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Selection of critical factors for identifying emerging food safety risks in dynamic food production chains

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ABSTRACT

A pro-active emerging risk identification system starts with the selection of critical factors related to the occurrence of emerging hazards. This paper describes a method to derive the most important factors in dynamic production chains starting from a gross list of critical factors. The method comprised the semi-quantitative evaluation of the critical factors for a relatively novel product on the Dutch market and a related traditional product. This method was tested in an expert study with three case studies. The use of group discussion followed by individual ranking in an expert study proved to be a powerful tool in identifying the most important factors for each case. Human behaviour (either producers' behaviour or human knowledge) was the most important factor for all three cases. The expert study showed that further generalization of critical factors based on product characteristics may be possible.

1. Introduction

Food safety has ameliorated over the years due to the application of Hazard Analysis Critical Control Points (HACCP) systems and the development of risk assessments (RA). HACCP is a systematic approach to the identification, evaluation and control of those steps in food manufacturing that are critical to product safety. The basic objective of the HACCP concept is assuring the production of safe food products by prevention instead of quality inspection (Luning, Marcelis, & Jongen, 2002). HACCP is a system applied to identify known food safety hazards, and is currently applied per stage in the production supply chain instead of the total production chain. Food safety RA comprises the scientific evaluation of known or potential adverse health effects resulting from human exposure to specific food borne hazards (Codex, 1999). It typically uses data on the particular hazard and production chain under consideration, and modelling to estimate the final likelihood of harm due to human exposure. Both HACCP and RA focus on known hazards and make use of historical data related to the particular hazard(s) as well as to the particular chain of interest. Risk managers and assessors need to get access to all available data on food safety hazards as soon as possible. For this purpose, there are various warning systems for notification on the likelihood of a hazard. Examples are the EU Rapid Alert System on Food and Feed (RASFF, http://ec.europa.eu/food/food/rapidalert/index_en.htm), the WHO-Global Outbreak Alert and Response Network (http://www.who.int/csr/outbreaknetwork/en/) and the Global Public Health Intelligence Network (GPHIN) in Canada (http://www.phac-aspc.gc.ca/media/nr-rp/2004/2004_gphin-rmispbk_e.html) (Marvin et al., 2009). Such warning systems address known, well-characterized food and feed safety hazards (Marvin et al., 2009; VWA, 2006).

In order to identify and prevent emerging hazards leading to food safety risks, it is necessary to move towards a more pro-active system for identification of emerging food and feed related risks (Marvin et al., 2009). An emerging risk (ER) is defined as a risk resulting from a newly identified hazard to which a significant exposure may occur, or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard (EFSA, 2007). ER may be directly linked to the food production chain or indirectly connected to it (Marvin et al., 2009). Therefore, in order to identify emerging risks in an early stage, an holistic approach is proposed (VWA, 2005). This approach implies that emergence of a risk can be the result from factors inside the production chain (endogenous) or outside the chain (exogenous). In addition, emergence of hazards related to risks is usually a result of a particular change inside or outside the production chain. A pro-active system for the identification of emerging food safety risks should, therefore, preferable be based on (endogenous and exogenous) factors characterizing the dynamics of a food production system. Endogenous factors (associated with changes within the production chain) may be related to technological innovations, their implementation driven from production perspectives. Exogenous

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factors (associated with changes outside the production chain) may include for example economic changes, climate change, international trade and changes in human behaviour. These exogenous factors are related to influential sectors as described in the EMRISK and PERI-APT project (VWA, 2005, 2006).

Once critical factors are identified, signals can be established that indicate (directly or indirectly) the occurrence of an emerging hazard; the so-called indicators. An example of a critical factor is climate change with temperature and rainfall as indicators (Van der Fels-Klerx, Kandhai, & Booij, 2008; VWA, 2005). These indicators form the key elements of an ER identification system. For these key indicators, information sources (data and expertise) and critical limits should be determined. When the limit of one or more indicators is exceeded, required actions can be taken in an early stage to prevent food safety problems occurring as a result of substantial changes in novel and/or dynamic production chains (VWA, 2006).

Several studies have been performed on the identification of critical factors to be used in an ER identification system. In these studies, a retrospective approach has been applied in which cases from the past were analysed in order to select the most important critical factors. Examples of cases studied are Avian Influenza (AI), Severe Acute Respiratory Syndrome (SARS), acrylamide, trans fatty acids, dioxins and Bovine Spongiform Encephalopathy (BSE) (Hagenaars et al., 2006; VWA, 2005, 2006). Although these studies elaborated on critical factors, they are restricted since they are event and/or hazard driven and, consequently, the results may be case-sensitive. As such, it is unclear whether these findings are also applicable to identify emerging food safety risks in dynamic production chains. The aim of this research is to explore the feasibility of a systematic approach to identify the most important critical factors related to changes in production chains that may lead to food safety problems.

2. Materials and methods

The method developed, to identify critical factors for emerging risks related to dynamics in production chains, was based on a two-stage approach:

1. Identification of the most important critical factors indicating changes in production chains.
2. Linking the selected factors to the occurrence of emerging food safety risks.

For this purpose, a comprehensive list of potential critical factors was established based on a literature review (Section 2.1) and their importance evaluated for three cases. The cases consisted of a traditional product versus a relatively novel product on the

Table 1
Critical factors for pasteurized milk and Valess (a vegetarian product prepared from algae and curdled milk). X = expert; G = group consensus workshop.

	Pasteurized milk 2006 compared to 2000										Valess compared to pasteurized milk in 2000									
	Identified change[a]					Related food safety risk[b]					Identified change[a]					Related food safety risk[b]				
	−2	−1	0	+1	+2	−2	−1	0	+1	+2	−2	−1	0	+1	+2	−2	−1	0	+1	+2
Endogenous factors																				
1. Number of chain participants			XG					XG						G	XG				XG	
2. Number of processing steps			G	X G			XG							G	XG				XG	
3. Number of raw materials			XG					XG							XG				XG	
4. Number of suppliers of raw materials	G	G		X			G	G	X			G	G		X			G	X	
5. Logistics (distribution of food over the chain)				XG			G		X						XG				XG	G
6. Destination of produce (niche, local, export)			G	X				XG					G	X				XG		
7. Firm size				XG	G		GX	G						XG	G				XG	G
8. Information exchange				XG			XG							XG			XG			
9. Contractual agreements (quality, safety)				XG			XG	G						XG			XG	G		
10. Integration and cooperation				XG			XG	G						XG			XG	G		
Producers' behaviour:																				
11. Food safety awareness				XG			XG	G					XG				XG	G		
12. Probability of detection				XG			XG						XG				XG			
13. Severity of sanction				XG			XG						XG				XG			
Technological innovation:																				
14. Product			XG	XG			XG	XG							XG		X		XG	
15. Package			XG	G				XG						X	G			G	X	
16. Transport (e.g. temperature)			XG	G			G	XG					XG	XG				XG	XG	
17. Process				XG			XG								XG				XG	G
18. Genetically modified raw materials[c]			XG					XG					XG					XG		
Exogenous factors																				
19. Origin of raw materials, global sourcing			XG					XG					XG	XG				XG	XG	G
20. Legal requirements			G	XG	G		G	XG					G	XG	G		G	XG		
21. Impact climate change			XG	G				XG	G				XG	G				XG	G	
22. Economic status			G	X				G	X					XG	G			G	X	
Consumer factors																				
23. Demand (quantity)		X	G					XG					G	X				XG		
24. Assortment				XG				XG						XG				XG		
Demand with respect to:																				
25. Environment			XG	G				XG					XG					XG		
26. Animal welfare			X	G	G			XG					X	G	G			XG		
27. Sensory-quality			XG					XG					XG					XG		
28. Convenience			XG	XG				XG					X	G	G			XG		
29. Health			XG	G				XG					G	XG				XG		

[a] Much less (−2), less (−1), no change (0), more (+1) much more (+2).
[b] Substantially declined food safety risk (−2), declined risk (−1), no impact (0), increased risk (+1) substantially increased risk (+2).
[c] Excluding animal feed.

Dutch market for the same food chain (Section 2.2). By means of expert elicitation, the critical factors indicating change in a production chain and their subsequent potential food safety implications were evaluated in each of the three cases (Section 2.3).

2.1. Identification of critical factors

First a gross list of critical factors was compiled that characterize both dynamics in food supply chains and potential food safety risks. Factors were divided into endogenous, exogenous and consumer related factors. The latter are also exogenous factors; however, they have a more short-term effect in comparison with exogenous factors such as climate change. For example, increased individualization in society (a lifestyle change) gives a higher demand for smaller consumption portions and ready-to-eat foods. This has a short-term effect on the production of novel products that can fulfil this demand. Therefore, consumer related factors are treated separately in this paper.

The gross list of critical factors related to the influential sectors identified in the EMRISK (VWA, 2006) and PERI-APT (VWA, 2005) project. This list was downsized based on results of (retrospective) cases (Hagenaars et al., 2006; Kleter, Groot, Poelman, Kok, & Marvin, 2009; Kleter, Poelman, Groot, & Marvin, 2006; VanderRoest et al., 2007) resulting in a list of critical factors that were generally seen as important in the sense that they both indicate dynamics in the food chain and can be linked to food safety risks (see Tables 1–3).

The first six factors (number of chain participants, number of processing steps, number of raw materials, number of suppliers of raw materials, logistics and destination of produce) relate to the food chain complexity. The more complex the system is, the higher the possibility of errors resulting in food safety risks. Factors 7–10 (firm size, information exchange, contractual agreements and integration and cooperation) are linked to the producers' attitude towards food safety (Deneux, Van der Fels-Klerx, Tromp, & De Vlieger, 2005). It is assumed that larger firms (factor 7) are more up-to-date with food safety requirements, which thus reduces food safety risks (Holt & Henson, 2000). Furthermore, network embeddedness (characterized by factors 8–10) influence the food safety status of a company (Deneux et al., 2005). The effect of companies on food safety risk is further characterized in producers' compliance to food safety regulations (factors 11–13). This compliance can be quantified using the 'Table of Eleven', developed by the Dutch Ministry of Justice (2006). The approach comprises 11 dimensions,

Table 2
Critical factors for domestic fruit and imported fruit (X = expert; G = group consensus workshop).

	Domestic fruit (Dutch apple) in 2006 compared to 2000										Exotic fruit (Mango) compared to domestic fruit in 2000									
	Identified change[A]					Related food safety risk[B]					Identified change[A]					Related food safety risk[B]				
	−2	−1	0	+1	+2	−2	−1	0	+1	+2	−2	−1	0	+1	+2	−2	−1	0	+1	+2
Endogenous factors																				
1. Number of chain participants		XG					G	X							XG				G	X
2. Number of processing steps			XG					XG					XG					XG		
3. Number of raw materials																				
4. Number of suppliers of raw materials		XG						XG							XG				G	X
5. Logistics (distribution of food over the chain)			XG					XG						X	G				XG	
6. Destination of produce (niche, local, export)				XG				XG						XG				XG		
7. Firm size				XG			G	X			X		G	G	G			G	G	X
8. Information exchange			X	G			G	X			X	G							XG	
9. Contractual agreements (quality, safety)			X	G			G	X			X	G	G						G	X
10. Integration and cooperation				XG			G	X			XG	G							XG	G
Producers' behaviour:																				
11. Food safety awareness				XG			XG				XG	G	G					G	G	XG
12. Probability of detection				XG			XG				XG	G	G					G	G	XG
13. Severity of sanction			X	G			G	X			X	G	G				G	G		X
Technological innovation:																				
14. Product			G	X				XG	G					XG				X	G	
15. Package			X	G				XG						XG				XG		
16. Transport (e.g. temperature)			XG					XG					X	G				X	G	
17. Process			XG					XG					XG					XG		
18. Genetically modified raw materials			XG					XG					XG					XG		
Exogenous factors																				
19. Origin of raw materials, global sourcing			XG					XG							XG			G	G	XG
20. Legal requirements[C]				XG			XG				X^{a}G^a		X^{b}G^b					X^{b}G^b		X^{a}G^a
21. Impact climate change			XG					XG					X G					XG		
22. Economic status			XG					XG						XG				XG		
Consumer factors																				
23. Demand (quantity)			XG					XG						XG				XG		
24. Assortment				XG				XG						XG				X	G	
Demand with respect to:																				
25. Environment				XG			XG						X	G				XG		
26. Animal welfare																				
27. Sensory-quality			G	X				XG						XG				XG		
28. Convenience			XG					XG					XG					XG		
29. Health			XG					XG					XG					XG		

[A] Much less (−2), less (−1), no change (0), more (+1) much more (+2).
[B] Substantially declined food safety risk (−2), declined risk (−1), no impact (0), increased risk (+1) substantially increased risk (+2).
[C] The "a" relates to legal requirements in the country of origin and the issue of frequently changing legal requirements in the Netherlands; "b" relates to the fact that, at a certain point of time, legal requirements for produce on the Dutch market are in principle identical for imported and Dutch produce.

Table 3
Critical factors for table potato and frozen stew (X = expert; G = group consensus workshop).

	Table potato 2006 compared to 2000										Frozen stew compared to table potato in 2000									
	Identified change[a]					Related food safety risk[b]					Identified change[a]					Related food safety risk[b]				
	−2	−1	0	+1	+2	−2	−1	0	+1	+2	−2	−1	0	+1	+2	−2	−1	0	+1	+2
Endogenous factors																				
1. Number of chain participants			XG					XG							XG				XG	G
2. Number of processing steps			XG					XG							XG				XG	
3. Number of raw materials			XG					XG							XG				XG	
4. Number of suppliers of raw materials		XG					X	G					XG				X	G		
5. Logistics (distribution of food over the chain)			XG					XG							XG				X	G
6. Destination of produce (niche, local, export)			XG					XG				G	X					XG		
7. Firm size				XG			XG						G	X			X	G		
8. Information exchange			XG					XG					XG					XG		
9. Contractual agreements (quality, safety)				XG			XG						X	G			X	G		
10. Integration and cooperation			XG					XG					X	G			G	X		
Producers' behaviour:																				
11. Food safety awareness				XG			G	X						XG		G		X		
12. Probability of detection			X	G			G	X						X	G	G		X		
13. Severity of sanction			X	G			G	X					X		G	G		X		
Technological innovation:																				
14. Product			XG					XG							XG			X	G	
15. Package			XG					XG							XG			XG		
16. Transport (e.g. temperature)			XG	G				G	X						XG				XG	
17. Process			XG					XG							XG				XG	G
18. Genetically modified raw materials			XG					XG					XG					XG		
Exogenous factors																				
19. Origin of raw materials, global sourcing			XG					XG					XG					XG		
20. Legal requirements				XG			XG	G						XG			XG			
21. Impact climate change			XG					XG					XG					XG		
22. Economic status		G	XG					XG							XG			XG		
Consumer factors																				
23. Demand (quantity)		XG	XG					XG				X	X	G				XG		
24. Assortment		G	XG	X				XG					X	X	G			XG	G	
Demand with respect to:																				
25. Environment			X	G				XG					XG					XG		
26. Animal welfare																				
27. Sensory-quality			XG					XG					XG					XG		
28. Convenience			X		G			XG							XG		G	X		
29. Health			XG					XG				G	XG	X				XG		
Additional factors																				
30. Human factor												G							G	

[a] Much less (−2), less (−1), no change (0), more (+1) much more (+2).
[b] Substantially declined food safety risk (−2), declined risk (−1), no impact (0), increased risk (+1) substantially increased risk (+2).

which together decide the extent to which legislation is complied with. For food safety issues and ease of elicitation these dimensions were aggregated into three factors that were judged to be critical: food safety awareness, probability of detection and severity of sanctions (factors 11–13). More technical factors related to innovation in the food chain are indicated in factors 14–18 and are linked to the influential sector 'science and technology'.

Other influential sectors are represented in the exogenous and consumer factors 20–29. Origin of raw materials is a factor that links to the influential sector 'industry and trade'. It implies the effect of trade on the food chain and possible import of food safety hazards. Legal requirements (factor 20) is a factor belonging to the influential sector 'government and politics'. A change in legislation will influence the food safety status of the food chain. Climate change (factor 22) belongs to the influential sector 'environment and energy'. An increase in temperature and humidity may influence the growth of fungi and thus the production of mycotoxins. Economic status is a factor related to the influential sector 'economy and finance'. A change in economic status may influence the finances available for the security of food safety in the chain.

Consumer related factors added to the list are related to the influential sectors 'information and communication' and 'health' and capture factual items, such as size of demand (factor 23), factors reflecting recent food trends such as the demand for convenience foods (factor 28) (Bondt et al., 2005), and factors covering consumer concerns such as animal welfare (factor 26), see for instance Meuwissen and van der Lans (2005). These factors can be seen as drivers that influence food chain dynamics with possible consequences for food safety.

The usefulness of the thus obtained gross list of critical factors (presented in Tables 1–3) to identify dynamic production chains related to food safety risks was evaluated in an expert study using three case studies.

2.2. Selection of case studies

In each case study, the factors were scored for their relevance for a traditional product as well as for a relatively novel product on the Dutch market produced for the same food chain. For the traditional product, developments over time were scored by comparing the list of factors for the year 2006 with 2000. Subsequently, the novel product in 2006 was compared to the traditional product in 2000. By comparing the scores of the two assignments, those factors can be filtered that indicate both dynamics in chains and food safety consequences.

Case studies were selected based on the stimulus for innovation, which can arise from inside the chain (endogenous), outside the chain (exogenous) or through consumer demands. The three cases are outlined below:

Case 1: the dairy case. This case focused on a dairy production chain in which packed pasteurized milk was compared with "Valess" (a vegetarian product prepared from algae and curdled milk) to represent an endogenous stimulus (technological innovation).

Case 2: the fruit case. This case focused on a fruit production chain in which a traditional domestically produced apple was compared with imported mango to represent an exogenous long-term stimulus. Due to increased international trade and global sourcing, the import of exotic products increases resulting in a changed product supply. For this case, all chain related factors for the novel product (mango) were compared to Dutch apple in 2000, but consumer related factors were compared to mango in 2000, since the two products were too different for comparison related to these factors.

Case 3: the potato case. This case focused on a potato production chain, in which traditional table potato (used for preparing mashed potatoes) was compared with frozen stew (which contained besides mashed potatoes, vegetables, meat or cheese, and herbs) to represent a consumer stimulus (increased demand for convenience foods).

2.3. Expert study

Expert studies were used to select the most important factors from each of the three cases, and to relatively weigh the various factors. The procedure followed included.

2.3.1. Individual in-depth interviews

The aim of the interviews was to determine whether the formulated gross list of critical factors (see Section 2.1) contained all relevant critical factors that characterize both dynamics in production chains and related food safety risks. For the 'dairy' case, the quality assurance manager of the producer of both pasteurized milk and Valess was interviewed. For the 'fruit' case, two experts from an agri-food research organization were consulted. For the potato case, an agricultural production expert (farmer as well as consultant) and the manager of research and development from a stew producing factory were consulted.

2.3.2. Group discussion in a workshop

The aim of the workshop was to digest the most important critical factors for each case and to evaluate possible generalization per stimulus of innovation. In total 36 experts were invited to participate in the workshop including 10 risk managers, 14 experts from the food industry, three experts from socio-professional organizations and nine experts from research institutes in food safety. The experts were selected in such a way that knowledge and expertise from each case was represented as well as general food safety expertise. Half of the invited experts attended the workshop; including seven risk managers, five experts from the food industry, one from a socio-professional organization and five from research institutes. The workshop consisted of two rounds. In the first round, participants were divided into three subgroups and each subgroup was asked to evaluate one case. Experts were divided over the subgroups such that their expertise matched the case. The dairy case consisted of representatives of research institutes, dairy (regulatory) industrial organizations, food safety authorities and the Dutch ministry of health, welfare and sports. The fruit case consisted of representatives of research institutes, food safety authorities, the horticulture product board, a socio-professional organization and the ministry of agriculture, nature and food quality (department of trade and industry). The potato case consisted of representatives of research institutes, food safety authorities and the agricultural product board. The experts were asked to score a change (over the period of 2000–2006) in the listed critical factors from −2 (much less change) to +2 (much more change). For each change in critical factors, its subsequent consequences on food safety risks were scored from −2 (much less risk) to +2 (much more risk). The findings of the in-depth interviews were depicted on a scoring-card. The scores were orally clarified using the arguments of the interviewees. This offered a basis for discussion and the experts proceeded by taking up the scoring tasks themselves. By no means was a consensus strived for, the approach merely facilitated the clarification of definitions used and relevant arguments. After the most important factors were extracted from the three cases, the subgroups gathered for a plenary session. The aim of this second round of the workshop was to determine whether the obtained critical factors per case could be used in general for stimuli originating either from inside the production chain (dairy case), outside the production chain (fruit case) or driven by the consumer (potato case). This was done by comparing the various cases with other products or processes originating from an endogenous, exogenous or consumer stimulus. For the dairy case, which had an endogenous stimulus, examples used for the discussion were products produced under Modified Atmosphere Packaging (MAP) or Pulsed Electric Field (PEF). Another example comparable to the fruit case, which had an exogenous stimulus, is the increased import of exotic products like couscous or kumquat. An increasing amount of convenience products and functional foods were additional examples that were compared with the potato case that originated from a consumer stimulus.

2.3.3. Individual ranking

The aim of this part of the expert study was to further specify the critical factors that were characterized in the workshop as most important for each case. In a mailing round, participating experts were asked individually to score the most important critical factors identified for their case. Participants were asked to give a score to each of these factors (from 1 to 100) with the restriction that the sum of the scores should be 100. Subsequently, the average scores (total score per factor divided by the number of respondents) and standard deviations were calculated and represented as the relative importance of each critical factor.

3. Results

3.1. Selection of important critical factors per case

According to the views of the experts of the in-depth interview (described in Section 2.3), the list of critical factors seemed to be complete for identifying critical factors indicating dynamics in production chains related to food safety risks. The approach was, therefore, further explored in a workshop with a group of food safety experts (see Section 2.3) examining three case studies. The results of the group discussions are depicted in Tables 1–3 and are described below. Factors that are marked with two scores (two 'G's in adjacent columns) in the tables were scored by the group as between two columns or group consensus was lacking. For example, in the dairy case the number of chain partners for "Valess" was seen as between +1 and +2 meaning that there were between 'more' and 'much more' chain partners for Valess production compared to pasteurized milk.

3.1.1. Dairy case

The most important factors for the dairy case, as deducted by the subgroup, were (between brackets: factor number and corresponding scores indicating change and food safety risk, respectively): number of chain participants (factor 1: +1.5 and +1); number of processing steps (factor 2: +1.5 and +1); number of raw materials (factor 3: +2 and +1); logistics (factor 5: +2 and +1.5); and origin of raw materials (factor 19: +0.5 and +1). The participants of the workshop rephrased the latter factor to ‘quality of raw materials’ and remarked that this quality is related to the producers’ food safety awareness. The higher this awareness, the better the quality of the raw materials and thus the lower the expected food safety risk. Since the exact origin of raw materials for Valess was unknown to the experts, the participants found it difficult to rate its food safety risk (bandwidth was collectively set at 0 up to +2). The other factors all relate to an increased product and chain complexity of Valess compared to pasteurized milk, since it contains more raw materials and has more process steps than pasteurized milk, which may result in increased food safety risks.

The group scores coincided well with the results of the in-depth interview, although some factors were rated differently. One of these was the number of suppliers of raw materials (factor 4). For the company of the interviewed expert (see Section 2.3), this number increased over time, whereas the group of experts judged that, overall for the Netherlands, this number decreased due to increased farm size over the years. Other factors that were rated differently included the consumer factors ‘animal welfare’ (factor 26) and ‘convenience’ (factor 28). Although these factors can indicate a change in the production process, they were judged as not important for food safety in this case and thus will not be elaborated upon. An increase in convenience can lead to more ready-to-eat refrigerated products, but in this case both products (milk and Valess) are refrigerated, so there is no difference in food safety risk. Within the group there was also variability in answers. One factor with large variation was ‘legal requirements’ (factor 20). In January 2007, the General Food Law has been implemented (EC, 2002). Some experts thought this implementation comprised a large change in the production chain compared to the previous system, whereas others thought the new regulations were comparable. The same accounts for the effect of these new EU regulations on food safety. Some experts judged that the General Food Law can be interpreted more freely offering possibilities for less high food safety standards. These considerations applied to both milk and Valess, since they belong to the same dairy sector.

3.1.2. Fruit case

The most important factors for the fruit case, as deducted in the workshop, were (between brackets: factor number and corresponding scores indicating change and food safety risk, respectively): logistics (factor 5: +2 and +1); information exchange (factor 8: −1 and +1); contractual agreements on quality and safety (factor 9: −0.5 and +1); origin of raw materials (factor 19: +2 and +1); and legal requirements (factor 20: −2 and +2). The workshop scores for ‘origin of raw materials’ (factor 19) illustrate well the situation for mangoes: compared to the Dutch apple there is a considerable shift in country of origin (+2) which, for mango, varies according to the season from e.g. Australia to India. As a result, workshop scores for the related food safety risk range from 0 to +2, since food safety risks are perceived rather differently for these countries. For example, small-scale producers in India have a higher perceived food safety risk than industrial plantations in Australia. For the same reason, almost identical ranges in food safety scores can be found for firm size (factor 7), integration and cooperation (factor 10), producers’ food safety awareness (factor 11), and probability of detection (factor 12). The rather extreme scores (−2 and +2) for ‘legal requirements’ (factor 20) when comparing mango to apple are due to two reasons. Firstly, in general, there are much less strict safety requirements in (some) countries of origin (−2), thereby potentially leading to an increased food safety risk for the Dutch market (+2). Secondly, for most exotic fruits legal agreements on authorised plant protection products are much less stable (−2), thereby inducing the regular introduction of unauthorised plant protection products (+2). The 0–0 scores for legal requirements relate to the Dutch market as they are in the end identical for all products sold in the Netherlands.

When comparing workshop scores with the in-depth expert interviews, it is evident that workshop scores, in general, are somewhat less extreme. This is caused by the fact that the individual expert mainly considered the local situation in a small-business country, i.e. India, while the workshop participants covered the whole range of mango producing countries, including long-distance transportation, information exchange and sanctions set by Western European retailers.

3.1.3. Potato case

The most important factors for the potato case, as deducted in the workshop, were (between brackets: factor number and corresponding scores indicating change and food safety risk, respectively): number of chain participants (factor 1: +2 and +1.5); number of processing steps (factor 2: +2 and +1); number of raw materials (factor 3: +2 and +1); logistics (factor 5: +2 and +2); transport (factor 6: +2 and +1); process (factor 7: +2 and +1.5) and human factor (factor 30: −1 and +1). Since the stew contains more ingredients than traditional potatoes, more chain partners are involved indicating an increased chain complexity, which (as in the dairy case) may result in increased food safety risks. Apart from increased chain complexity, the production process is also more complex in comparison with table potato, since it comprises more process steps. As stew should be kept frozen, which has its implications for transport and logistics, this may have its impact on food safety according to the expert group. It is essential to keep the ingredients frozen during transport, therefore, truck drivers should understand this importance and act accordingly. For this purpose, the “human factor” (factor 30) was added by the subgroup, comprising knowledge of the importance of cooling the product, especially during transport.

Factors that the group of experts rated higher than the consulted expert of the in-depth interview related to the impact that a frozen, composed product will have on food safety in comparison to a fresh, non-composed product (factors 1, 5 and 17). Group expert opinions were more profound (i.e., rated as a substantially increased risk), while the individual expert rated these factors merely as an increased risk. The latter compared those factors with other frozen products within the same company concluding that risks increased slightly (+1). Group experts compared the innovative stew product, in line with the task at hand, with a traditional table potato and thus came to a different conclusion regarding food safety risks related to the factors 1, 5 and 7 (+1.5 or +2). On the other hand, workshop participants expected considerable improvements in factors related to producers’ behaviour (factors 11–13). This can be explained by the fact that a recall will harm a large-scale processor much more than a product which is marketed by relatively small-scale producers. The stew expert compared those factors with other frozen products within the same company concluding no change.

3.2. Towards a generalization of critical factors

According to the workshop participants, the most important factors identified in the three cases could not be generalized to other novel products with an identical stimulus. On the other hand, resemblances between the factors selected in the potato and dairy case were recognized (like number of chain participants and number of process steps). In these cases, a simple product (either pasteurized milk or table potato) was compared to a more complex product (Valess and stew) resulting in comparable critical factors. Therefore, according to the workshop experts, generalization of the critical factors identified may be possible based on product characteristics rather than on the originating stimulus.

Another outcome of the plenary session was that some of the factors identified as most important were strongly related and could be clustered. For example, the number of processing steps and the number of raw materials (factors 2 and 3) could be clustered into product complexity. These identified clusters are depicted in Table 4.

3.3. Relative importance of critical factors per case

After the workshop, the same experts were asked to score the most important factors individually in order to facilitate a ranking of factors. In this ranking procedure, the clusters as analysed in the plenary session of the workshop were used instead of the separate critical factors. Since a generalization per stimulus was not possible, items were rated for the three cases separately. The results of this mailing round are given in Table 4, which shows the relative importance of the various factors.

For the fruit case, the highest relative importance, both for indicating change in the production chain and related food safety risk, was attributed to "origin" with scores of 38.8 and 35.0 respectively. Also, "compliance and information" and "producers' food safety awareness" were perceived to be important factors. From the three clustered factors presented for the potato and dairy case, "product complexity" was perceived to be the far most important factor for indicating change (with scores of 50.0 and 42.5 respectively). However, this factor was not (solely) perceived as being most important for food safety. In the dairy case, food safety risks related both to changes in product complexity (38.3) as well as to quality of raw materials and food safety awareness (42.5). The large standard deviations of these clustered critical factors do not allow any prioritisation. In the potato case, food safety risks were perceived to be mainly related to the so-called "human factor" (50.0).

Table 4
Mean scores and standard deviation (stdev) of clustered critical factors (CF) per case[a].

	Change		Food safety risk	
	Mean	Stdev	Mean	Stdev
Dairy case (n = 6)				
Chain complexity: # chain participants (CF 1)	21.7	8.2	19.2	7.4
Product complexity: # processing steps (CF 2), # raw materials (CF 3)	50.0	15.8	38.3	20.2
Producer's food safety awareness (CF 11) and quality of raw materials (CF 19)[b]	28.3	17.2	42.5	22.3
Fruit case (n = 4)				
Origin: # chain partners (CF 1), firm size (CF 7), origin of raw materials (CF 19)	38.8	8.5	35.0	10.0
Long distance transport: logistics (CF 5)	12.5	10.0	8.8	7.5
Compliance and information: information exchange (CF 8), contractual agreements (CF 9)	23.8	4.8	22.5	11.9
Producer's food safety awareness (CF 11)	18.8	10.3	23.8	14.9
Legal requirements (CF20)	6.3	2.5	10.0	7.1
Potato case (n = 4)				
Chain complexity: # chain participants (CF 1)	22.5	2.9	20.0	8.2
Product complexity: # processing steps (CF 2), # raw materials (CF 3)	42.5	21.2	30.0	8.2
Human factor i.e. knowledge of cooling importance (CF 30)	35.0	23.5	50.0	14.1

[a] Numbers refer to critical factors mentioned in Tables 1–3.
[b] For the dairy case, participants of the workshop rephrased 'origin of raw materials' (CF 19) to 'quality of raw materials'.

4. Discussion

The three cases showed that for traditional products relatively few changes in the production chain have occurred during the past 5 years, whereas the selected novel products coincided with many changes in the production chain. This shows that the current method helps to identify the most important changes in a production chain indicating innovation. Not all changes were judged to be equally important with respect to food safety. In general, for both the dairy and the potato case endogenous factors clustered in 'product complexity' were evaluated as important. In these cases, the novel products originated from the same production chain as the traditional product, the stimulus being either consumer or producer driven. This may explain why exogenous factors were judged to be less important. In the fruit case, the selected novel product originated from outside the Dutch production chain and, consequently, exogenous factors like the origin of the raw materials were judged to be important for food safety. In general, the consumer factors (factor 25–29) can be seen as drivers for product innovation, but in the cases examined, they did not have a direct impact on food safety. For all three cases, factors related to human behaviour played an important role: in the fruit case this included compliance with contractual agreements; in the dairy case, producers' food safety awareness was judged important; and in the potato case, knowledge of the importance of cooling (human factor) was the most important factor influencing food safety. The importance of factors related to human behaviour was also recognized in the PERI-APT and EMRISK project. In those projects, it was concluded that introducing human factors into the risk analysis paradigm would make the process more pro-active (VWA, 2005, 2006).

Previous studies on emerging risks identified critical factors based on (retrospective) cases (Hagenaars et al., 2006; Kleter et al., 2006, 2009; Van der Roest et al., 2007; VWA, 2006) resulting in factors that are specific for the case chosen. In our approach, we aimed to extract a list of critical factors from these and other literature studies that are of general importance to food safety thereby using endogenous and exogenous factors. The expert study revealed that the compiled gross list of critical factors was complete for indicating dynamics in production chains related to food safety risks. The only factor added was the human factor in the potato case (see Table 3). Based on this gross list of critical factors, the most important factors were filtered in the workshop by the three subgroups. In the second round of the workshop, the group discussion revealed that some factors were related and could be clustered for ease of quantifying the relative importance of the various factors. Furthermore, this round showed that selection of factors from the gross list was case-sensitive. In this regard, the stimulus for innovation (either endogenous, exogenous or consumer driven) played a less important role in the selection of critical factors than the product characteristics. Therefore, generalization of critical factors should preferably be based on product features, which should be further explored. For example, by comparing a 'simple' product with few ingredients with a more complex product, domestically produced products with imported products, or cooled products with fresh products.

The established gross list contains many critical factors for which it is not realistic to determine indicators and monitor signals in a pro-active ER system. Therefore, it is necessary to filter the most important ones from this list (Marvin et al., 2009). In this paper, expert studies were used for ranking the critical factors. Experts used were divided over the cases according to their expertise.

Many studies have been performed on the quality of expert judgements and what makes a person an expert (Bolger & Wright, 1994; Rowe & Wright, 2001). The choice of experts used in our case and the relative proportion in the group will have influenced the outcome of the study. A repetition of this study with another set of experts may thus give different ranking results. However, it is expected that, overall, the most important factors derived for each of the three cases will be identical, since experts used had considerable knowledge and experience in food safety and/or production processes. A different set of experts with comparable background is thus believed to result in the same factors as depicted in Table 4 (although the percentages may differ).

There are different ways in setting up an expert study varying from the use of individuals (isolated or coacting), statistical aggregates (such as pooled responses) or group processes. In general, group performance is qualitatively and quantitatively superior to the performance of the average individual (Hill, 1982). In our study, in-depth interviews with individual experts in the field were used as a starting point for the group discussion in the workshop. This may have influenced the group discussion; however, the advantage of this approach was that it facilitated clarification of the critical factors used. A consensus was not strived for, as can be seen in the different ratings between the group and the individual experts (Tables 1–3). Selection of most important factors was based on discussion within a group of experts and subsequent ranking by the individual experts following a hybrid interacting/nominal procedure. One of the disadvantages of interacting groups is the dominance of higher status, more expressive or stronger personalities (Van de Ven & Delbecq, 1974). Another approach to filter most important items from a broad list of factors is the use of a group decision room. In this approach, factors are ranked individually and anonymously using a Delphi procedure on the computer (Rowe & Wright, 1999). Such an approach will give better insights in individual scores of various items, but has the disadvantage that factors may be interpreted differently among participants (Van de Ven & Delbecq, 1974). In our case, a uniform interpretation of the critical factors used was essential, therefore, interaction in a group was needed. Once this is established, evaluation of factors can be based on the same underlying definitions and the effect of misinterpretation can thus be minimized. The group discussions were followed by nominal voting allowing individual ranking with the group decision as the pooled outcome of the individual votes (Van de Ven & Delbecq, 1971). Combining individual forecasts to an average rate has in many fields shown to be the best or almost best method (Clemen, 1989). In our case the average score was used to identify the most important factors related to food safety risks.

This hybrid interacting/nominal procedure in which group discussions were followed by nominal voting enabled us to optimally combine the advantages of using both group work and individual scoring of experts.

5. Conclusions and future outlook

This study described a method to filter the most important critical factors indicating dynamics in production chains related to food safety risks based on a gross list of critical factors. The method comprised a comparison between a traditional and a new product from the same food chain using expert judgement. The use of group discussion followed by individual ranking proved to be a powerful tool in deriving these factors. The identified critical factors were case-sensitive with human behaviour as common feature in all three cases. A further generalization of most important factors may be possible, and should be further investigated, based on product characteristics rather than the stimulus for innovation.

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