduce HM uptake in fish.

On the one hand, the interaction between crop and animals in an integrated rice-duck-fish system can result in a mutualistic interaction, leading to reduced fertilizer and pesticide application, and thus possibly reduced HM deposition [20,65,66]. On the other hand, the presence of animal manure may result in increased HM deposition. Furthermore, studies showed that exposure to outdoor environment could increase the likelihood of HM concentrations in animal-derived food products (i.e., meat), as was observed in poultry raised with outdoor access and free-range poultry [79,80].

Regardless of the hypothesis above, no studies were found that investigate the impact of an integrated rice-duck-fish farming system on the occurrence of HMs in the resulting products. Duan et al. [81] reported that HM concentrations in rice and fish grown in a rice-fish system were considered safe for human consumption. However, this study did not investigate HM levels in products grown in a rice or fish monoculture system and thus levels could not be compared between the two systems. Altogether, the effect of an integrated rice-duck-fish-farming on the occurrence of HMs was evaluated as unknown.

Other chemical contaminants. Next to water, agricultural land can be a source of contamination due to anthropogenic (environmental) chemical contaminants, such as dioxins, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), PFASs, and microplastics. Specifically relevant for Vietnam is the spraying of tactical herbicides including Agent Orange during the Vietnam war (1965–1972) [82]. The herbicide was contaminated with a toxic and persistent dioxin (2,3,7,8-tetrachlorodibenzo-*p*-dioxin; TCDD) [82,83].

In comparison to rearing animals indoor, outdoor access might increase the exposure to (persistent) environmental chemical contaminants. These contaminants could be taken up and accumulate in animal tissues, consequently resulting in higher levels as compared to indoor rearing. For example, livestock reared outdoor can accumulate dioxins in their tissues [84,85]. Such an occurrence has for example been observed in free-range eggs in Vietnam [86].

In both current and future systems, ducks have outdoor access and could be exposed to above contaminants. Thus, the likelihood of occurrence of these contaminants in ducks was evaluated as similar. For fish grown in an integrated farming system, it remains unknown whether exposure to environmental chemical contaminants would be affected. Meanwhile, rice is grown outdoor in both current and future system, and since outdoor exposure could be considered the major source of these contaminants, their levels are expected to be similar.

3.3. Case study 3 – quinoa: introduction of a new crop

In the third case study, growing quinoa instead of rice was evaluated for its potential impact on food safety. Available literature data for quinoa on certain foodborne pathogens, mycotoxins, HMs, and pesticide residues were analysed, as summarized in Fig. 5.

3.3.1. Microbiological hazards

Data on the occurrence of foodborne pathogens in quinoa are limited, with available studies reported that quinoa seeds harboured a wide variety of yeast, fungi, and bacteria, including spore forming *Bacillus* spp. [87,88]. The presence of *Bacillus* spp. can be considered a quality concern as it may affect the quality of quinoa-based products such as bread and quinoa-based drinks [88,89]. Additionally, the pathogenic species *Bacillus cereus* pose a safety concern due to its heat-resistance ability [87]. Accounting available data, *B. cereus* can be considered a potential microbiological hazard for both rice and quinoa. However, the comparison of its occurrence in rice and quinoa is not known.

3.3.2. Chemical hazards

Natural toxins. Mycotoxins are a common food safety issue in tropical regions like Vietnam [90]. Like in other (pseudo)cereal grains, the occurrence of mycotoxins in quinoa can be expected as well. A study reported that although *Penicillium* spp. and *Aspergillus* spp. were found to be present in quinoa, only fumonisin B1 was detected in trace amounts, while other mycotoxins that can be formed by these species were absent (i.e., aflatoxins, cyclopiazonic acid and citrinin) [91]. These authors argued that the low mycotoxin levels in quinoa were due to its character as small grains; small grains (like amaranth) were reported to be less susceptible to mycotoxins than larger grains such as corn [91]. In another study, Vásquez-Ocmín et al. [92] reported beauvericin and enniatins as emerging mycotoxins as these Fusarium mycotoxins were frequently reported in pseudocereals (quinoa included) but not yet regulated. Meanwhile, RASFF data (2019–2024) showed two notifications on OTA levels in quinoa above the EU limit for cereal products of 3

	Food safety hazards	Future scenario Quinoa cultivation
Current situation Rice cultivation	Foodborne pathogenic bacteria	?
	Mycotoxins	≈
	Pesticide residues	≈
	Heavy metals	-

Fig. 5. Expected changes in the likelihood of occurrence of food safety hazards in quinoa cultivation as a future scenario compared to rice cultivation as the current system. Decreased as - (in green), ≈ similar (in yellow), ? unknown (in grey). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

μg/kg [93], while there are no notifications of other types of mycotoxins in quinoa. To conclude, data on the occurrence of mycotoxins in quinoa are scarce and more studies are required to understand their susceptibility to mycotoxins. Regardless, mycotoxins can be considered potential hazards in both rice and quinoa, although the specific mycotoxins and their level might differ between the two crops.

Pesticide residues. Both rice and quinoa may contain some residues from pesticide application during cultivation and post-harvest steps. Findings from literature indicated that pesticide residues could be present in quinoa [94]. RASFF notifications from 2019 to February 2024 also involved the presence of unauthorised substances (i.e., ethylene oxide and chlorpyrifos) in imported quinoa entering the EU market. Ethylene oxide is commonly used as fumigants in cereals, but its use is banned in the EU [95]. Currently, Vietnam has no specific regulations on the use of ethylene oxide in food and agricultural production [96]; however, nine RASFF notifications from 2022 to 2024 concerned export products from Vietnam, mainly instant noodles, suggested that this pesticide was used in Vietnam. No directly comparable data on pesticide residues on quinoa and rice were reported in the literature, to the best of our knowledge. Due to pesticide application during cultivation and the post-harvest stage, pesticide residues are considered common hazards in crops, including rice and quinoa; however, the substances and concentrations thereof may differ depending on the application.

Heavy metals. Like in cereals such as rice, HMs can be considered as a potential food safety hazard in quinoa, as quinoa can accumulate HMs [97,98]. Both quinoa and rice are known to be able to accumulate HMs present in the soil and irrigation water. A high cadmium concentration (0.38 mg/kg) was reported in quinoa samples grown in contaminated soil in Chile [99]; this concentration was higher than the EU maximum level of cadmium in quinoa [93]. Pizarro et al. [99] also reported a high concentration of arsenic (0.2 mg/kg); although no regulatory limit was found for arsenic in quinoa. The EU sets the maximum level for arsenic in rice at 0.15 mg/kg [93]. Another study from Peru reported HM concentrations in both rice and quinoa, showing generally lower concentrations in quinoa compared to rice. Arsenic and cadmium concentrations in quinoa were 0.06 and 0.02 mg/kg, respectively, compared to 0.17 and 0.11 mg/kg in rice [100].

Based on available literature data, it seems that quinoa accumulates HMs to a lower extent as compared to rice. However, further studies comparing the uptake of the two crops are needed to clarify this, since quinoa is also reported regularly in literature as a hyperaccumulator (i.e. plants that can accumulate high levels of heavy metals in their tissues) [96,98].

4. Discussion

In this study, a theoretical generic food safety framework was applied to identify changes in the likelihood of microbiological and chemical food safety hazards occurring in current and possible future food systems in the VMD. Microbiological and chemical hazards were identified for three case studies. Case study 1 explored the effect of changing water sources for agricultural purposes. Our theoretical analysis found that shifting from surface water to groundwater or collected rainwater would likely decrease the occurrence of most chemical and microbial hazards. An opposite shift would be expected to increase these hazards.

Case study 2 discussed a change from separate rice, duck, and fish farming to an integrated rice-livestock farming system. Compared to separate farming systems, some new hazards could occur in the integrated farming system, such as veterinary drug residues in rice and pesticide residues in fish. Some hazards were expected to decrease, for instance, pesticide residues in rice and ducks, and mycotoxins and veterinary residues in ducks and fish. Some hazards were expected to remain similar, such as mycotoxins in rice and environmental contaminants in rice and ducks. The likelihood of other hazards (pathogenic bacteria, AMR, heavy metals) in an integrated system could not be determined due to the lack of data. Furthermore, various factors related to the farming system could influence the occurrence of these hazards, such as animal feeding and agrochemical application (pesticides, veterinary drugs).

Case study 3 dealt with the introduction of quinoa as a new crop in the VMD. This change would probably result in a reduced or similar likelihood of chemical and microbial hazards as compared to rice. As quinoa would be a new crop in Vietnam, it can be assumed that the local population would not consume this grain on a large scale soon, and that quinoa production in the VMD will be, at least initially, mainly for export markets such as the American and European markets. This example emphasizes that changes in a food production system in a certain country will not only affect food supply chains locally and nationally with all their opportunities and hazards, but also internationally due to the globalized supply chain. Moreover, as quinoa is a new commodity in Vietnam, building awareness on food safety parameters in the supply chain is an important step in supporting efforts to transition to a more sustainable food system.

Across the case studies, water quality can be considered an important factor affecting food safety hazards, as elaborated in case study 1 and corroborated in case studies 2 and 3. Furthermore, water quality is affected by many environmental factors such as geographical location and season. For example, contaminated or acidic sulphate soils can lead to water contamination, and so can algae blooms [59,101]. Specific to the VMD, the long-term impacts of Agent Orange are to be considered [82,83]. Changes due to climate change, such as expected increases in water temperature and respective influences on contaminants, need further attention in the long term. It is, thus, important to carefully examine local factors when evaluating food safety hazards in the context of food system transitions, as these can have a great impact on the outcome of the hazard analysis.

The qualitative framework can be easily adopted and applied to other delta areas facing similar pressures as in the VMD, such as the Netherlands and Bangladesh. Of the three case studies in the VMD, case study 1 is the most directly applicable to The Netherlands as another low-lying delta region although located in Europe. Dutch farmers also cope with different water sources and trade-offs, though specific conditions will differ. Dutch groundwater can be brackish, may contain pesticide residues, and its use can contribute to land subsidence. Surface water quality can be enhanced through flushing carried out by the water authorities (i.e. government body responsible for water management). Some farmers started to collect and store rainwater at a large scale, both underground and above ground, which can again possibly result in specific hazards. Similar to case study 3, efforts to introduce new crops in The Netherlands such as polder rice and soybean are currently ongoing, though still very incipient [102].

Bangladesh, located in south Asia, is another important delta currently facing similar pressures on climate change. It was evaluated as the most vulnerable country to climate change according to the Global Climate Risk Index (Harmeling [103] as cited in CIAT; World Bank [104]) These pressures are severely affecting agricultural production in Bangladesh and drive the adoption of some adaptation strategies. Corresponding to case study 1, farmers in Bangladesh must find other water sources to cope with water scarcity. Groundwater is used in 80 % of cultivated area [104], while other sources are also continuously explored such as river water and (harvested) rainwater. Using groundwater is crucial to fulfil water demand, however, this practice results in lowering the groundwater table, creating new problems. For example, farmers need to use diesel-powered wells to extract groundwater in the field, which can result in oil spills. Such incidents contaminate both water and fields. Agricultural production in Bangladesh also faces common issues with intensive farming. The overuse of agrochemicals (mineral fertilizer, pesticides) [105] and their impurities [106] continuously challenge the safe production of food. Various strategies are being explored to tackle this ongoing issue. For example, farmers adopt various approaches in rice cultivation, such as alternate wetting and drying, direct seeding of rice, and bed planting to reduce groundwater demand for agriculture. Another example is the adoption of new farming systems in Bangladesh, similar to the integrated farming investigated in case study 2. Moreover, several new crops with certain traits such as drought- and salt tolerance have been introduced in Bangladesh to adapt to climate change pressure, similar to case study 3. These crops include quinoa, perilla, dragon fruit, and tomatillo. The introduction of new crops may impact the agricultural practices, such as pest management approaches. Altogether, the food safety risks of newly introduced crops in Bangladesh still need further investigation.

In the present study, the application of the framework was shown to be useful to pinpoint a selection of relevant hazards when shifting to a different primary production system. For example, case study 2 on the integrated-farming system showed that pesticide residues originating from rice cultivation could be considered a new hazard in fish-derived products of a rice-duck-fish integrated system compared to pond farming of fish alone. This is important to understand in advance to ensure the safety of derived food products. However, it also became evident that a lack of available literature hampered the outcomes of the analysis. Especially direct comparisons of relevant samples of both the current and future scenarios were largely lacking. Undertaking more research and data collection on levels of chemical and microbial hazards in different food systems is recommended to complete and refine the analysis. In this sense, applying this food safety framework also provides an overview of knowledge gaps in the current literature. Important to note is that the applied framework was limited to analysing impacts at the primary production stage, while impacts can also occur at a later stage in the food supply chain. A full supply chain analysis could thus be considered to provide a thorough overview of the effects of adopting an adaptation strategy at the primary production level on food safety hazards. This knowledge can help to formulate specific food safety objectives in a food system transition process. Adaptation strategies in the farming systems will have multifaceted impacts. While this study focuses on the impacts of changing farming systems in delta areas with a focus on food safety effects, impacts on other areas such as socio-economics, biodiversity, and environment should be considered as well. Moreover, upstream factors (e.g., fair sourcing of adequate quality inputs), downstream factors (e.g., impact on public health due to dietary choices) and further societal effects of the changing production systems over time and space should be included in a comprehensive approach. Stakeholders are active at various levels of production systems, value chains, and ultimately food systems, and play important roles in implementation and planning. The framework application can be tailored to their specific spheres of influence. For instance, based on the food safety framework, groundwater was reported to be beneficial for several reasons. However, the increasing usage of groundwater, as currently occurring, can be detrimental in the long run due to decreasing groundwater levels, resulting in an ever-increasing capacity needed to pump it up. Therefore, applying a food system approach can provide a thorough overview of multiple aspects and impacts of implementing an adaptation strategy within the broader transition to a more sustainable food system. The framework applied in the present study could be used to complement the food system approach as proposed by Berkum et al. (2018). For example, the assessment of the likelihood of the potential hazards in the new scenarios will help to prioritize hazards and their mitigation measures. This could also contribute to the evaluation of synergies and conflicts of objectives in the implementation of certain adaptation strategies in a farm or even a region.

5. Conclusion

The food safety framework applied in this study aimed to analyse the impacts of implementing adaptation strategies in the primary production system in delta areas on food safety using a qualitative, hazard-based analysis. The theoretical application of the generic food safety framework to three case studies in the VMD resulted in the identification and likelihood of occurrence of food safety hazards in a future scenario, as compared to the current scenario. To make informed decisions, knowledge of potential hazards is required. We encourage food safety researchers and competent authorities to employ this framework to evaluate potential hazards when considering changes in the primary production. Moreover, the outcome of the analysis could serve as an input for risk assessment and can facilitate prioritization for hazard monitoring in changing food production systems. The qualitative output of the framework corresponds to hazard identification and can thus serve as input for further risk assessment where quantitative data needs to be incorporated, for example on the dietary exposure. The subsequent outputs can be used by policymakers to aid in prioritization of monitoring or mitigation of food safety hazards when shifting to another food production system.

6. Future outlook

To evaluate the robustness of the framework, other foreseen or possible adaptation strategies could be used as case studies as well, such as the application of desalinisation technologies to remove salt from salty or brackish water and increase freshwater availability, the use of biostimulants in crop production, and changes in the application of pesticides and veterinary drugs in farming systems. Our study also identified data gaps concerning the food safety hazards in the future (but also current) scenario of the investigated case studies. To verify results of the theoretical analysis, it is highly encouraged to validate them with analytical measurements. Finding the best suited analytical measurements, such as on-site analyses or screening tools, would be highly recommended.

CRediT authorship contribution statement

Rosa A. Safitri: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Lianne M.S. Bouwman:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Marianna Siegmund-Schultze:** Writing – review & editing, Funding acquisition. **Tri Minh Nhan:** Writing – review & editing, Writing – original draft. **Mohammed Ariful Islam:** Writing – review & editing, Writing – original draft. **Esther D. van Asselt:** Writing – review & editing, Methodology, Conceptualization. **Katja C.W. van Dongen:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Data availability

No data was used for the research described in the article.

References

[1] M.M. Rahman, G. Penny, M.S. Mondal, M.H. Zaman, A. Kryston, M. Salehin, Q. Nahar, M.S. Islam, D. Bolster, J.L. Tank, M.F. Müller, Salinization in large river deltas: drivers, impacts and socio-hydrological feedbacks, Water Secur 6 (2019) 100024, https://doi.org/10.1016/j.wasec.2019.100024.

[2] J. Verhagen, B. Elzen, E. Koopmanschap, S. Reinhard, C. Verburg, M. Naranjo Barrantes, K. Beekmann, R. Creusen, D. Debrot, L. Klapwijk, M. Siegmund-Schultze, A. Veldhuizen, G. Wilbers, H.T. Nguyen, D.T. Nhan, C. Terwisscha van Scheltinga, Deltas Under Pressure, Guidelines to Facilitate Transition Pathways, 2022.

[3] M. Focker, E.D. van Asselt, B.J.A. Berendsen, M.G.M. van de Schans, S.P.J. van Leeuwen, S.M. Visser, H.J. van der Fels-Klerx, Review of food safety hazards in circular food systems in Europe, Food Res. Int. 158 (2022) 111505, https://doi.org/10.1016/j.foodres.2022.111505.

[4] R.A. Safitri, E.D. van Asselt, J. Müller-Maatsch, S. Vogelgsang, T. Dapcevic-Hadnadev, M. de Nijs, Generic food safety assessment: a framework to evaluate food safety hazards emerging from change(s) in the primary production system – a case study involving intercropping, J. Food Protect. 87 (11) (2024) 100371, https://doi.org/10.1016/j.jfp.2024.100371.

[5] E.D. van Asselt, A. Arrizabalaga-Larrañaga, M. Focker, B.J.A. Berendsen, M.G. M. van de Schans, H.J. van der Fels-Klerx, Chemical food safety hazards in circular food systems: a review, Crit. Rev. Food Sci. Nutr. (2022) 1–13, https://doi.org/10.1080/10408398.2022.2078784.

[6] J.P. van der Berg, G.A. Kleter, E. Battaglia, L.M.S. Bouwman, E.J. Kok, Application of the safe-by-design concept in crop breeding innovation, Int. J. Environ. Res. Publ. Health 17 (17) (2020) 6420, https://doi.org/10.3390/ijerph17176420.

[7] D.D. Tran, L.H. Huu, L.P. Hoang, T.D. Pham, A.H. Nguyen, Sustainability of rice-based livelihoods in the upper floodplains of Vietnamese Mekong Delta: prospects and challenges, Agric. Water Manag. 243 (2021) 106495, https://doi.org/10.1016/j.agwat.2020.106495.

[8] D. The Anh, T. Van Tinh, N. Ngoc Vang, The domestic rice value chain in the Mekong Delta, in: R. Cramb (Ed.), White Gold: the Commercialisation of Rice Farming in the Lower Mekong Basin, Springer Nature Singapore, Singapore, 2020, pp. 375–395.

[9] H.T.D. Vu, D.D. Tran, A. Schenk, C.P. Nguyen, H.L. Vu, P. Oberle, V.C. Trinh, F. Nestmann, Land use change in the Vietnamese Mekong Delta: new evidence from remote sensing, Sci. Total Environ. 813 (2022) 151918, https://doi.org/10.1016/j.scitotenv.2021.151918.

[10] H.V.T. Minh, K. Lavane, T.V. Ty, N.K. Downes, T.T.K. Hong, P. Kumar, Evaluation of the impact of drought and saline water intrusion on rice yields in the Mekong Delta, Vietnam, Water 14 (21) (2022) 3499, https://doi.org/10.3390/w14213499.

[11] B. Nguyen Thanh, T. Le Van Thuy, M. Nguyen Anh, M. Nguyen Nguyen, T. Nguyen Hieu, Drivers of agricultural transformation in the coastal areas of the Vietnamese Mekong Delta, Environ. Sci. Pol. 122 (2021) 49–58, https://doi.org/10.1016/j.envsci.2021.04.010.

[12] S.v. Berkum, J. Dengerink, R. Ruben, The Food Systems Approach: Sustainable Solutions for a Sufficient Supply of Healthy Food, Wageningen Economic Research, The Hague, 2018.

[13] FAO, Primary production – Section 2, FAO Good Hygiene Practices (GHP) and Hazard Analysis and Critical Control Point (HACCP) Toolbox for Food Safety, 2023. Rome.

[14] D. Nhan, N. Be, N. Trung, Water Use and Competition in the Mekong Delta, 2007. Vietnam.

[15] G.-J. Wilbers, R. Creusen, W. Appelman, K.C.W. van Dongen, D.K. Nhan, V.P. D. Tri, Towards transition pathways in agriculture and livestock in the Vietnamese Mekong Delta from an agricultural water management perspective, Int. J. Water Gov. 12 (2025), https://doi.org/10.59490/ijwg.12.2025.6993.

[16] C. Ringler, M. Agbonlahor, J. Barron, K. Baye, J.V. Meenakshi, D.K. Mekonnen, S. Uhlenbrook, The role of water in transforming food systems, Global Food Secur. 33 (2022) 100639, https://doi.org/10.1016/j.gfs.2022.100639.

[17] L.C.B. Tho, C. Umetsu, Rice variety and sustainable farming: a case study in the Mekong Delta, Vietnam, Environ. Chall. 8 (2022) 100532, https://doi.org/10.1016/j.envc.2022.100532.

[18] M. Mallareddy, R. Thirumalaikumar, P. Balasubramanian, R. Naseeruddin, N. Nithya, A. Mariadoss, N. Eazhilkrishna, A.K. Choudhary, M. Deiveegan, E. Subramanian, B. Padmaja, S. Vijayakumar, Maximizing water use efficiency in rice farming: a comprehensive review of innovative irrigation management technologies, Water 15 (10) (2023) 1802, https://doi.org/10.3390/w15101802.

[19] S. Salaheen, D. Biswas, Chapter 2 - organic farming practices: integrated culture versus monoculture, in: D. Biswas, S.A. Micallef (Eds.), Safety and Practice for Organic Food, Academic Press, 2019, pp. 23–32.

[20] J. Suh, Theory and reality of integrated rice–duck farming in Asian developing countries: a systematic review and SWOT analysis, Agric. Syst. 125 (2014) 74–81, https://doi.org/10.1016/j.agsy.2013.11.003.

[21] B. Kaveney, E. Barrett-Lennard, K. Chau Minh, M. Dang Duy, K.P. Nguyen Thi, P. Kristiansen, S. Orgill, B. Stewart-Koster, J. Condon, Inland dry season saline intrusion in the Vietnamese Mekong River Delta is driving the identification and implementation of alternative crops to rice, Agric. Syst. 207 (2023) 103632, https://doi.org/10.1016/j.agsy.2023.103632.

[22] K. Kim Dang, T.H. Do, T.H.L. Le, T.T.H. Le, T.D. Pham, Impacts of farmers' adaptation to drought and salinity intrusion on rice yield in Vietnam's Mekong Delta, J. Agribus. Dev. Emerg. Econ. 11 (1) (2021) 27–41. https://doi.org/10.1108/JADEE-08-2019-0132.

[23] FAO, Duck farming systems and Avian influenza in the Mekong Delta of Vietnam by Bui Xuan men, in: FAO Smallholder Poultry Production, FAO, Rome, 2010.

[24] N.N. Tri, N.P.C. Tu, D.T. Nhan, N.V. Tu, An Overview of Aquaculture Development in Vietnam, 2021.

[25] J.L. Banach, H.J. Van Der Fels-Klerx, Microbiological reduction strategies of irrigation water for fresh produce, J. Food Protect. 83 (6) (2020) 1072–1087, https://doi.org/10.4315/JFP-19-466.

[26] Y. Pachepsky, D.R. Shelton, J.E.T. McLain, J. Patel, R.E. Mandrell, Chapter two - irrigation waters as a source of pathogenic microorganisms in produce: a review, in: D.L. Sparks (Ed.), Advances in Agronomy, Academic Press, 2011, pp. 75–141.

[27] T.G. Nguyen, K.A. Phan, T.H.N. Huynh, Major concerns of surface water quality in south-west coastal regions of Vietnamese Mekong Delta, Sustain. Environ. Res. 32 (1) (2022) 46, https://doi.org/10.1186/s42834-022-00156-5.

[28] G.-J. Wilbers, Z. Sebesvari, A. Rechenburg, F.G. Renaud, Effects of local and spatial conditions on the quality of harvested rainwater in the Mekong Delta, Vietnam, Environ. Pollut. 182 (2013) 225–232, https://doi.org/10.1016/j.envpol.2013.07.019.

[29] N.T. Giao, H.T.H. Nhien, P.K. Anh, P. Thuptimdang, Groundwater quality assessment for drinking purposes: a case study in the Mekong Delta, Vietnam, Sci. Rep. 13 (1) (2023) 4380, https://doi.org/10.1038/s41598-023-31621-9.

[30] S.T. Nguyen, H. Honma, T. Geurden, M. Ikarash, Y. Fukuda, V.V. Huynh, D. T. Nguyen, Y. Nakai, Prevalence and risk factors associated with Cryptosporidium oocysts shedding in pigs in Central Vietnam, Res. Vet. Sci. 93 (2) (2012) 848–852, https://doi.org/10.1016/j.rvsc.2012.01.007.

[31] N.T. Tram, P.D. Phuc, N.H. Phi, L.T. Trang, T.T. Nga, H.T.T. Ha, P.D. Cam, T. Q. Canh, P. Karanis, Cryptosporidium and giardia in biogas wastewater: management of manure livestock and hygiene aspects using influent, effluent, sewage canal samples, vegetable, and soil samples, Pathogens 11 (2) (2022) 174, https://doi.org/10.3390/pathogens11020174.

[32] C.P. Gerba, C.Y. Choi, Role of irrigation water in crop contamination by viruses, in: S.M. Goyal (Ed.), Viruses in Foods, Springer US, Boston, MA, 2006, pp. 257–263.

[33] V.E. Prez, L.C. Martínez, M. Victoria, M.O. Giordano, G. Masachessi, V.E. Ré, J. V. Pavan, R. Colina, P.A. Barril, S.V. Nates, Tracking enteric viruses in green vegetables from central Argentina: potential association with viral contamination of irrigation waters, Sci. Total Environ. 637–638 (2018) 665–671, https://doi.org/10.1016/j.scitotenv.2018.05.044.

[34] N.Q.L. Tran, D. Connell, T. Hieu Nguyen, D. Phung, Climate Change and Water-Related Diseases in the Mekong Delta Region, Oxford University Press, 2023.

[35] T.T.N. Huynh, H.Q. Nguyen, P.V. Vinh, S. Baker, A. Pathirana, Enteric pathogens in flood-related waters in urban areas of the Vietnamese Mekong Delta: a case study of Ninh Kieu district, Can Tho city, Urban Water J. 16 (9) (2019) 634–641, https://doi.org/10.1080/1573062X.2020.1713381.

[36] B. Trung, T.-S. Dao, E. Faassen, M. Lürling, Cyanobacterial blooms and microcystins in Southern Vietnam, Toxins 10 (11) (2018) 471, https://doi.org/10.3390/toxins10110471.

[37] Y. Huang, K. Miyauchi, G. Endo, L.D. Don, N.C. Manh, C. Inoue, Arsenic contamination of groundwater and agricultural soil irrigated with the groundwater in Mekong Delta, Vietnam, Environ. Earth Sci. 75 (9) (2016) 757, https://doi.org/10.1007/s12665-016-5535-3.

[38] L. Sagar, S. Singh, M. Attri, S. Maitra, T. Shankar, M. Sairam, T. Aftab, A. Hossain, Arsenic contamination in soil and water across South East Asia: its impact and mitigation strategies, in: N.K. Niazi, I. Bibi, T. Aftab (Eds.), Global Arsenic Hazard: Ecotoxicology and Remediation, Springer International Publishing, Cham, 2023, pp. 533–560.

[39] N.D. Chau, Z. Sebesvari, W. Amelung, F.G. Renaud, Pesticide pollution of multiple drinking water sources in the Mekong Delta, Vietnam: evidence from two provinces, Environ. Sci. Pollut. Res. Int. 22 (12) (2015) 9042–9058, https://doi.org/10.1007/s11356-014-4034-x.

[40] T.H. Nguyen, An Overview of Agricultural Pollution in Vietnam: the Crop Sector, 2017.

[41] N.H. Lam, C.-R. Cho, K. Kannan, H.-S. Cho, A nationwide survey of perfluorinated alkyl substances in waters, sediment and biota collected from aquatic environment in Vietnam: distributions and bioconcentration profiles, J. Hazard. Mater. 323 (2017) 116–127, https://doi.org/10.1016/j.jhazmat.2016.04.010.

[42] B.K. Veettil, V. Puri, S. Acharki, R.D. Ward, N.D. Khoa, Microplastic pollution in Vietnam's estuarine, coastal and riverine environments: research advances and future prospects, Estuar. Coast Shelf Sci. 301 (2024) 108749, https://doi.org/10.1016/j.ecss.2024.108749.

[43] T.-C. Kieu-Le, Q.-T. Thuong, T.-N.-S. Truong, T.-M.-T. Le, Q.-V. Tran, E. Strady, Baseline concentration of microplastics in surface water and sediment of the northern branches of the Mekong River Delta, Vietnam, Mar. Pollut. Bull. 187 (2023) 114605, https://doi.org/10.1016/j.marpolbul.2023.114605.

[44] D. Rodrigo, C.M. Rosell, A. Martinez, Risk of bacillus cereus in relation to rice and derivatives, Foods 10 (2) (2021), https://doi.org/10.3390/foods10020302.

[45] German Federal Institute for Risk Assessment (BfR), Risky delicacy: pink duck breast. https://www.bfr.bund.de/en/press_information/2008/02/risky_delicacy_pink_duck_breast-10703.html, 2008. (Accessed 15 April 2024).

[46] A. Gonçalves-Tenório, B.N. Silva, V. Rodrigues, V. Cadavez, U. Gonzales-Barron, Prevalence of pathogens in poultry meat: a meta-analysis of European published surveys, Foods 7 (5) (2018), https://doi.org/10.3390/foods7050069.

[47] D. Ljubojević Pelić, S. Vidaković Knežević, M. Pelić, M. Živkov Baloš, D. Milanov, The epidemiological significance of duck meat as a source of Salmonella spp. a review, Worlds Poult. Sci. J. 77 (1) (2021) 105–114, https://doi.org/10.1080/00439339.2020.1866960.

[48] A. Delabouglise, B. Nguyen-Van-Yen, N.T.L. Thanh, H.T.A. Xuyen, P.N. Tuyet, H. M. Lam, M.F. Boni, Poultry population dynamics and mortality risks in smallholder farms of the Mekong River Delta region, BMT Vet. Res. 15 (2019), https://doi.org/10.1186/s12917-019-1949-y.

[49] EFSA, Avian influenza. https://www.efsa.europa.eu/en/topics/topic/avian-influenza, 2024. (Accessed 2 May 2024).

[50] A. Novoslavskij, M. Terentjeva, I. Eizenberga, O. Valciņa, V. Bartkevičs, A. Bērziņš, Major foodborne pathogens in fish and fish products: a review, Ann. Microbiol. 66 (1) (2016) 1–15, https://doi.org/10.1007/s13213-015-1102-5.

[51] FAO, Risk Profile Group B Streptococcus (GBS) Streptococcus Agalactiae Sequence Type (ST) 283 in Freshwater Fish, 2021.

[52] T.H. Nguyen, P. Dorny, T.T.G. Nguyen, V. Dermauw, Helminth infections in fish in Vietnam: a systematic review, Int. J. Parasitol. Parasites Wildl. 14 (2021) 13–32, https://doi.org/10.1016/j.ijppaw.2020.12.001.

[53] G.H. Liu, M.M. Sun, H.M. Elsheikha, Y.T. Fu, H. Sugiyama, K. Ando, W.M. Sohn, X.Q. Zhu, C. Yao, Human gnathostomiasis: a neglected food-borne zoonosis, Parasit. Vectors 13 (1) (2020) 616, https://doi.org/10.1186/s13071-020-04494-4.

[54] H.S. Lee, B. Wieland, H. Nguyen, U. Magnusson, Use of Veterinary Drugs in Livestock Production in Vietnam: Study Report on Survey in CRP Livestock Targeted Sites, CGIAR, 2019.

[55] J.J. Carrique-Mas, M. Choisy, N. Van Cuong, G. Thwaites, S. Baker, An estimation of total antimicrobial usage in humans and animals in Vietnam, Antimicrob. Resist. Infect. Control 9 (1) (2020) 16, https://doi.org/10.1186/s13756-019-0671-7.

[56] M. Choisy, N. Van Cuong, T.D. Bao, B.T. Kiet, B.V. Hien, H.V. Thu, N. Chansiripornchai, E. Setyawan, G. Thwaites, J. Rushton, J. Carrique-Mas, Assessing antimicrobial misuse in small-scale chicken farms in Vietnam from an observational study, BMT Vet. Res. 15 (1) (2019) 206, https://doi.org/10.1186/s12917-019-1947-0.

[57] A. Petersen, J.S. Andersen, T. Kaewmak, T. Somsiri, A. Dalsgaard, Impact of integrated fish farming on antimicrobial resistance in a pond environment, Appl. Environ. Microbiol. 68 (12) (2002) 6036–6042, https://doi.org/10.1128/aem.68.12.6036-6042.2002.

[58] M. Zhou, Y. Xu, P. Ouyang, J. Ling, Q. Cai, Q. Du, L. Zheng, Spread of resistance genes from duck manure to fish intestine in simulated fish-duck pond and the promotion of cefotaxime and as, Sci. Total Environ. 731 (2020) 138693, https://doi.org/10.1016/j.scitotenv.2020.138693.

[59] M.F. Abdallah, W.H.R. Van Hassel, M. Andjelkovic, A. Wilmotte, A. Rajkovic, Cyanotoxins and food contamination in developing countries: review of their types, toxicity, analysis, occurrence and mitigation strategies, Toxins 13 (11) (2021) 786, https://doi.org/10.3390/toxins13110786.

[60] F.S. Ferre, Worldwide occurrence of mycotoxins in rice, Food Control 62 (2016) 291–298, https://doi.org/10.1016/j.foodcont.2015.10.051.

[61] L.T.K. Phan, S. De Saeger, M. Eeckhout, L. Jacxsens, Public health risk due to aflatoxin and fumonisin contamination in rice in the Mekong Delta, Vietnam, Food Saf. Risk 10 (1) (2023) 4, https://doi.org/10.1186/s40550-023-00104-0.

[62] J. Tolosa, Y. Rodríguez-Carrasco, M.J. Ruiz, P. Vila-Donat, Multi-mycotoxin occurrence in feed, metabolism and carry-over to animal-derived food products: a review, Food Chem. Toxicol. 158 (2021) 112661, https://doi.org/10.1016/j.fct.2021.112661.

[63] S.N. Mohd Nizam, N.S. Haji Baharudin, H. Ahmad, Application of pesticide in paddy fields: a Southeast Asia case study review, Environ. Geochem. Health 45 (8) (2023) 5557–5577, https://doi.org/10.1007/s10653-023-01668-8.

[64] G. Braun, M. Braun, J. Kruse, W. Amelung, F.G. Renaud, C.M. Khoi, M.V. Duong, Z. Sebesvari, Pesticides and antibiotics in permanent rice, alternating rice-shrimp and permanent shrimp systems of the coastal Mekong Delta, Vietnam, Environ. Int. 127 (2019) 442–451, https://doi.org/10.1016/j.envint.2019.03.038.

[65] U. Khumairoh, E.A. Lantinga, I. Handriyadi, R.P.O. Schulte, J.C.J. Groot, Agro-ecological mechanisms for weed and pest suppression and nutrient recycling in high yielding complex rice systems, Agric. Ecosyst. Environ. 313 (2021) 107385, https://doi.org/10.1016/j.agee.2021.107385.

[66] Y. Zhang, C. Guan, Z. Li, J. Luo, B. Ren, C. Chen, Y. Xu, J. Ding, H. Huang, Review of rice–fish–duck symbiosis system in China—One of the globally important ingenious agricultural heritage systems (GIAHS), Sustainability 15 (3) (2023) 1910. https://www.mdpi.com/2071-1050/15/3/1910.

[67] J. Lu, X. Li, Review of rice–fish-farming systems in China — one of the globally important ingenious agricultural heritage systems (GIAHS), Aquaculture 260 (1) (2006) 106–113, https://doi.org/10.1016/j.aquaculture.2006.05.059.

[68] K.C. Parsons, P. Mineau, R.B. Renfrew, Effects of pesticide use in rice fields on birds, Waterbirds 33 (sp1) (2010) 193–218, https://doi.org/10.1675/063.033.s115, 26.

[69] A. Rashid, B.J. Schutte, A. Ulery, M.K. Deyholos, S. Sanogo, E.A. Lehnhoff, L. Beck, Heavy metal contamination in agricultural soil: environmental pollutants affecting crop health, Agronomy 13 (6) (2023) 1521, https://doi.org/10.3390/agronomy13061521.

[70] D.B. Chu, H.T. Duong, M.T. Nguyet Luu, H.-A. Vu-Thi, B.-T. Ly, V.D. Loi, Arsenic and heavy metals in Vietnamese rice: assessment of human exposure to these elements through rice consumption, J. Anal. Methods Chem. 2021 (2021) 6661955, https://doi.org/10.1155/2021/6661955.

[71] T.P. Nguyen, H. Ruppert, B. Sauer, T. Pasold, Harmful and nutrient elements in paddy soils and their transfer into rice grains (Oryza sativa) along two river systems in northern and central Vietnam, Environ. Geochem. Health 42 (1) (2020) 191–207, https://doi.org/10.1007/s10653-019-00333-3.

[72] M.M. Uddin, M.C.M. Zakeel, J.S. Zavahir, F. Marikar, I. Jahan, Heavy metal accumulation in rice and aquatic plants used as human food: a general review, Toxics 9 (12) (2021), https://doi.org/10.3390/toxics9120360.

[73] H. Li, N. Luo, Y.W. Li, Q.Y. Cai, H.Y. Li, C.H. Mo, M.H. Wong, Cadmium in rice: transport mechanisms, influencing factors, and minimizing measures, Environ. Pollut. 224 (2017) 622–630, https://doi.org/10.1016/j.envpol.2017.01.087.

[74] Z. Atafar, A. Mesdaghinia, J. Nouri, M. Homaee, M. Yunesian, M. Ahmadimoghaddam, A.H. Mahvi, Effect of fertilizer application on soil heavy metal concentration, Environ. Monit. Assess. 160 (1) (2010) 83–89, https://doi.org/10.1007/s10661-008-0659-x.

[75] E. Gimeno-García, V. Andreu, R. Boluda, Heavy metals incidence in the application of inorganic fertilizers and pesticides to rice farming soils, Environ. Pollut. 92 (1) (1996) 19–25, https://doi.org/10.1016/0269-7491(95)00090-9.

[76] P. Adamse, H.J. Van der Fels-Klerx, J. de Jong, Cadmium, Lead, Mercury and Arsenic in animal feed and feed materials – trend analysis of monitoring results, Food Addit. Contam.: Part A. 34 (8) (2017) 1298–1311, https://doi.org/10.1080/19440049.2017.1300686.

[77] M. Hejna, D. Gottardo, A. Baldi, V. Dell'Orto, F. Cheli, M. Zaninelli, L. Rossi, Review: nutritional ecology of heavy metals, Animal 12 (10) (2018) 2156–2170, https://doi.org/10.1017/S175173111700355X.

[78] P. Chanpiwat, S. Sthiannopkao, K. Widmer, S. Himeno, H. Miyataka, N.-U. Vu, V.-V. Tran, T.-T.-N. Pham, Assessment of metal and bacterial contamination in cultivated fish and impact on human health for residents living in the Mekong Delta, Chemosphere 163 (2016) 342–350, https://doi.org/10.1016/j.chemosphere.2016.08.003.

[79] Z.J. Mbilu, M.E. Lyimo, Heavy metals contamination in soils and selected edible parts of free-range local chicken, Int. J. Env. Sci. Tech. 12 (4) (2015) 1409–1414, https://doi.org/10.1007/s13762-014-0519-x.

[80] T. Yazdanparast, V. Strezov, P. Wieland, Y.-J. Lai, D.E. Jacob, M.P. Taylor, Lead poisoning of backyard chickens: implications for urban gardening and food production, Environ. Pollut. 310 (2022) 119798, https://doi.org/10.1016/j.envpol.2022.119798.

[81] Y. Duan, Q. Li, L. Zhang, Z. Huang, Z. Zhao, H. Zhao, J. Du, J. Zhou, Toxic metals in rice-fish co-culture systems and human health, Ecotoxicol. Environ. Saf. 241 (2022) 113797, https://doi.org/10.1016/j.ecoenv.2022.113797.

[82] K. Olson, L. Morton, Long-term fate of Agent Orange and dioxin TCDD contaminated soils and sediments in Vietnam hotspots, Open J. Soil Sci. 9 (2019) 1–34, https://doi.org/10.4236/ojss.2019.91001.

[83] T.T.A. My, N.D. Dat, K. Van Langenhove, M.S. Denison, H.T. Long, M. Elskens, Evaluation of the dioxin-like toxicity in soil samples from Thua Thien Hue province using the AhR-CALUX bioassay – an update of Agent Orange contamination in Vietnam, Ecotoxicol. Environ. Saf. 212 (2021) 111971, https://doi.org/10.1016/j.ecoenv.2021.111971.

[84] P. Adamse, S. Schoss, R.M.C. Theelen, R.L.A.P. Hoogenboom, Levels of dioxins and dioxin-like PCBs in food of animal origin in the Netherlands during the period 2001–2011, Food Addit. Contam.: Part A. 34 (1) (2017) 78–92, https://doi.org/10.1080/19440049.2016.1252065.

[85] R. Weber, C. Herold, H. Hollert, J. Kamphues, M. Blepp, K. Ballschmiter, Reviewing the relevance of dioxin and PCB sources for food from animal origin and the need for their inventory, control and management, Environ. Sci. Eur. 30 (1) (2018) 42, https://doi.org/10.1186/s12302-018-0166-9.

[86] A.D. Kudryavtseva, A.A. Shelepchikov, E.S. Brodsky, Free-range chicken eggs as a bioindicator of dioxin contamination in Vietnam, including long-term Agent Orange impact, Emerging Contam. 6 (2020) 114–123, https://doi.org/10.1016/j.emcon.2020.02.003.

[87] J. Jovanovic, S. Tretiak, K. Begyn, A. Rajkovic, Detection of enterotoxigenic psychrotrophic presumptive bacillus cereus and cereulide producers in food products and ingredients, Toxins 14 (4) (2022), https://doi.org/10.3390/toxins14040289.

[88] A. Reale, M.C. Messia, C. Pulvento, A. Lavini, S. Nazzaro, T. Di Renzo, Microbial and qualitative traits of Quinoa and Amaranth seeds from experimental fields in Southern Italy, Foods 12 (9) (2023) 1866, https://doi.org/10.3390/foods12091866.

[89] P. Canaviri Paz, R.J. Janny, Å. Håkansson, Safeguarding of quinoa beverage production by fermentation with Lactobacillus plantarum DSM 9843, Int. J. Food Microbiol. 324 (2020) 108630, https://doi.org/10.1016/j.ijfoodmicro.2020.108630.

[90] W. Siri-Anusornsak, O. Kolawole, W. Mahakarnchanakul, B. Greer, A. Petchkongkaew, J. Meneely, C. Elliott, K. Vangnai, The occurrence and co-occurrence of regulated, emerging, and masked mycotoxins in rice bran and

maize from Southeast Asia, Toxins (Basel) 14 (8) (2022), https://doi.org/10.3390/toxins14080567.
[91] U. Pappier, V. Fernández Pinto, G. Larumbe, G. Vaamonde, Effect of processing for saponin removal on fungal contamination of quinoa seeds (Chenopodium quinoa Willd.), Int. J. Food Microbiol. 125 (2) (2008) 153–157, https://doi.org/10.1016/j.ijfoodmicro.2008.03.039.
[92] P.G. Vásquez-Ocmín, G. Marti, A. Gadea, G. Cabanac, J.A. Vásquez-Briones, S. Casavilca-Zambrano, N. Ponts, P. Jargeat, M. Haddad, S. Bertani, Metabotyping of Andean pseudocereals and characterization of emerging mycotoxins, Food Chem. 407 (2023) 135134, https://doi.org/10.1016/j.foodchem.2022.135134.
[93] EC, Commission regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing regulation (EC) no 1881/2006. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R0915&qid=1688376879435, 2023.
[94] M. Kluche, E.F. Hoek-van den Hil, E.D. van Asselt, Overview of Chemical Hazards in Cereals, Seeds and Nuts, 2020.
[95] EC, Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 Concerning the Placing of Plant Protection Products on the Market and Repealing Council Directives 79/117/EEC and 91/414/EEC, 2009. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02009R1107-20221121.
[96] P. Nhat, Vietnam to issue technical regulations on EO residue limit. https://hanoitimes.vn/vietnam-to-issue-technical-regulations-on-eo-residue-limit-318695.html, 2021. (Accessed 15 April 2024).
[97] M. Amjad, M.M. Iqbal, G. Abbas, A.B.U. Farooq, M.A. Naeem, M. Imran, B. Murtaza, M. Nadeem, S.-E. Jacobsen, Assessment of cadmium and lead tolerance potential of quinoa (Chenopodium quinoa Willd) and its implications for phytoremediation and human health, Environ. Geochem. Health 44 (5) (2022) 1487–1500, https://doi.org/10.1007/s10653-021-00826-0.
[98] M. Haseeb, S. Iqbal, M.B. Hafeez, H. Baloch, N. Zahra, M. Mumtaz, G. Ahmad, E. M. Fatima, Jahanzaib, S. Raza, A. Raza, M.S. Saddiq, Characterizing of heavy metal accumulation, translocation and yield response traits of Chenopodium quinoa, J. Agric. Food Res. 14 (2023) 100741, https://doi.org/10.1016/j.jafr.2023.100741.
[99] I. Pizarro, M. Gómez-Gómez, J. León, D. Román, M.A. Palacios, Bioaccessibility and arsenic speciation in carrots, beets and quinoa from a contaminated area of Chile, Sci. Total Environ. 565 (2016) 557–563, https://doi.org/10.1016/j.scitotenv.2016.04.199.
[100] Y. Román-Ochoa, G.T. Choque Delgado, T.R. Tejada, H.R. Yucra, A.E. Durand, B. R. Hamaker, Heavy metal contamination and health risk assessment in grains and grain-based processed food in Arequipa region of Peru, Chemosphere 274 (2021) 129792, https://doi.org/10.1016/j.chemosphere.2021.129792.
[101] N.N. Tereshchenko, V.Y. Proskurnin, O.D. Chuzhikova-Proskurnina, N.T. Hiep, Dissolved and particulate metals and metalloids in the eastern Mekong Delta, Vietnam, Mar. Pollut. Bull. 206 (2024) 116679, https://doi.org/10.1016/j.marpolbul.2024.116679.
[102] WUR, Dutch soybeans and polder rice: new crops in a changing climate. https://www.wur.nl/en/show-longread/dutch-soybeans-and-polder-rice-new-crops-in-a-changing-climate.htm, 2024. (Accessed 19 December 2024).
[103] S. Harmeling, Global Climate Risk Index 2011, Germanwatch, 2011.
[104] CIAT; World Bank, Climate-smart agriculture in Bangladesh, in: CSA Country Profiles for Asia Series, International Center for Tropical Agriculture (CIAT); World Bank, Washington, 2017.
[105] Z.O. Barois, M.M. Hasan, F. Ahmed, S.R. Rozario, M.A. Islam, M.M.H. Kazal, N. Shaheen, J. Dengerink, An Overview of the Bangladesh Food System: Outcomes, Drivers and Activities, Foresight4Food: Oxford, 2024.
[106] J. Ferdousi, Determination of heavy metals from pesticide, in: Department of Agricultural Chemistry, Sher-E-Bangla Agricultural University, Dhaka, 2022.