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Health based animal and meat safety cooperative communities

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A R T I C L E I N F O

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A B S T R A C T

The purposes of meat inspection have been formulated for more than 100 years as (a) protecting health of consumers, (b) maintain the reputation of the meats in home and export markets, and (c) detecting communicable diseases of animals before they have spread beyond easy control. Today, one would add to protect animal welfare, clarify that protecting consumer health includes both chemical and biological hazards, and add food fraud to the issues of reputation. To transform the scientific knowledge into modern meat safety assurance systems (MSAS), the risk managers need to understand the social capital in the meat value chain to align the behaviors of farmers, food business operators and competent authorities with technical knowledge. The meat value chain could be perceived as a commons – a material or immaterial property held jointly by the members of a community, whom may govern access to and use of the property through social structures, traditions, and/or formal rules i.e. social capital. The social capital and food safety culture amongst farmers and food business operators is a key driver for successful meat safety while information asymmetry increases risks for a tragedy of commons scenario. Ostrom's core design principles for stable commons could inform the design of MSASs. Tools for reducing the information asymmetry and building trust and social capital between all stakeholders within the meat value chain include the food safety culture, food chain information, use of health epidemiological indicators, sensors and block chains, industry/private standards, and the applying system approach from farm to fork.

1. Introduction

The purposes of meat inspection at slaughter have remained the same for more than 100 years and in USA Salmon already in (1889 formulated the purposes of meat inspection as to protect health of consumers; to maintain the reputation of the meats in home and export markets; and to detect communicable diseases of animals before they have spread beyond easy control.

Today one would have added protection of animal welfare to the purposes, and perhaps clarified that protecting health includes both chemical and biological hazards, as well as added food fraud to the issues of reputation. The question of the most fit for purpose or most cost effective meat safety assurance including meat inspection has been the subject of debates all along these years thereafter. For example, the title of the Salmon paper from 1889 was 'Necessity of a more rigorous meat inspection at time of slaughter' discussing the conditions in USA while

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another title was 'Inspection of Meat: The Present System and Where It Needs Reform' (Anonymous, 1912). Just after the Second World War, several papers discussed the need for modernizing the meat inspection (Ginsberg, 1947; Tweed, 1948). The focus of the traditional meat inspection procedures was visual inspection of surfaces, and palpation and incision of tissues, particularly lymph nodes, to detect abnormalities (Huey, 2012). Initially, these abnormalities included abscesses, tuberculous lesions, parasitic cysts and tissues with unusual colors, consistencies and odors affecting the carcass and/or the organs. Fraud, adulteration, counterfeiting and other fraudulent practices have been challenging the reputation of meats and hampering consumer trust since long before Salmon's paper (1889). One of the first conferences on the control of food frauds took place in 1908 in Geneva, Switzerland (Wiley, 1908). The major driver for food fraud has appeared to be economic gains and profits for the individual food business operator (FBO) (Everstine et al., 2013). Everstine et al. (2013) noted that long and complicated supply chains were risk factors while efficient monitoring, clear official standards and industry trade groups were mitigating factors.

The discussion on what is fit for purpose meat inspection, has continued since then and been driven by the emergence and recognition of the meat borne bacteriological risks such as *Salmonella* and *Campylobacter* as the main food safety issues (Billy & Wachsmuth, 1997; Sun, 1985). Meat inspection has also emerged as a key data collection point for surveillance of the livestock population and for feedback to farmers on animal health and welfare (Feltmate, 1985). The notions of risk based meat inspection and HACCP (hazard analysis and critical control points) were advanced to inform the modernization and fit for purpose meat inspection (Hathaway & McKenzie, 1991). However, the HACCP is mainly an in-house food safety measure at one FBO while we still have to connect the HACCPs and other food safety measures to make the whole meat value chain safe.

The European Commission's White Paper on food safety (2000) and its Scientific Expert Committee's opinion on food borne zoonoses (SCVMPH, 2000) both noted the need for an integrated and comprehensive control framework from farm to fork of food safety controls, and the dominance of bacteriological risks of animal origin in official disease reporting. It was moreover highlighted the complexity of food production and the difficulties of current food control to deliver food safety. The drivers for this complexity include technological, environmental, economic, social and political forces. Thus, a working risk management program such as a meat safety assurance system (MSAS) would have been fit for purpose in this broad and complex context. Another insight was the importance of fraudulent practices for food and feed safety exemplified by the crises due to dioxin contamination of feedstuffs (Bernard et al., 2002). The White Paper noted furthermore that the consumer confidence in European food production and control is fundamental. In a paper on thoroughly modern meat inspection Huey (2012) noted these developments and argued for the introduction of risk-based meat controls in Europe. Huey (2012) was also critical of the meat industry's own ability to deliver safe food without official controls due to the focus on short-term profits. In USA, Olson (2011) noted that to deliver food safety, the controls must be aligned with scientific advances and changes in food production. During 2011–2013, the European Food Safety Authority (EFSA) has issued scientific opinions on meat inspection and safety assurance for swine, poultry, bovines, small ruminants, solipeds and farmed game. In the swine opinion (EFSA, 2011), a new philosophy was outlined. This novel philosophy for meat safety outlined a strong focus on the meat safety assurance system in the meat value chain from farm to the chilled carcass and suggested establishing output-based objectives – e.g., prevalence targets for the pathogens of concern along this supply chain (Blagojevic et al., 2021).

To promote this philosophy, the RIBMINS (risk-based meat inspection and integrated meat safety assurance system) COST Action was commenced 2018 where experts and scientists from 38 European countries as well as from US, Brazil, Australia, and New Zealand, contributed to the vision of a risk-based meat safety assurance system from the farm to the chilled carcass. One insight emerged - to transform the scientific knowledge into meat safety assurance, we need to understand the behavior of farmers and FBOs. Risk management needs to align the behavior of farmers, meat industry and competent authorities (CA) with technical and biological knowledge, to be successful. Rivera, Knickel, Diaz-Puente, and Afonso (2019) noted that farmers' and meat industry's' mutual trust and cooperation, as well as sense of community and the culture and traditions for collaboration play a critical role agricultural development.

To make meat safety assurance systems work, we need to have an idea on how farmers and FBOs relate to each other, organize themselves and interact i.e., the meat value chains and their social capital. Meat value chains could be described as the full range of farms and FBOs and their value adding activities that produce meats and process the meat into food products to be sold to the final consumer in manner that is profitable and broad based benefits for the society FAO (2014). We also propose that the meat value chain could be perceived as a commons - a type of material or immaterial property held and governed jointly by its members. Putnam (1994, 2000) noted that failures to cooperate for mutual benefit hampers the development and profitability of a business of which the tragedy of the commons is one example. In the absence of coordination and credible mutual commitments, all FBOs from farm to fork will optimize their own business without regard to other FBOs or stakeholders with sub-optimisation as a result. Hence, both food safety hazards, industry structure and social capital are relevant considerations when designing meat safety assurance system.

In this regard the relevant question is: Should the meat safety assurance system take into account the market conditions and social capital (Putnam, 1994) as well as presence of industry or 3rd party standards? This question will be analyzed by looking into concepts such as market governance and perfect competition including the assumption of perfect information and deviations like food fraud, vertical integration, risk preference and loss aversion, the meat value chain being seen as a commons and its link to social capital and Ostrom's principle for a stable commons (1990). Moreover, could scenarios like the stable commons and its critical conditions and on the other hand the tragedy of commons, inform the design of.meat safety assurance systems? We will then explore the usefulness of mitigation tools like food safety culture (FSC), food chain information (FCI), harmonized epidemiological indicators (HEI), use of sensors and blockchains, industry or private standards, and system approaches i.e., from farm to fork. All with a view to suggest practical possibilities of incorporating this knowledge into future meat safety assurance systems.

2. Background

2.1. Market governance – competitive markets assumptions

A key assumption for competitive markets is that perfect information is equally available to buyers and sellers (Robinson, 1934; Rushton, 2009). However, in the meat value chain (Fig. 1), this is not always the case – the upstream selling FBOs (e.g., farmer) tend to be more knowledgeable about the animal, carcass (abattoir) or the meat product traded than the buyers downstream, either FBO or consumer. As the selling FBOs can profit from this information asymmetry, the risk is that the whole meat value chain ends up with diminished consumer trust and, consequently, reduced earnings and profits for all. Food fraud or economically motivated adulteration of foods is an example of this information asymmetry that causes problems in the food including the meat value chain (FAO, 2021). This means that a negative externality (a cost or benefit not reflected in the price) can develop in the meat value chain. In other words, the sellers' exploitation of their knowledge advantage limits the value creation along the meat value chain downstream, thereby causing losses to all involved FBOs. These problems of asymmetric information, coupled with issues of market governance, loss

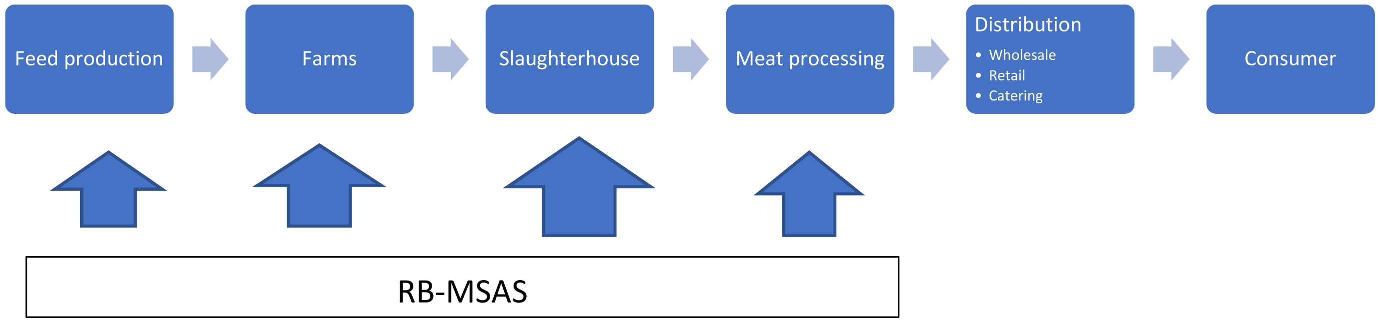

Fig. 1. The Meat Value Chain simplified and the RB-MSAS (risk-based meat safety assurance system) focus.

aversion and risk preference, should inform the design of meat safety assurance systems including the distribution of tasks between FBOs, 3rd party independent auditors and competent authorities (CAs). One goal is to ensure that equal information on safety and quality is available for all FBOs.

2.2. Information in the meat value chain

The assumption of homogenous products and perfect information available for both buyers and sellers is very idealistic. This means that any deviation in quality and safety is equally detectable for buyers and sellers along the meat value chain. One example in the meat value chain is when buying a piece of meat, the consumer or FBO can detect quality attributes relating to spoilage, but not contamination with either biological and chemical food safety hazards. Thus, the buying FBO downstream has to trust the seller to be honest about any flaws in regard to safety or quality risks of the meat or meat product. As the selling FBO or farmer may not know everything, one has to trust selling farmers' or FBOs due diligence of controls and checks being sufficient. This raises the question on how to share the risk equitably between buyer and seller in an uncertain real world.

One of the reasons for this asymmetry is that earlier in the meat value chain the abattoir and official control staff can only detect those conditions or infections that either is notified in the food chain information (FCI) or that cause visible and/or clinical signs in live animals during ante-mortem inspection (AMI) or that cause pathological signs on the carcass and/or organs seen at post-mortem inspection (PMI). For example, incoming pigs can carry zoonotic pathogens, such as *Salmonella, Yersinia* and *Toxoplasma*, without the abattoir or official control staff being able to detect these infections visually at AMI or PMI (EFSA, 2011a, b). Moreover, many infections in pigs are latent, and the current FCI is not helpful in these cases (Bonardi et al., 2021). However, serological information from screening the herd of origin included in the FCI could be helpful for pigs (Felin et al., 2016). For cattle, it is difficult to detect contaminations with the main biological hazards (i.e. STEC or *Salmonella*) during AMI or PMI (EFSA, 2013). Likewise, *Salmonella,* extended-spectrum β-lactamase (ESBL) bacteria and *Campylobacter* might be present in incoming broilers without apparent clinical or pathological symptoms enabling detection at slaughter (EFSA, 2012b). For the slaughterhouse, there are several control options for dealing with this negative externality (Barco et al., 2015; Cota et al., 2019; Hauge et al., 2011, 2015; Hue et al., 2010). Another example is contamination with *Listeria monocytogenes*, a major hazard in processed meat products. *L. monocytogenes* is ubiquitous, and often contaminates processing environments, is present in biofilms and frequently becomes established as an in-house microorganism in food processing establishments (Fagerlund et al., 2022; Sharan et al., 2022). The outbreak of Enterohaemorrhagic *E. coli* (EHEC) in Sweden associated with the consumption of fermented beef sausages during the autumn of 2002 is one example of such information asymmetry; when the information on slaughtering of dirty cattle was not disseminated downstream to the processing FBOs thereby not enabling them to take mitigating actions, thus presenting consumers for risks they could not detect when eating fermented sausages (Sartz et al., 2008). The source of the outbreak was not found, but the expert opinion was that this outbreak was linked to slaughtering of visible dirty animals as the microbiological indicators of slaughter hygiene at the slaughterhouse were non-compliant at that period. In the EU Regulation (No 2073/2005) on microbiological criteria there are special rules for pathogenic microorganisms to protect the consumer and downstream FBO. However, while the interpretation of criteria in terms of positive findings (i.e., non-compliance with the legislation) is easy, it is difficult in terms of compliance - negative findings. Indeed, while hazard presence in a sample is evidence of the presence in a population, hazard absence in a sample is no evidence of absence in a population. The absence in a sample enables a statement on the prevalence and/or concentration being lower than a threshold with a certain probability (EFSA, 2017).

2.3. Food fraud – information asymmetry in real life

Food fraud or economically motivated adulteration is a major issue in the food chains globally (FAO, 2021; Li et al., 2023). Food fraud occurs when a food supplier intentionally deceives their customers on quality and contents of the foodstuffs they are buying (Winkler et al., 2023). In the UK the costs of food fraud appear to be equivalent to the profit margins in the food industry (Cox et al., 2020). In the European Union (EU) the annual impact approaches billions of Euro in losses (European Commission, 2020). In addition food fraud is associated with threats to public health and food safety, damaging the FBOs' reputations, deceiving consumers and uncertain food quality. A more sinister consequence is the loss of consumer, producer and trading partner confidence in the sectors affected and the loss of trust in official controls and competent authorities. A trust deficit can lead to an economic deficit as gainful economic activity results in trade and consequent tax revenues fail to take place (Cox et al., 2020). The fact that an individual FBO has an economic motivation for fraud means that the collective of FBOs and consumers might lose while the individual gains and the losses are larger than gains.

Fraud includes a broad range of activities such as substitution, dilution, concealment, counterfeiting, grey market forgery, unapproved enhancement, and mislabeling (European Commission, 2020). Fraud has implications for the market for meat products as consumers and honest FBOs are defrauded while fraudulent FBOs gain undue advantages. Fraud occurs in the meat chain from farm to fork and may constitute a risk for both public and animal health. Tahkapaa et al. (2015) noted that food of animal origin such as meat is most commonly reported in terms of food fraud. What are the drivers and enablers of food fraud? Moyer et al. (2017) and Saskia van Ruth et al. (2017) examined the drivers and possible enablers of food fraud. In brief, opportunities, motivations both economic and cultural/behavioral and control measures' efficacy were drivers or enablers for food fraud. On insight was that the control measures need both to include technical and managerial ones (Moyer et al., 2017) to achieve the wanted results. It appears that technical control measures (hard controls) are to some extent in place, but managerial (soft) controls which counteract motivations-related (e.g., fraud) factors are less present. Managerial controls at the wider environment level, such as social control and food policy and enforcement, are perceived as lacking or insufficient in many cases. These insights should inform the design of meat safety assurance system and help to build resilient meat value chains.

2.4. Market governance vertical integration

There are several ways of organising the meat value chains in terms of market governance (Table 1), with challenges for joint optimisation (Rushton, 2009), including the tragedy of the commons situation (Hardin, 1968) due to the asymmetric information in the meat value chain. Vertical integration is defined as a company's (e.g., FBO) control over the different stages of the production process (Rushton, 2009). Vertical integration is one way of handling uncertainties and asymmetric information and, thus, is often seen as quite beneficial, while horizontal integration – a FBO's control of one stage in the production process – entails the risk of dominant market power with negative consequences. The types of governance and degree of vertical integration of markets can either increase or reduce information asymmetries in meat value chains. Some examples of market governance (Rushton, 2009) are outlined in Table 1.

The market governance based on perfect competition rests on several idealising assumptions. One assumption is that both buyer and seller have equal and perfect information about the foodstuff or commodity traded. However, this assumption is difficult to achieve in real markets (Blaug, 2001). On the other hand, markets that are competitive, but not perfect tend to deliver better results than monopolies. Thus, one strives to both mitigate information asymmetries and make the markets as competitive as possible. One alternative is relational market governance with mutual dependencies, where the FBOs are mutually dependent on keeping their reputation and, thereby, the reputation of the food value chain. Other elements include strong social controls and transparency often linked to standards for trade between FBOs and foreseeable sanctions for violations. Moreover, the information asymmetry of the meat value chain will have a big impact if there is large horizontal trading in the value chain. This means that the farmers or FBOs at the same stage in the meat value chain trade between themselves. Examples are the trade of live animals between farms or the trade in carcasses between abattoirs and cutting plants.

On the other hand, a more vertically integrated market governance could enhance the impact of mitigating measures, such as industry standards with independent 3rd party auditing, a food safety culture (FSC), food chain information (FCI), delivery guarantees and sensors. A dominant FBO could require the use of sensors or binding industry or 3rd party standards for trade. Moreover, distributed ledger technologies (DLT), including blockchains, are tools for vertical integration of the information flows in the meat value chain, without necessarily requiring market governance based on vertical integration. Accordingly, the meat safety assurance system should be adapted to the types of market governance and mitigating measures already used.

Three conclusions appear reasonable, looking at the organisation of markets. Firstly, the governance of markets could either enhance or mitigate the problems of asymmetric information. This has implications for the CA and its design of the official meat safety assurance system that could be more audit oriented in vertically integrated markets and more hands-on in competitive markets unless there are strong 3rd party or industry standards and systems for sharing information. Secondly, the design of the meat safety assurance system should be adapted to the type of market governance of the meat value chain. In a competitive market, extensive use of industry and 3rd party standards that are audited carefully is an alternative to on-the-spot controls. In a scenario with extensive vertical integration and captive or relational elements, the focus of the CA should rather be on auditing. Thirdly, while the meat market governance is a political question, the political answers to this question have consequences for the official meat control.

Table 1
Possible types of market governance of meat value chains (adapted from Rushton, 2009), vertical integration and risks to meat safety.

Type of governance	Description	Control possibilities of meat safety risks
Markets (perfect competition)	Several small FBOs who trade between themselves and along the meat value chain. No FBO dominates, and it is easy to switch between suppliers and customers. All FBOs are price takers. All relevant information is easily available for all FBOs.	Possible to control meat safety risks with tools dealing with information asymmetries, such as use of sensors, block chains, industry standards, 3rd party standards or assurance schemes.
Modular value chains	Small FBOs produce and sell according to the specifications of a dominant FBO downstream in the value chain. The dominant FBO tend to pay better prices than other possible FBOs in the same chain stage.	Possible control of risk if the dominant FBO's specifications deal with asymmetric information concerning food safety.
Relational value chains (commons)	FBOs are mutually dependent with a view towards keeping their reputations. Strong social controls and spatial proximity enable transparency.	Possible to control the risk if social capital and mutual trust are available (i.e., Ostrom's criteria for stable commons).
Captive value chains	A dominant FBO, usually late in the meat value chain, prescribes the requirements for upstream FBOs and monitors the compliance of smaller FBOs. FBO cannot leave the value chain easily.	Possible to control the risk if the dominant FBO specifies how to ensure food safety.
Hierarchical chains with vertical integration	One company controls the value chain from feed to consumer. Typical of poultry meat production where one company controls feed production, breeding pyramids, farms, slaughterhouses, cutting plants, production, distribution and sale.	Possible to control risk if the company (FBO) internalises the information flows, and has control measures to ensure compliance.

2.5. Risk preference and loss aversion

Kahneman (2011) noted people have complex and contradicting relationships to risks, as a consequence of peoples' value functions being concave at the gains and convex at the losses. To illustrate, sometimes people prefer to take risks and other times the same people wish to avoid risks, e.g., by paying for a lottery ticket and paying for insurance, respectively (Kahneman & Tversky, 1979). These relationships are not always obvious and have implications for farmers' and FBOs' behaviour in the meat value chain (Table 2).

It follows from Table 2 that if the probability of a gain is high, there is a risk aversion, i.e., if one expects to make a profit of 200k€ with 100% certainty, that outcome would be preferred to an equivalent outcome – a 50% probability of making 400 k€ and 50% of making 0 k€. If you expect

Table 2
Risk aversion or preference as a function of economic outcomes and probabilities (adapted from Kahneman, 2011).

Probability	Economic outcome	
	Profits	Losses
High	Risk aversion	Risk preference
Low	Risk preference	Risk aversion

to make a loss of 200k€ with certainty, you prefer to take a gamble with a 50% risk of losing nothing (0 k€), albeit with a 50% risk of losing 400 k€. If making a profit, a FBO tends to be risk averse and take out insurance. On the other hand, if the FBO is under financial stress (e.g., losing money, at risk of insolvency or suffering from high debt), then there is a tendency to be more risk-accepting, even gambling to cover the losses. That is, the FBO is loss-averse (Barberis, 2013; Camerer, 2004). This might include cutting corners in terms of food safety and/or fraud in the absence of a strong food safety culture (FSC). One example of this was the horsemeat in lasagne scandal, where the normal ingredient, beef, was replaced by horsemeat (Premanandh, 2013) to cut costs. An additional driver in this scandal, was the asymmetry in power and information between the different FBOs in the chain (Madichie & Yamoah, 2017). It appears that the FBOs' risk aversion or preferences should be important inputs for the design and operations of meat safety assurance systems as well as for the competent authorities planning of meat controls. Consequently, if a farmer or a FBO is losing money, that might change their behaviour from avoiding to taking risks. Hence, lack of profitability ought to raise concerns on compliance in 3rd party audits or official food controls.

2.6. Social capital

Social capital is the mutual horizontal networks, norms and trust that facilitate collaboration and collective action (Putnam, 1994; 2000). This collaboration will augment the benefits from investments in physical and human capital. We believe the meat safety assurance systems should build social capital or acknowledge as well as strengthen already present civic collaboration. The interplay between the market organization, information asymmetries and social capital will be crucial for successful meat safety assurance systems. When the FBOs can trust each other as well as the competent authority (CA) to act fairly and to the best of their abilities, this facilitates a well-functioning meat value chain and safety assurance system. The design of food control systems ought to consider the social capital and market conditions amongst the farmers and FBOs in addition to scientific knowledge on biological and chemical risks. For example, in countries with a culture of collaboration (i.e., social capital, like in Denmark) amongst farmers and FBOs the likelihood of successful food safety schemes improves (Svendsen & Svendsen, 2000). Smaller farmer and FBO communities within a country such as those producing regional specialties should also have a higher probability of success as social capital within the communities and the incentives for individual and community are aligned. One could perceive the Parma ham production as one example of a community with social capital i.e., where producers are obliged to comply with the quality assurance and where the Parma ham production is strictly controlled (RIBMINS, 2023). As the meat safety assurance system will be a form of collective action and dependent on the mutual trust amongst FBOs, meat value chains with large social capital elements can be foreseen to deliver better food safety.

2.7. Meat value chain as a commons

In a legal context, a commons is a type of material or immaterial property held jointly by the members of a community, whom may govern access to and use of the property through social structures, traditions, and/or formal rules i.e. social capital. An ancient, successful example of a stable commons has been the farmer-managed irrigation water systems and associated tribunals to settle conflicts and disputes found in Valencia, Spain (Ortega-Reig et al., 2014) for thousand years. The meat value chain exemplifies a joint commons between farmers, food business operators (FBOs) and consumers. Meat safety assurance systems will be more effective if appreciating the context of the meat value chain as a commons. Moreover as a consequence, meat safety and hygiene is a joint and common responsibility of all farmers and FBOs in the meat value chain. The consequences of a few farmers' or FBOs' failures or frauds will be shared amongst all farmers and FBOs. The success will to a large extent depend on the social capital in the meat value chain or commons.

2.8. Tragedy of the commons - a possible scenario in the meat value chain

The failure to sustainably manage the commons, of which the meat value chain is one example, for joint benefits will create a tragedy of the commons (Hardin, 1998). The classic example of the tragedy of the commons is when animals overgraze and, in the end, destroy common pastures (Hardin, 1968). The essence of the tragedy of the commons is the depletion of a shared resource, as the individual users do not pay the true costs for its use, thereby creating a negative externality. This shared resource can be any open-access and unregulated resource, such as the atmosphere, oceans, rivers, ocean fish stocks, or even the shared milk meant for coffee and tea in the office refrigerator. Another example is the security of Internet. If some users fail to protect their computers and thereafter do not warn others of their high-risk status, the utility of all Internet users will diminish (Rose & Gordon, 2003).

Why could one think of the meat value chain as a commons? This common's critical resource is the FBO's and consumer's trust in the chain's upstream FBOs and their work in food safety and animal health and welfare in the meat value chain from farm to fork. The FBO and consumer can check the quality attributes like smell, taste, texture, and colour of the meat, but they both have to place their trust in the selling FBO for non-visible attributes, such as food safety, animal welfare, organic farming, authenticity and origin. The consumer cannot confirm the absence of *Salmonella* when purchasing meat in the supermarket. Hence, if the pledges on non-visible attributes like food safety are not respected, consumers will lose trust in the meat value chain. As a result, the global profits and sustainability of the meat value chain will suffer, as will consumer confidence and demand for meat and meat products. The type of market governance and mitigating measures used (e.g., FCI or private standards) could influence the problem. For example, a competitive market presumes full information about the animals and foodstuffs traded in the meat value chain (Rushton, 2009). This assumption means that at the point of trade, buyers and sellers have all relevant information about attributes, such as meat safety, quality, animal welfare and origin. Hence, both the asymmetric information resulting in a negative externality, and the type of market governance along with an absence of mitigating factors could result in tragedy of the commons scenarios for the meat value chain. On the other hand, it is possible to manage commons sustainably i.e., a stable commons for the benefit of all stakeholders over long periods, as exemplified by the water management governance of Valencia (Ortega-Reig et al., 2014).

2.9. Stable commons - Ostrom's criteria and design principles

There are several examples of commons being managed successfully for many years, such as fisheries, land irrigation systems, communal forests and farmlands (Ostrom et al., 1999; Ostrom & Ostrom, 1972). Moreover, Ostrom (2009) extended the concept of commons to socio-ecological systems, and their sustainability. Ostrom's four criteria for a stable commons could give valuable insights into the design of meat safety assurance systems (Ostrom, 2009). The two first criteria are often complied with (1) that the meat value chains are well defined and have clear boundaries, and (2) that meat is a valuable commodity and substitutes are not easily available. However, with the caveat that meat can often be substituted with plant proteins in highly processed foods. The third and fourth criteria are more discerning and concerning: (3) the presence of a community that promotes sustainability by having strong social networks and norms guiding the governance of the market and the community-based rules, and (4) built-in incentives for responsible use and clear and foreseeable sanctions for abuse. The Irish Origin Green (https://www.origingreen.ie) sustainability program is one example of managing the food including the meat value chain as a commons, for competitive advantage. Ostrom (1990) elaborated these criteria further and suggested eight core principles for designing a stable commons Table 3.

We suggest that the design principles outlined in Table 3 can inform the design of meat safety assurance systems. Several important elements are already in place such as food chain information (FCI) based on harmonized epidemiological indicators (HEI) as tools for mitigating the information asymmetry at the pre-harvest stage (farming) and the harvest stage (slaughter) of the meat value chain (EFSA, 2011a, b; EFSA, 2012a, b; Alban et al., 2012; Gomes-Neves et al., 2018). These monitoring possibilities should enable farmers, FBOs and consumers to share more equally information on quality, safety and origin of the meat. The social capital is another element (collective action and possible to self-organize) that would be crucial for successful meat safety assurance systems.

2.10. Summing up the challenge of governing the meat value chains

The key message is that asymmetric information will often appear in meat value chain, and unless dealt with, causing negative externalities both in terms of meat safety but also spoilage and shelf-life. Unless these negative externalities are managed and the costs are shared, the meat value chain could experience a scenario where trust is depleted and everyone loses including farmers, FBOs and consumers. Within the EU, the farmers and FBOs are responsible for meat safety, while the competent authorities audit or verify the FBOs' compliance through official controls. The challenge is how to govern the meat value chains to ensure benefits for all and joint optimisation. For example, if any incident happens, are the system's checks and balances sufficient to safeguard meat safety, quality and economic sustainability for all stakeholders (farmers, FBOs and finally consumers)? Hence, a sustainable meat safety assurance system prerequisite is that its governance is resilient and able to deal with imperfect information and information asymmetries. The eight core design principles of a stable commons could be helpful in this regard.

Table 3
Core design principles for stable commons adapted from Ostrom (1990).

Design principle	Explanation
1. Clearly defined boundaries	The identity of the group and the boundaries of the shared resource are clearly delineated. Groups of farmers and FBOs involved in the production of regional specialities e.g., Parma ham.
2. Proportional equivalence between benefits and costs	Members of the group must negotiate a system that rewards their contributions. High status or other benefits must be earned as unfair inequality will poison collective efforts.
3. Collective-choice arrangements	Group members must be able to create at least some of their own rules and make their own decisions by consensus. People hate being told what to do but will work for group goals that they have agreed upon
4. Monitoring	Managing a commons is inherently vulnerable to free-riding and active exploitation. Unless these undermining strategies can be detected at a relatively low cost by norm-abiding members of the group, the tragedy of the commons will occur
5. Graduated sanctions	Transgressions need not require heavy-handed punishment, at least initially. Often gossip or a gentle reminder is sufficient, but more severe forms of punishment must also be waiting in the wings for use when necessary
6. Conflict resolution mechanisms	It must be possible to resolve conflicts quickly and in ways that are perceived as fair by members of the group
7. Possible to organize	Groups must have the authority to conduct their own affairs. Externally imposed rules are unlikely to be adapted to local circumstances and violate principle 3
8. For groups that are parts of larger systems, there must be appropriate coordination among relevant groups	Every sphere of activity has an optimal scale. Large scale governance requires finding the optimal scale for each sphere of activity and appropriately coordinating the activities. A related concept is subsidiarity, which assigns governance tasks by default to the lower jurisdiction, unless this is explicitly determined to be ineffective

3. Possibilities for dealing with the information asymmetry

It is important to recall that from the farmers' and FBOs' perspectives, the meat safety assurance systems will most likely be embedded in their general quality assurance systems. These have a broader scope, as they include meat quality, hygiene and safety as well as other attributes, such as animal welfare, organic production, authenticity, labelling, origin, sustainability and composition (RIBMINS, 2023). There are several possible tools for enabling a meat value chain becoming a stable commons and creating a meat safety assurance system that mitigates the information asymmetry and delivers safe meat. We believe implementation of tools such as food safety culture (FSC), food chain information (FCI), use of sensor and distributed ledger technologies like block chains, adoption of industry and 3rd party standards would be helpful. The role of the competent authority (CA) would be to facilitate this process and audit that it works.

3.1. Food safety culture (FSC)

It is often said that 'culture eats strategy for breakfast' and 'rules state facts while culture lives through the human experience'.Yiannas (2016) formulated it as to develop a food safety culture you need clear metrics to follow up, role models, and always to recall that positive consequences (or feedback) eats negative for lunch. We believe that in a complex meat value chain delivering food safety demands more than a reliance on written rules, regulatory oversight and safe food practices (GFSI, 2019). In other words, food safety must go beyond formal regulations to live within the culture of a farmer or FBO - a food safety culture (FSC) is needed. Food safety culture is a critical factor for reducing the risk of food borne diseases by encouraging a more pro-active working approach to risk management (Zanin et al., 2021). Hence we believe the culture of the farmers and FBOs involved is crucial, as no technological fixes will help, unless the culture of the enterprise aims at food safety. The attitudes, values and beliefs of its employees are the farmer's and FBO's culture of food safety. The culture reflects the commitment of the farm's and FBO's management. In September 2020, the Codex Alimentarius Commission adopted a revision of its General Principles of Food Hygiene (CXC 1-1969) that introduced the concept of (FSC), and aimed at increasing the awareness and improving the behaviour of employees in food establishments. Consumers in Europe and all countries to which European countries export expect adherence to this Codex principle. The EU Commission amended in 2021 the Regulation (No 852/2004) to include food safety culture as a requirement of FBOs. The food safety culture requirements include communicating to all FBO staff the roles and responsibilities (including supervision) for each activity of the food business and ensuring appropriate training of staff. The requirements also include verifying compliance with food safety regulations, i.e., that the controls are done and documentation thereof is timely.

In addition, the FBOs should establish a culture of continual improvements based on new knowledge. An important part of a food safety culture is the open and clear communications and sharing of information between the farmers and FBOs. Another is the ability to learn from mistakes, near mistakes as well as from successes – creating a learning culture. It is important that farmers or FBOs can report mistakes without fear of repercussions. One example is the varying risk management procedures in European countries when sows suspected of having antimicrobial residues are accidently sent for slaughter (Alban et al., 2023). We believe the concept of a food safety culture fits neatly with and complements the development of a meat safety assurance system.

3.2. Food chain information (FCI) and harmonized epidemiological indicators (HEI)

The current meat inspection at slaughter does not address the food safety hazards most relevant in the different animal species (EFSA, 2011a; 2012a, 2013). Therefore, there is a need to know more on the pre-harvest infection and chemical exposure status of the animals arriving for slaughter. The basic idea of FCI is to inform the slaughterhouse of the status of incoming animals in terms of biological and chemical hazards, thereby enabling control of food safety risks. However, not all of the harmonized epidemiological indicators (HEIs) proposed by EFSA for food safety hazards are included in the FCI (Bonardi et al., 2021; Gomes-Neves et al., 2018). For example, for poultry, two prioritized biological hazards, Extended Spectrum Beta-Lactamase (ESBL) coliforms and thermophilic *Campylobacter*, are not included in the FCI (EFSA, 2012a, b). Inadequate FCI is a major obstacle to the implementation of new meat inspection and safety assurance systems in Europe (Antunovic et al., 2021). A working FCI that contains delivery guarantees would lessen the information asymmetry between farmers and abattoirs. Furthermore, a working FCI would aid the control of the microbial and chemical hazards currently representing the major food safety risks.

3.3. Sensors

Sensors can deliver objective information on the state of the animal or product (Neethirajan, 2017; Newsome et al., 2014). Biosensors used for animal health management have gained recognition as a key tool for precision livestock farming (Neethirajan, 2017). For example, Du and Zhou (2018) noted that biosensors are available for *Salmonella* and *Toxoplasma* antibodies. Such sensors should be connected to the meat safety assurance systems to create a real-time, online monitoring system for food safety. If the information from sensors used on-farm on food safety risks were available for the risk manager at the slaughterhouse this would create a system with more equal and shared information. In that case the risk manager can use the information to implement risk management procedures such as freezing pig carcases if *Toxoplasma* infection is suspected.

3.4. Distributed ledger technology (DLT) and blockchains

The complexity of food supply chains drove the attention of FBOs and other stakeholders towards solutions to ensure chain integrity (Antonucci et al., 2019). In addition, fraud and fraudulent inputs in meat production have emerged as issues reflecting the information asymmetries amongst FBOs (Manning et al., 2016). Distributed ledger technologies (DLT), would help information to flow better across different processing stages, and improve transparency and traceability (Collart & Canales, 2022; Kraft & Kellner, 2022). DLT are digital, permanent and verifiable databases with a decentralised architecture (meaning the same information is stored in multiple locations). These databases store encrypted chains made of blocks of information that are added step-by-step and are shared with all authorised entities in a network holding the codes. DLT are distributed on various platforms such as blockchains (Antonucci et al., 2019; Office for Product Safety and Standards, 2020). DLT enable more targeted traceability and back-tracking of foods and could provide data on the food safety history of a specific food product; this means DLT could be used as part of a risk-based food control (Donaghy et al., 2021). DLT could pave the way towards concepts such as precision food safety and precision public health (Donaghy et al., 2021; Dowell et al., 2016), and should be one of the elements in future meat safety assurance.

3.5. Industry standards

In many countries, industry standards i.e., GFSI approved standards (Global Food Safety Initiative) with independent 3rd party auditing are important elements of food and meat safety assurance systems (RIBMINS, 2023). The meat safety elements are often embedded in broader meat quality schemes implemented by the FBO. The scopes of a quality assurance program extends beyond food safety, animal welfare and health, to attributes such as: (1) absence of characteristics objectionable to the consumer – wholesomeness; (2) authenticity – the chilled carcass is free from adulteration and is what it says it is (food fraud issues) and/or (3) specific consumer expectations e.g., organic, halal, or locally produced. Examples of industry standards or certification schemes appear in Table 4.

An example of a certification scheme is the British Retail Consortium (BRC) Food Safety Standard that provides a framework to manage product safety, integrity, legality, quality and the operational controls in the food and food ingredient manufacturing, processing and packing industry (Rincon-Ballesteros et al., 2021). The BRC Food Safety Standard emphasises management commitment, HACCP-based food safety programs, and supporting quality management systems. This standard assists FBOs to comply with meat safety requirements through a risk-based approach to the management of meat safety. The focus is on auditing the implementation of prerequisite programmes, such as good manufacturing practice (GMP) and good hygienic practice (GHP) with emphasis on those production areas that are associated with recalls and withdrawals (e.g., label and packing management). The future meat safety assurance systems will most likely be embedded in or interlinked with these industry standards or independent 3rd party certification schemes. This could offer small- and medium-sized FBOs the possibility of having a working meat safety assurance system without the large costs of establishing a bespoke program. While the goals of a meat safety assurance system – safe meat, is not voluntary, the choice of ways to reach the goal should be voluntary as the farmer or FBO sees fit.

4. Systems approach

There are technological solutions that could mitigate the information asymmetry between farmer and slaughterhouse. It also appears that the food safety benefits from technological solutions will be larger if integrated in the contexts of food safety culture and industry standards. However, one concern is the differences in the observations in official controls versus 3rd party audits (Turku et al., 2018), with the consequence that the quality of the 3rd party audits and certifications are questioned. This points to an important challenge for the competent authority if using 3rd party audits and industry standards as part of the

Table 4
Examples of food safety related industry standards or certification schemes.

Scheme	Description
Certification scheme	Scheme that relies on independent third party attestation procedures. For the purposes of this study, an independent third party is a certification body that issues a certificate or statement on the FBO's fulfilment of the scheme's requirements.
Self-declaration scheme	Scheme that does not have independent third party attestation. Fulfilment of the scheme's requirements is declared by FBO.
Umbrella food labelling scheme	A collection of food labelling schemes with similar characteristics.
Public food labelling scheme	A scheme that clearly states it is owned or managed by a public body

food control strategy – which numbers are reliable. The systems approach was crucial when assessing and managing the risks for bovine spongiform encephalopathy (BSE) in the European Union (Salman et al., 2012). The epidemic was controlled only by looking at and implementing measures in the whole bovine and beef chain system including feed. Along the same lines of thinking, a systems approach would facilitate the design of a working meat safety assurance system. A meat safety assurance system will best achieve its aims by being longitudinally integrated from farm to fork, with multiple interventions along the meat value chain (Blagojevic et al., 2021). The meat safety assurance system will include following attributes: (1) evidence- and risk-based; (2) aims at those hazards that present the major meat-borne risks with a view to reduce the overall consumer risk; (3) including an appropriate food safety culture and food chain information coupled with technological solutions such as use of sensors and distributed ledger technologies; (4) designed having regard to local conditions including social capital and collaborative actions between farmers and FBOs and use of industry and 3rd party standards; and (5) adaptable to changes.

5. General discussion

The merits of integrated production systems of meat producing animals and food control has been discussed for more than 30 years in Europe. Integrated production systems could enable modern system-based approaches to control meat at slaughter and game meat at handling. In a brief opinion, the Scientific Committee for Veterinary Measures relating to Public Health identified several animal production systems, such as beef, mutton, poultry and rabbits, where integration was possible (SCVMPH, 2001). The criteria for an integrated food production system were: (1) the ability to treat the food production as one epidemiological unit, (2) the free flow of information and transparency of all FBOs along the production chain, and (3) the ability to trace all foodstuffs backwards and to track foodstuffs forwards in the meat value chain. A reasonable deduction from these criteria was that a meat value chain that is either vertically integrated, or has clearly captive or relational elements amongst the participating FBOs, is better placed to deliver meat safety. A meat safety assurance system could be embedded into these meat value chains. This conclusion links to the issue of asymmetric information, i.e., that the seller knows more about the product than does the buyer. The asymmetric information is the driver for many challenges to safety, quality and fraud in the meat value chain. If we conceptually look at the meat value chain as a commons, it is of interest to look for drivers for the tragedy of the commons scenarios. Possible drivers could be market governance coupled with limited social capital and ability for collective actions, and loss aversion if the FBO was in dire economic straits (Kahneman & Tversky, 1979). A strong food safety culture (Wang et al., 2017) could, however, be a counterweight to these drivers, as would governance of the meat value chain based on captive and relational elements. The use of industry (GFSI approved) standards is one way of introducing captive and relational elements (i.e., community-based rules) in the meat value chain, to reduce the information asymmetries between seller and buyer. The impact will be larger by integrating the available technical tools for sharing information between buyers and sellers, such as food chain information (FCI), sensors, and distributed ledger technologies (e.g., blockchains) coupled with a strong food safety culture. We encourage empirical research on this topic due to the current lack of knowledge in relation to the meat value chain. A meat safety assurance system that integrates the use of food chain information, delivery guarantees, sensors, food safety culture, distributed ledger technologies, and compliance with established industry standards, should reduce the risks, but we need to know the magnitudes of the reductions in order to assess benefits and costs.

In conclusion, governance of the meat value chain, the FBO's economic situation and the food safety culture and use of technological solutions should inform the design of meat safety assurance systems and the competent authority's planning of food controls. Moreover, Ostrom's core design principles (Table 3) for a stable commons should be considered when designing a meat safety assurance system.

CRediT authorship contribution statement

Ivar Vågsholm: Conceptualizsation, Supervision, Writing – original draft, Writing – review & editing. **Simone Belluco:** Writing – original draft, Writing – review & editing. **Silvia Bonardi:** Writing – original draft, Writing – review & editing. **Fredrik Hansen:** Writing – original draft, Writing – review & editing. **Terje Elias:** Writing – original draft, Writing – review & editing. **Mati Roasto:** Writing – original draft, Writing – review & editing. **Eduarda Gomes-Neves:** Writing – original draft, Writing – review & editing. **Boris Antunovic:** Writing – original draft, Writing – review & editing. **Arja Helena Kautto:** Writing – original draft, Writing – review & editing. **Lis Alban:** Writing – original draft, Writing – review & editing. **Bojan Blagojevic:** Project administration, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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Data availability

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References

Alban, L., Antunović, B., Belous, M., Bonardi, S., García-Gimeno, R. M., Jenson, I., Kautto, A. H., Majewski, M., Oorburg, D., Sakaridis, I., Sirbu, A., Vieira-Pinto, M., Vågsholm, I., Bērziņš, A., & Petersen, J. V. (2023). Mapping ways of detecting and handling antimicrobial residues in pigs and pig meat in- and outside Europe. *Food Control, 153*, Article 109899. https://doi.org/10.1016/j.foodcont.2023.109899

Alban, L., Baptista, F. M., Møgelmose, V., Sørensen, L. L., Christensen, H., Aabo, S., & Dahl, J. (2012). Salmonella surveillance and control for finisher pigs and pork in Denmark – a case study. *Food Research International, 45*, 656–665. https://doi.org/10.1016/j.foodres.2011.02.050

Anonymous. (1912). The inspection of meat: The present system and where it needs Reform. *Hospital, 52*, 104.

Antonucci, F., Figorilli, S., Costa, C., Pallottino, F., Raso, L., & Menesatti, P. (2019). A review on blockchain applications in the agri-food sector. *Journal of the Science of Food and Agriculture, 99*, 6129–6138. https://doi.org/10.1002/jsfa.9912

Antunovic, B., Blagojevic, B., Johler, S., Guldimann, C., Vieira-Pinto, M., Vågsholm, I., Meemken, D., Alvseike, O., Georgiev, M., & Alban, L. (2021). Challenges and opportunities in the implementation of new meat inspection systems in Europe. *Trends in Food Science & Technology, 116*, 460–467. https://doi.org/10.1016/j.tifs.2021.08.002

Barberis, N. C. (2013). Thirty years of prospect theory in economics: A review and assessment. *The Journal of Economic Perspectives, 27*, 173–196. https://doi.org/10.1257/jep.27.1.173

Barco, L., Belluco, S., Roccato, A., & Ricci, A. (2015). A systematic review of studies on Escherichia coli and Enterobacteriaceae on beef carcasses at the slaughterhouse. *International Journal of Food Microbiology, 17*, 30–39. https://doi.org/10.1016/j.ijfoodmicro.2015.04.027

Bernard, A., Broeckaert, F., De Poorter, G., De Cock, A., Hermans, C., Saegerman, C., & Houins, G. (2002). The Belgian PCB/dioxin incident: Analysis of the food chain contamination and health risk evaluation. *Environmental Research, 88*, 1–18. https://doi.org/10.1006/enrs.2001.4274

Billy, T. J., & Wachsmuth, I. K. (1997). Hazard analysis and critical control point systems in the United States Department of Agriculture regulatory policy. *Rev Sci Tech, 16*, 342–348. https://doi.org/10.20506/rst.16.2.1029

Blagojevic, B., Nesbakken, T., Alvseike, O., Vågsholm, I., Antic, D., Johler, S., Houf, K., Meemken, D., Nastasijevic, I., Vieira Pinto, M., Antunovic, B., Georgiev, M., &

Alban, L. (2021). Drivers, opportunities, and challenges of the European risk-based MSAS. *Food Control, 124*, Article 107870. https://doi.org/10.1016/j.foodcont.2021.107870
Blaug, M. (2001). Is competition such a good thing? Static efficiency versus dynamic efficiency. *Review of Industrial Organization, 19*, 37–48. https://doi.org/10.1023/A:1011160622792
Bonardi, S., Blagojevic, B., Belluco, S., Roasto, M., Gomes-Neves, E., & Vågsholm, I. (2021). Food chain information in the European pork industry: Where are we? *Trends in Food Science and Technology, 118*, 833–839. https://doi.org/10.1016/j.tifs.2021.10.030
Camerer, C. F. (2004). Prospect theory in the wild: Evidence from the field. In C. F. Camerer, L. George, & M. Rabin (Eds.), *Advances in behavioral economics* (pp. 148–161). USA: Princeton University Press.
Collart, A. J., & Canales, E. (2022). How might broad adoption of blockchain-based traceability impact the U.S. fresh produce supply chain? *Applied Economic Perspectives and Policy, 44*, 219–236. https://doi.org/10.1002/aepp.13134
Cota, J. B., Silva, V. F. D., Chambel, L., Veloso, M. G., Vieira-Pinto, M., & Oliveira, M. (2019). Pheno and genotyping of Salmonella from slaughtered pigs in a Portuguese slaughterhouse reveal differential persistence ability. *Veterinary Microbiology, 239*, Article 108457. https://doi.org/10.1016/j.vetmic.2019.108457
Cox, A., Wohlschlegel, A., Jack, L., & Smart, E. (2020). *The cost of food crime* (p. 38). London, UK: Food Standards Agency – FS 301065.
Donaghy, J. A., Danyluk, M. D., Ross, T., Krishna, B., & Farber, J. (2021). Big data impacting dynamic food safety risk management in the food chain. *Frontiers in Microbiology, 12*, Article 668196. https://doi.org/10.3389/fmicb.2021.668196
Dowell, S. F., Blazes, D., & Desmond-Hellmann, S. (2016). Four steps to precision public health. *Nature, 540*, 189–191. https://doi.org/10.1038/540189a
Du, X., & Zhou, J. (2018). Application of biosensors to detection of epidemic diseases in animals. *Research in Veterinary Science, 118*, 444–448. https://doi.org/10.1016/j.rvsc.2018.04.011
EFSA. (2011a). Scientific Opinion on the public health hazards to be covered by inspection of meat (swine). *EFSA Journal, 9*, 2351. https://doi.org/10.2903/j.efsa.2011.2351
EFSA. (2011b). Scientific Report on Technical specifications on harmonized epidemiological indicators for public health hazards to be covered by meat inspection of swine. *EFSA Journal, 9*, 2371. https://doi.org/10.2903/j.efsa.2011.2371
EFSA. (2012a). Scientific opinion on the public health hazards to be covered by inspection of meat from poultry. *EFSA Journal, 10*, 2741. https://doi.org/10.2903/j.efsa.2012.2741
EFSA. (2012b). Technical specifications on harmonised epidemiological indicators for biological hazards to be covered by meat inspection of poultry. *EFSA Journal, 10*, 2764. https://doi.org/10.2903/j.efsa.2012.2764
EFSA. (2013). Scientific Opinion on the public health hazards to be covered by inspection of meat (bovine animals). *EFSA Journal, 11*, 3266. https://doi.org/10.2903/j.efsa.2013.3266
EFSA BIOHAZ Panel (EFSA Panel on Biological Hazards). (2017). Scientific Opinion on the guidance on the requirements for the development of microbiological criteria. *EFSA Journal, 15*(5052), 60. https://doi.org/10.2903/j.efsa.2017.5052
European Commission. (2000). White paper on food safety, 52 pp. Available at: https://op.europa.eu/en/publication-detail/-/publication/6d4b523b-dad8-4449-b2b4-9fa9b0d6e2be. (Accessed 8 May 2023).
European Commission. (2020). Food fraud: What does it mean?. https://food.ec.europa.eu/safety/agri-food-fraud/food-fraud-what-does-it-mean_en. (Accessed 21 June 2023).
Everstine, K., Spink, J., & Kennedy, S. (2013). Economically motivated adulteration (EMA) of food: Common characteristics of EMA incidents. *Journal of Food Protection, 76*, 723–735. https://doi.org/10.4315/0362-028X.JFP-12-399
Fagerlund, A., Wagner, E., Møretrø, T., Heir, E., Moen, B., Rychli, K., & Langsrud, S. (2022). Pervasive Listeria monocytogenes is common in the Norwegian food system and is associated with increased prevalence of stress survival and resistance determinants. *Applied and Environmental Microbiology, 88*, Article e0086122. https://doi.org/10.1128/aem.00861-22
FAO. (2014). *Developing sustainable food value chains - guiding principles* (p. 77). Rome.
FAO. (2021). Food fraud – intention, detection and management. In *Food safety technical toolkit for Asia and the Pacific No. 5* (p. 30). Bangkok.
Felin, E., Jukola, E., Raulo, S., Heinonen, J., & Fredriksson-Ahomaa, M. (2016). Current food chain information provides insufficient information for modern meat inspection of pigs. *Preventive Veterinary Medicine, 127*, 113–120. https://doi.org/10.1016/j.prevetmed.2016.03.007
Feltmate, T. E. (1985). The modern role of meat inspection and food hygiene. *Canadian Veterinary Journal, 26*(1), 29–33, 1985 Jan.
GFSI. (2019). A culture of food safety. A psotion paper from the global food safety initative (GFSI). v1.0-4/11/18, 54 pp. Available at: https://mygfsi.com/wp-content/uploads/2019/09/GFSI-Food-Safety-Culture-Full.pdf. (Accessed 7 July 2023).
Ginsberg, A. (1947). The modern outlook on meat inspection. *The Veterinary Record, 59*, 255.
Gomes-Neves, E., Müller, A., Correia, A., Capas-Peneda, S., Carvalho, M., Vieira, S., & Cardoso, M. F. (2018). Food chain information: Data quality and usefulness in meat inspection in Portugal. *Journal of Food Protection, 81*, 1890–1896. https://doi.org/10.4315/0362-028X.JFP-18-266
Hardin, G. (1968). The tragedy of the commons. *Science, 162*, 1243–1248. https://doi.org/10.1126/science.162.3859.1243
Hardin, G. (1998). Extensions of the tragedy of the commons. *Science, 280*, 682–683. https://doi.org/10.1126/science.280.5364.682
Hathaway, S. C., & McKenzie, A. I. (1991). Postmortem meat inspection programs; separating science and tradition. *Journal of Food Protection, 54*, 471–475. https://doi.org/10.4315/0362-028X-54.6.471
Hauge, S. J., Nesbakken, T., Moen, B., Røtterud, O. J., Dommersnes, S., Nesteng, O., Østensvik, Ø., & Alvseike, O. (2015). The significance of clean and dirty animals for bacterial dynamics along the beef chain. *International Journal of Food Microbiology, 214*, 70–76. https://doi.org/10.1016/j.ijfoodmicro.2015.07.026
Hauge, S. J., Wahlgren, M., Røtterud, O. J., & Nesbakken, T. (2011). Hot water surface pasteurisation of lamb carcasses: Microbial effects and cost-benefit considerations. *International Journal of Food Microbiology, 146*, 69–75. https://doi.org/10.1016/j.ijfoodmicro.2011.02.003
Hue, O., Le, Bouquin, S., Laisney, M. J., Allain, V., Lalande, F., Petetin, I., Rouxel, S., Quesne, S., Gloaguen, P. Y., Picherot, M., Santolini, J., Salvat, G., Bougeard, S., & Chemaly, M. (2010). Prevalence of and risk factors for Campylobacter spp. contamination of broiler chicken carcasses at the slaughterhouse. *Food Microbiology, 27*, 992–999. https://doi.org/10.1016/j.fm.2010.06.004
Huey, R. (2012). Thoroughly modern meat inspection. *The Veterinary Record, 170*, 68–70. https://doi.org/10.1136/vr.e81
Kahneman, D. (2011). *Thinking fast and slow*. London, UK: Penguin Books.
Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47*, 263–292.
Kraft, S. K., & Kellner, F. (2022). Can blockchain Be a basis to ensure transparency in an agricultural supply chain? *Sustainability, 14*, 8044. https://doi.org/10.3390/su14138044
Li, X., Zang, M., Li, D., Zhang, K., Zhang, Z., & Wang, S. (2023). Meat food fraud risk in Chinese markets 2012-2021. *NPJ Sci Food, 7*, 12. https://doi.org/10.1038/s41538-023-00189-z
Madichie, N. O., & Yamoah, F. A. (2017). Revisiting the European horsemeat scandal: The role of power asymmetry in the food supply chain crisis. *Thunderbird International Business Review, 59*, 663–675. https://doi.org/10.1002/tie.21841
Manning, L., Smith, R., & Soon, J. M. (2016). Developing an organizational typology of criminals in the meat supply chain. *Food Policy, 59*, 44–54. https://doi.org/10.1016/j.foodpol.2015.12.003
Moyer, D. C., DeVries, J. W., & Spink, J. (2017). The economics of a food fraud incident – case studies and examples including Melamine in Wheat Gluten. *Food Control, 71*, 358–364. https://doi.org/10.1016/j.foodcont.2016.07.015
Neethirajan, S. (2017). Recent advances in wearable sensors for animal health management. *Sensing and Bio-Sensing Research, 12*, 15–29. https://doi.org/10.1016/j.sbsr.2016.11.004
Newsome, R., Balestrini, C. G., Baum, M. B., Corby, J., Fisher, W., Goodburn, K., Labuza, T. P., Prince, G., Thesmar, H. S., & Yiannas, F. (2014). Applications and perceptions of date labeling of food. *Comprehensive Reviews in Food Science and Food Technology, 13*, 744–769.
Office for product safety and standards. (2020). The use of distributed ledgers to verify the provenance of goods. In *Final report 2020/036* (p. 70). London, UK: BEIS Research Paper. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/923608/use-distributed-ledgers-verify-provenance-goods.pdf. (Accessed 23 February 2023).
Olson ED. Protecting food safety: More needs to be done to keep pace with scientific advances and the changing food supply. Health Affairs 30:915-923. Doi: 10.1377/hlthaff.2010.1265.
Ortega-Reig, M., Palau-Salvador, G., Sempere, M. J. C., Benitez-Buelga, J., Badiella, D., & Trawick, P. (2014). The integrated use of surface, ground and recycled waste water in adapting to drought in the traditional irrigation system of Valencia. *Agricultural Water Management, 133*, 55–64. https://doi.org/10.1016/j.agwat.2013.11.004
Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. New York: Cambridge University Press. https://doi.org/10.1017/CBO9780511807763
Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science, 325*, 419–422. https://doi.org/10.1126/science.1172133
Ostrom, E., Burger, J., Field, C. B., Norgaard, R. B., & Policansky, D. (1999). Revisiting the commons: Local lessons, global challenges. *Science, 284*, 278–282. https://doi.org/10.1126/science.284.5412.278
Ostrom, V., & Ostrom, E. (1972). Legal and political conditions of water resource development. *Land Economics, 48*, 1–14. https://doi.org/10.2307/3145634
Premanandh, J. (2013). Horse meat scandal – a wake-up call for regulatory authorities. *Food Control, 34*, 568–569. https://doi.org/10.1016/j.foodcont.2013.05.033
Putnam, R. D. (1994). Social capital and public affairs. *Bulletin of the American Academy of Arts and Sciences, 47*, 5–19.
Putnam, R. (2000). *Bowling alone: The collapse and revival of American community*. USA: Simon & Schuster.
RIBMINS. (2023). Report on the scope of meat safety assurance systems (MSAS) and competences and roles of risk manager. CA18105 - risk-based meat inspection and integrated meat safety assurance, 86 pp. Available at: https://ribmins.com/wp-content/uploads/2023/02/RIBMINS-WG1-Deliverable.pdf. (Accessed 23 February 2023).
Rincon-Ballesteros, L., Lannelongue, G., & González-Benito, J. (2021). Effective implementation of a food safety management system and its relationship with business motivations. *British Food Journal, 123*, 990–1011. https://doi.org/10.1108/BFJ-04-2020-0283
Rivera, M., Knickel, K., Diaz-Puente, J. M., & Afonso, A. (2019). The role of social capital in agricultural and rural development: Lessons learnt from case studies in seven countries. *Sociologia Ruralis, 59*, Article 12218. https://doi.org/10.1111/soru.12218
Robinson, J. (1934). What is perfect competition? *Quarterly Journal of Economics, 49*, 104–120. https://doi.org/10.2307/1883878

Rose, C., & Gordon, J. (2003). Internet security and the tragedy of the commons. *Journal of Business & Economics Research, 1*, 67–72. https://doi.org/10.19030/jber.v1i11.3070

Rushton, J. (2009). Tools that go beyond the enterprise, farm or business level: Investigating markets, market trends and assessing public investments in the livestock sector. In J. Rushton (Ed.), *The economics of animal health and production* (pp. 115–136). Wallingford, UK: CABI Publishing.

Tweed, W. (1948). The modern abattoir and meat inspection. *J R Sanit Inst, 68*, 494–502.

van Ruth, S. M., Huisman, W., & Luning, P. A. (2017). Food fraud vulnerability and its key factors. *Trends in Food Science & Technology, 67*, 70–75. https://doi.org/10.1016/j.tifs.2017.06.017

Salman, M., Silano, V., Heim, D., & Kreysa, J. (2012). Geographical BSE risk assessment and its impact on disease detection and dissemination. *Preventive Veterinary Medicine, 105*, 255–264. https://doi.org/10.1016/j.prevetmed.2012.01.006

Sartz, L., De Jong, B., Hjertqvist, M., Plym-Forshell, L., Alsterlund, R., Löfdahl, S., Osterman, B., Ståhl, A., Eriksson, E., Hansson, H. B., & Karpman, D. (2008). An outbreak of Escherichia coli O157:H7 infection in southern Sweden associated with consumption of fermented sausage; aspects of sausage production that increase the risk of contamination. *Epidemiology and Infection, 136*, 370–380. https://doi.org/10.1017/S0950268807008473

SCVMPH. (2000). Opinion of the scientific committee on veterinary measures relating to public health on food-borne zoonoses. 203. In *Scientific veterinary committee on veterinary measures relating to public health*. Brussels, Belgium: European Commission, 203 pp. Available at: https://food.ec.europa.eu/system/files/2020-12/sci-com_scv_out32_en.pdf Accessed at May 8, 2023.

SCVMPH. (2001). Identification of species/categories of meat producing animals in integrated production systems where meat inspection may be revised. In *Scientific veterinary committee on veterinary measures relating to public health*. Brussels, Belgium: European Commission, 13 pp. Available at: https://food.ec.europa.eu/system/files/2020-12/sci-com_scv_out42_en.pdf. (Accessed 23 February 2023).

Sharan, M., Vijay, D., Dhaka, P., Bedi, J. S., & Gill, J. P. S. (2022). Biofilms as a microbial hazard in the food industry: A scoping review. *Journal of Applied Microbiology, 133*, 2210–2234. https://doi.org/10.1111/jam.15766

Sun, M. (1985). U.S. Meat inspection needs modernization. *Science, 229*, 450–451. https://doi.org/10.1126/science.229.4712.450-a

Svendsen, G. L. H., & Svendsen, G. T. (2000). Measuring social capital: The Danish Co-operative dairy movement. *Sociologia Ruralis, 40*, 72–86. https://doi.org/10.1111/1467-9523.00132

Tähkäpää, S., Maijala, R., Korkeala, H., & Nevas, M. (2015). Patterns of food frauds and adulterations reported in the EU rapid alert system for food and feed and in Finland. *Food Control, 47*, 175–184. https://doi.org/10.1016/j.foodcont.2014.07.007

Turku, M., Lepistö, O., & Lundén, J. (2018). Differences between official inspections and third party audits of food establishments. *Food Control, 85*, 459–465. https://doi.org/10.1016/j.foodcont.2017.10.031

Wang, M., Rieger, M. O., & Hens, T. (2017). The impact of culture on loss aversion. *Journal of Behavioral Decision Making, 30*, 270–281. https://doi.org/10.1002/bdm.1941

Wiley, H. W. (1908). International congress for the suppression of adulteration. *Science, 27*, 672. https://doi.org/10.1126/science.27.695.672

Winkler, B., Maquet, A., Reeves-Way, E., Siegener, E., Cassidy, T., Valinhas de Oliveira, T., Verluyten, J., Jelic, M., & Muznik, A. (2023). Fighting fraudulent and deceptive practices in the agri-food chain. In *Technical report "implementation of article 9(2) of regulation (EU) 2017/625"*. Luxembourg: Publications Office of the European Union. https://doi.org/10.2760/31366,JRC131525, 2023.

Yiannas, F. (2016). Food Safety = Behaviour. 30 proven techniques to enhance employer compliance. In *Food microbiology and fodo safety. Practical approaches* (p. 115). New york: Springer. https://doi.org/10.1007/978-1-4939-2489-9.

Zanin, L. M., Stedefeldt, E., da Silva, S. M., da Cunha, D. T., & Luning, P. A. (2021). Influence of educational actions on transitioning of food safety culture in a food service context: Part 2 - effectiveness of educational actions in a longitudinal study. *Food Control, 120*, Article 107542. https://doi.org/10.1016/j.foodcont.2020.107542