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ABSTRACT

More than a decade ago, the European Food Safety Authority (EFSA) sparked a substantial modernisation effort in traditional meat safety systems in Europe by publishing a range of EFSA opinions that were followed, from 2014 to 2019, by amendments to relevant EU legislation. A novel, risk-based meat safety assurance system (RB-MSAS) was proposed to address the latest, most relevant meat-borne hazards and protect human health as well as animal health and welfare. This new framework was thought to offer substantial advantages with regard to the combination and longitudinal integration of prevention and control measures along the meat production chain. Official veterinarians (OVs) are expected to take on a central role as risk managers in RB-MSAS and will benefit from the use of harmonised epidemiological indicators (HEIs) and food chain information (FCI). In this article, we aim to provide an introduction to the key concepts of RB-MSAS and elaborate on the potential training needs of OVs as key risk managers in this novel framework. To this end, we present an overview of the components of an RB-MSAS along with the main factors that may hamper its development *vis-à-vis* the current status of the European meat inspection system. We state key future challenges related to the conceptual and practical implementation of a RB-MSAS and give potential solutions. In addition, the technical description of the HEIs proposed by EFSA for different animal species and at specific stages of the food chain is provided, as is their use to categorise farms and abattoirs according to the risk and to conduct risk-based meat inspection. Finally, advanced training tools for OVs enabling them to effectively and efficiently operate as risk managers in the future RB-MSAS environment are outlined.

Credit author statement

Maurizio Ferri, Sophia Johler, Madalena Vieira-Pinto and Eduarda Gomes-Neves devised the project, contributed to the conceptualization, methodology and wrote the original draft preparation; all other co-authors provided the technical and editing support during the revision process, discussed the results and contributed to the final manuscript.

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1. RB-MSAS: an introduction

The main purpose of meat inspection is to verify compliance with human and animal health and animal welfare requirements as outlined by Commission Implementing Regulation (EU) 2019/627 (EU, 2019a). Historically, traditional meat inspection systems were geared towards the detection of gross lesions in slaughtered animals caused by the relevant zoonoses at the time, e.g. tuberculosis, trichinellosis, cysticercosis, and anthrax. Therefore, visual inspection, palpation, and incision became mandatory once these systems were more formalised, and contributed to public health protection from these visible zoonoses, as is reflected in massive reductions of food-borne parasitosis and the decline of tuberculosis in industrialised countries (Edwards et al., 1997; Mousing et al., 1997; Uzal et al., 2002). With the emergence of invisible or only microscopically detectable bacterial hazards, which for fresh meat are *Salmonella, Campylobacter,* verocytotoxin-producing *E. coli* (VTEC), *Yersinia,* and antimicrobial-resistant (AMR) bacteria, currently considered the most relevant causes of zoonotic diseases in Europe (EFSA & ECDC, 2021), the 'old' hazards have become much less epidemiologically important (Fredriksson-Ahomaa, 2014). In addition, concerns have increased about the presence of harmful chemicals in meat, such as industrial contaminants (EFSA Panel on Biological Hazards [BIOHAZ], 2011b). The inability of the traditional meat inspection to detect these invisible agents and chemicals, and the need to ensure that the objectives of human and animal health, as well as animal welfare requirements, are met, led to the concept of a modernised European risk-based meat safety assurance system (RB-MSAS) (Blagojevic et al., 2021). The RB-MSAS aims to address widely recognised weaknesses of the EU traditional meat inspection systems, to take into account epidemiological data, and to promote the sharing of integrated data among all interested actors and risk managers along the whole meat production chain. The historical development of the risk-based concept started in 1995, with the World Trade Organization (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures (World Trade Organization [WTO], 1995), which stressed the importance of a harmonised risk assessment in food controls that aimed to facilitate trade, adaptation to regional conditions and transparency. Subsequently, with the same purpose, in 2005, the World Health Organization (WHO)/Food and Agriculture Organization of the United Nations (FAO) published the Code of Hygiene Practice (Codex Alimentarius Commission, 2005), which stands as the main international standard for meat hygiene. The Code's principles stipulated that: (i) meat inspection should be conducted according to a science- and risk-based approach; (ii) meat hygiene requirements should control hazards to the greatest extent practicable throughout the entire food chain, and hazard analysis and critical control points (HACCP) should be applied wherever practicable as the system of choice for process control; (iii) while the competent authority (CA) has final responsibility for verifying that regulatory meat hygiene requirements are met, the food business operator (FBO) has the responsibility to produce meat that is safe and suitable; (iv) as appropriate to the circumstances, and with the purpose of requirement review, meat inspection should take into account results of monitoring and surveillance of animal and human diseases, and be adaptable to the changing status of individual countries or regions. In 2019, FAO (FAO, 2019), and 2021, the World Organisation for Animal Health (WOAH, 2022) published technical guidance on the application of risk-based meat inspection and recommended the respective protocols. These efforts contributed to the development of a universally acknowledged modern RB-MSAS which is longitudinally integrated, flexible, and dynamic, with the main responsibility for meat safety being placed on FBOs, and with the CAs playing an advisory and auditory role in official control. To effectively control major food/meat hazards, meat inspection must be re-assessed based on a risk-based approach and be part of an integrated control system throughout the meat production chain, with a focus on the farm and abattoir level. This conceptual model of a risk-based and farm-to-fork approach to meat safety, and the application of the principles of risk analysis, dates back to 2000 (Commission of the European Communities, 2000; European Commission, Health & Consumer Protection Directorate-General, 2000). Cornerstones of this concept were the White Paper on Food Safety, the Opinion of the Scientific Committee on veterinary measures relating to public health on revision of meat inspection procedures Regulation (EC) No 178/2002 (The General Food Law) (EC, 2002), and the Hygiene Package legislation of 2004 (EC, 2004a; 2004b; 2004c; 2004d).

Since 2007, the EU, triggered *inter alia* by the enlargement process, issued a broad repertoire of regulatory acts encompassing food safety, food quality, and the official control system of food of animal origin. The new legislative environment, on one hand, advanced the EU approach to food safety and related enforcement, on the other hand, became a blueprint for the law in third countries (Bondoc, 2016a; 2016b; 2016c; 2016d).

On the path to consistently modernise meat inspection across the EU, the European Commission (EC) prompted scientific work by asking the European Food Safety Authority (EFSA) to provide scientific opinions to rank and prioritise biological and chemical hazards according to their risk for public health and to recommend a new RB-MSAS. Consequently, from 2011 to 2013, EFSA published a number of opinions covering the meat inspection of pigs, poultry, cattle, sheep, goats, horses and farmed game, including ranked priority hazards for each species (Table 1). EFSA also proposed a generic framework for MSAS, which incorporates official meat inspection with food safety management systems managed by FBOs.

Notably, for biological hazards, the priority ranking is based on assessment of their impact on the incidence of the disease, the severity of the disease in humans, and on evidence that the consumption of meat from the various species is an important risk factor for the occurrence of the disease in humans (Buncic et al., 2019a). The new RB-MSAS

Table 1
Priority hazards as ranked by EFSA.

Species	Biological hazards	Chemical hazards	EFSA scientific opinions
Pigs	- *Salmonella* - *Yersinia enterocolitica* - *Toxoplasma gondii* - *Trichinella*	- dioxins - dioxin-like polychlorinated biphenyls - chloramphenicol	EFSA Panel on Biological Hazards [BIOHAZ] (2011b)
Poultry	- *Campylobacter* - *Salmonella* - ESBL-AmpC gene-carrying bacteria[a]	- dioxins - dioxin-like polychlorinated biphenyls - chloramphenicol - nitrofurans - nitroimidazoles	EFSA Panel on Biological Hazards [EFSA Panel (2012a)
Cattle	- pathogenic *Escherichia coli* - Salmonella	- dioxins - dioxin-like polychlorinated biphenyls	EFSA Panel on Biological Hazards [BIOHAZ] (2013b)
Sheep and goats	- pathogenic *Escherichia coli* - *Toxoplasma gondii*	- dioxins - dioxin-like polychlorinated biphenyls	EFSA Panel on Biological Hazards [BIOHAZ] (2013a)
Horses	- *Trichinella*	- phenylbutazone - cadmium	EFSA Panel on Biological Hazards [BIOHAZ] (2013d)
Farmed game	Deer: - *Toxoplasma gondii*	None	EFSA Panel on Biological Hazards [BIOHAZ] (2013c)
	Wild boar: - *Salmonella* - *Toxoplasma gondii* - *Trichinella*	None	
	Other: None	None	

[a] Extended-spectrum β-lactamase and AmpC β-lactamase.

Table 2
HEIs for pigs (EFSA, 2011).

Indicator/ Hazard	Food Chain Stage	Analytical/ Diagnostic Method	Specimen	Outcome
HEI 1 *Salmonella* in breeding pigs	Farm	Microbiology: serotyping for epidemiological purposes	Pooled sample faeces	
HEI 2 *Salmonella* in fattening pigs prior to slaughter	Farm	Microbiology: serotyping for epidemiological purposes	Pooled sample faeces	
HEI 3 Controlled housing conditions (CHC) at the farm both for breeding pigs and fattening pigs	Farm	Auditing and practices of: biosecurity management		
HEI 4 Transport and lairage conditions both for breeding pigs and fattening pigs	Transport and lairage	Auditing of: the transportation duration; mixing of batches and; reuse of pens in the lairage		HEI 2 + HEI 4 = influence of transport and lairage conditions in the *Salmonella* carriage of pigs.
HEI 1 *Toxoplasma gondii*	Farm	Auditing of CHC including control of cats and boots		
HEI 1 *Trichinella*	Farm	Auditing of: CHC and *Trichinella*-free status according to Commission Implementing Regulation (EU) 2015/1375		

hallmarks a modern meat inspection system, by which official controls can be carried out in a more cost-effective way. Key components of the shift towards more evidence- and risk-based meat inspection are the harmonised epidemiological indicators (HEIs) developed by EFSA for the different food-producing animal species (EFSA, 2011, 2012, 2013), and the food chain information (FCI). Within its role as EU risk manager, the DG Health and Food Safety (DG SANTE) of the European Commission examined EFSA's opinions and embarked on legislative changes for the practical implementation of the new RB-MSAS. Since 2014, these changes included: Commission Regulation (EU) No 219/2014 (EU, 2014c), which allowed the visual-only ante- and post-mortem inspection of low-risk slaughtered pigs; Commission Regulation (EU) No 217/2014 (EU, 2014a) establishing more stringent process hygiene criteria for *Salmonella* on pork carcasses; Commission Implementing Regulation (EU) 2015/1375 exempting *Trichinella* testing of pigs raised in high-level biosecurity farms (EU, 2015); Commission Regulation (EU) 2017/1495 establishing a process hygiene criterion for *Campylobacter* in broiler carcasses (EU, 2017b), and finally; Commission Implementing Regulation (EU) 2019/627, laying down new requirements for meat inspection procedures for all farm species (EU, 2019b). Still, the modernisation process of the European meat inspection system has not yet been fully implemented and is often lagging behind the legislation, facing the major obstacles of trade requirements, costs, and inadequate FCI (Antunović et al., 2021).

2. Meat-borne biological hazards

Each year and worldwide, unsafe food containing biological hazards, such as harmful bacteria, viruses, and parasites, causes 600 million cases of food-borne diseases, almost 1 in 10 people, and 420,000 deaths, with 30% of deaths occurring among children under 5 years of age (WHO, 2022a; 2022b). Sources of food-borne illness can be food of animal origin, with meat and meat products representing the most important food vehicles for biological hazards (Nielsen et al., 2021). Other common sources include cheese, fish, fresh fruits, vegetables, and drinking water. Well-identified causes of concern with regard to meat safety are key pathogens such as *Salmonella, Campylobacter*, *Yersinia enterocolitica,* VTEC and *Listeria.* They can occur at any stage of the meat chain, i.e. primary production (farming), transport, slaughter, processing, storage, distribution, and consumption (EFSA & ECDC, 2018). Animals can be hosts of many bacteria, viruses, and parasites, and it is estimated that two-thirds of all human infections originate from animals (Jones et al., 2008). This association has steadily increased over the past 50 years due to an increasing demand for animal protein and the use and exploitation of wildlife, along with unsustainable agricultural intensification, utilisation of natural resources, human and animal travel and transportation, and changes to food supply chains and to the global climate. Moreover, epidemiological data tell us that in the last two decades, 75% of emerging infectious diseases were zoonotic, meaning that transmits between animals and humans, directly or indirectly (e.g. food-borne, vector-borne), and the risk of zoonotic infections, will increase in the future due to key anthropogenic drivers (e.g. agricultural intensification, increased demand for animal protein causing more conversion of land to agricultural purposes, and global warming), which bring people into closer contact with disease vectors (United Nations Environment Programme and International Livestock Research Institute, 2020). In 2017, the European Union (EU) member states (MSs) collectively reported 5079 food-borne and water-borne outbreaks (43,400 cases), with 60% of the strong-evidence food-borne outbreaks attributed to food of animal origin, and with meat and meat products being the foods most frequently implicated (EFSA & ECDC, 2018). According to the latest joint EFSA/ECDC zoonoses report (EFSA & ECDC, 2021), the two top zoonotic food-borne diseases in Europe in 2019 were caused by *Campylobacter* and *Salmonella.* While the notification rate is high for *Campylobacter*, with 59.7 cases per 100,000 population (220,682 cases reported), it is lower for *Salmonella* with 20.0 cases per 100,000 population (87,923 cases reported). Human cases of food-borne infection caused by *Campylobacter* were mainly associated with consumption of raw milk, cheese made with unpasteurised milk, raw or undercooked poultry, and contaminated drinking water. The most frequently implicated foods in food-borne salmonellosis outbreaks were eggs and egg products, followed by bakery products, pig meat and products, and mixed food. The occurrence of microbial hazards in meat is unavoidable because the microorganisms are present on animals and in their environments. Although the muscles of healthy animals contain either no or only very few microorganisms (Gill, 1979), the carcass surfaces are exposed to varying degrees of contamination during the long chain of slaughter, evisceration, processing, storage and distribution. Poor hygiene conditions at the abattoir and its environment (e.g. equipment, utensils and workers) are important factors contributing to the contamination of the raw and processed meat with various types of spoilage and pathogenic microorganisms. To keep the microbial load of carcasses and raw meat low, and to reduce the microbiological risks to both producers and consumers, evisceration and handling practices should follow good hygiene practices (GHP), and the principles of HACCP (Codex Alimentarius Commission, 2005). In the last 10–20 years, due to their increased frequency of detection, food-borne parasitic infections have gained statuses of emerging and/or re-emerging zoonotic pathogens at the global level. It was estimated that there are 407 million cases of human parasitic diseases globally per year, of which 91.1 million cases and 52,000 deaths are related to food-borne parasitic diseases (Torgerson et al., 2015). Food-borne parasites of greatest importance are *Echinococcus multilocularis*, *Toxoplasma gondii*, *Trichinella* spp., *Echinococcus granulosus sensu lato* and *Cryptosporidium* (Bouwknegt

Table 3
HEIs for cattle (EFSA, 2013).

Indicator/Hazard	Food Chain Stage	Analytical/Diagnostic Method	Specimen	Outcome
HEI 1 *Salmonella:* risk of introducing the pathogen onto the farm	Farm	Auditing of: purchase policy; mixing with other herds; access to pasture and; access to surface water		
HEI 2 *Salmonella*	Farm	Auditing on-farm practices and conditions		
HEI 3 *Salmonella* status of the group(s) containing animals to be slaughtered within one month	Farm	Microbiology	Pooled faeces	
HEI 4 *Salmonella*	Transport and lairage	Auditing of: the duration spent in each phase; vehicle cleanliness; lairage cleanliness and cross-contamination		HEI 3 + HEI 4 = influence of transport and lairage conditions on the hide
HEI 5 *Salmonella*	Lairage	Visual inspection of the hide conditions at lairage (clean animal scoring system)		HEI 4 + HEI 5 = slaughter batch risk
HEI 1 Verocytotoxin- producing *E. coli* (VTEC)	Farm	Auditing of: purchase policy; mixing with other herds; access to pasture and; access to surface water		
HEI 2 VTEC	Farm	Auditing of: purchase policy; mixing with other herds; access to pasture and; access to surface water		
HEI 3 VTEC status of the group(s) containing animals to be slaughtered in one month	Farm	Microbiology	Pooled faeces/floor samples	
HEI 4 VTEC	Transport and lairage	Auditing of: the duration spent in each phase; vehicle cleanliness; lairage cleanliness and cross-contamination		
HEI 5 VTEC	Lairage	Visual inspection of the hide conditions at lairage (clean animal scoring system)		HEI 3 + HEI 5 = VTEC carriage
HEI 1 *Taenia saginata* (*Cysticercus bovis*)	Farm	Auditing husbandry conditions that could contribute to avoiding the contact of livestock with possible sources of infection	HEI 1 *Taenia saginata* (*Cysticercus bovis*)	Farm
HEI 1 *Mycobacteria*	Farm	Auditing the official status of bovine tuberculosis of the herd using FCI	HEI 1 *Mycobacteria*	Farm

et al., 2018). Their potential risks have long been neglected as they often cause insidious, chronic effects, rather than acute diseases (Robertson, 2018), and are closely associated *inter alia* with poor animal husbandry practices, unsafe management and disposal of human and animal waste products, global warming, increased international travel, food supply globalisation and increased global population (Cavallero et al., 2021; Murrell, 2013). With regard to viral infections, hepatitis E virus (HEV) is of the utmost relevance in the context of food-borne diseases (Crotta et al., 2021). According to WHO, 20 million HEV infections occur worldwide annually, leading to an estimated 3.3 million symptomatic cases (WHO, 2022c). In the past, cases of HEV infection in Europe were mainly associated with international travel, especially to endemic areas. However, as stated by an EFSA opinion (EFSA Panel on Contaminants in the Food Chain [CONTAM] et al., 2017), HEV is now endemic in many European countries, and consumption of raw or undercooked pork is the most common cause of human infection. Future research on biological hazards should focus on developing effective monitoring and surveillance systems able to warn about any new and emerging meat safety issues (Buncic, 2015). This will greatly enhance the sustainability of the meat production chain and prevent future food-borne outbreaks. Since biological hazards can occur at any stage of the meat chain, i.e., primary production (farming), transport, slaughter, processing, storage, distribution and consumption, meat safety assurance requires an integrated, multidisciplinary and risk-based approach encompassing the whole chain, which has become inherently complicated due to globalisation of the food supply. In this context, the official veterinarians' (OVs') contributions throughout the farm-to-fork continuum (i.e. from animal production systems to the post-harvest stage) make them key actors for ensuring meat safety.

3. Components of the RB-MSAS

To make the RB-MSAS properly functional, longitudinally integrated, adaptable to changes in the importance of meat-borne hazards, and flexible enough to meet the needed goals (Blagojevic et al., 2021), it is necessary to implement its key components, and assure that they all function properly. The four components to achieve final targets for biological hazards in chilled carcasses are: (i) FCI; (ii) HEIs, which are aids/tools for risk categorisations of farms and abattoirs; (iii) risk-based meat inspection; (iv) additional/reactive interventions (e.g. chemical decontamination or thermal treatment, such as freezing of meat to reduce risk of toxoplasmosis). The OV by virtue of his skills and experience would play a key role in this RB-MSAS and is fit to operate as a risk manager (Fig. 1).

3.1. Food chain information (FCI)

A comprehensive RB-MSAS combines a range of preventive measures, controls and tools applied both on the farm and at the abattoir in a longitudinally integrated way. To assist the risk manager on the best logistics to apply, it is crucial that they have timely access to credible on-farm hazard data, which could/should be included in the FCI. Regulation (EC) No 853/2004 (EC, 2004b) defines FCI as a self-declaration document written by the farmer and required to accompany food producing animals (cattle, calves, pigs, poultry, horses, sheep, goats and farmed game) before they can be accepted for slaughter by the abattoir. The receipt of FCI is mandatory for abattoir operators who are obliged to request, receive, check and act upon any information recorded on the declaration as part of their HACCP system. The FCI, consisting of epidemiological, herd health and production data, helps to ensure *inter alia* that specified veterinary medicines or animals affected by disease do not enter the food chain, and that the meat is safe for human consumption. Basically, the FCI entails a two-way process linking the veterinary practitioner/farmer with the OV at the abattoir. The involvement of the veterinary practitioner at pre-harvest level can provide a valuable contribution to integrated process control, which is central to RB-MSAS. The information required to be in the FCI is: (i) health status of the farm (the holding must not be under any animal disease movement restrictions or restrictions for public health reasons); (ii) observed withdrawal periods (no risk of known veterinary medicine residues in the meat); (iii) animal health status (have not been exposed to any disease, condition or chemical/veterinary medicine residues that could compromise the animal health or the safety of the end product). FCI should also contain the previous ante- and post-mortem inspection

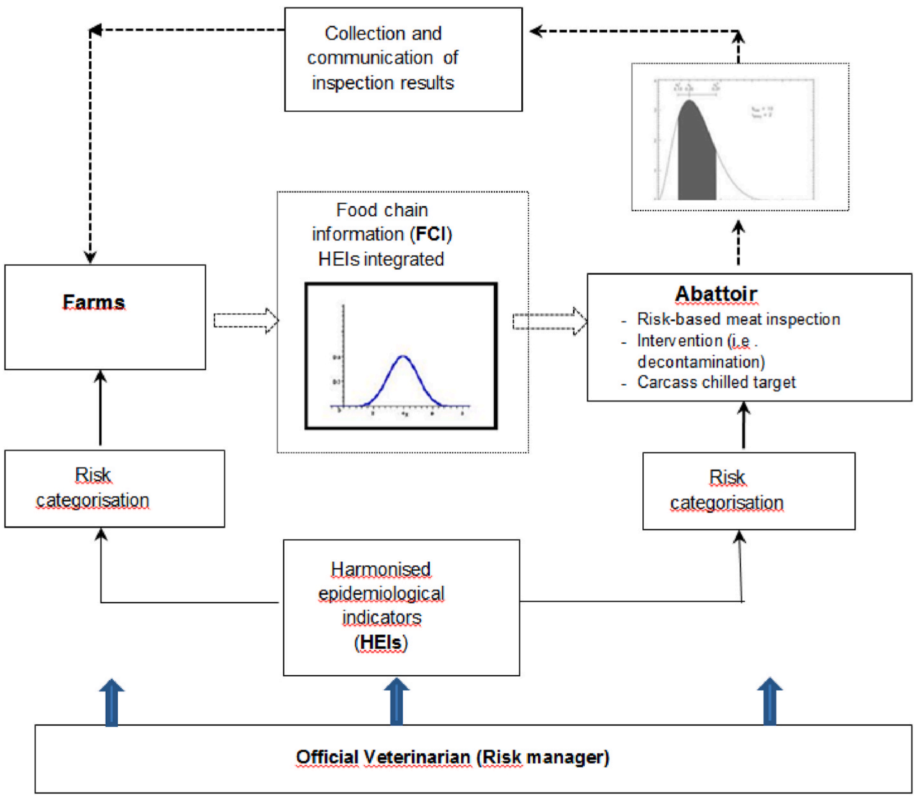

Fig. 1. The key role of the official veterinarian in the RB-MSAS components with related information flow (indicated as arrows).

results from the abattoir for the farm in question, which might provide relevant information for the incoming herd/flock, and for herd/flock health planning to promote improvements in animal health and welfare. Thus, the goals are to improve food safety as well as the efficiency, profitability and sustainability of livestock and meat production. FCI, ideally combined with the HEIs for high-priority risks (see sub-chapter 3.2) and for risks that might emerge in the future, should enable evidence-based risk categorisation of incoming animals based on their on-farm hazard burden, as well as of slaughter processes regarding their capacity to reduce the established risk. For example, the FBO can use FCI to organize slaughter operations and implement hygienic measures, while the OV can properly adapt slaughter methods and inspection procedures based on key parameters, and can carry out additional controls according to Commission Implementing Regulation (EU) 2019/627 (EU, 2019b). In reliable FCI, well-structured and trustworthy epidemiological data on the main biological hazards, and other hazards related to production and mortality rates, will feed the implementation of both risk-based meat inspection and risk categorisation of abattoirs, with both leading to more efficient hygiene/hazard process control. There is general agreement on the following minimum requirements of FCI: appropriateness, reliability, relevance, and accessibility. Appropriateness is related to public health significance; reliability refers to trustworthy and correct information being provided by farmers and veterinary practitioners; relevance refers to the type of animal species and the existing integrated farming system or controlled housing conditions; accessibility refers to the ease of disseminating information among interested actor making use of electronic forms of communication as much as possible (O'Sullivan et al., 2015). Unfortunately, current practice in the EU shows the implementation of FCI is lagging behind its original intentions, and its use has largely not been achieved to date (Antunović et al., 2021; Buncic et al., 2019b; Gomes-Neves et al., 2018). The concept of FCI is relatively easily applied in the integrated poultry and pig industries, in which it is facilitated by the controlled housing conditions on the farms, and the existence of the an integrated system. In contrast, the cattle and sheep industries, with their high numbers of producers, a limited amount of integration, and different marketing methods, present difficulties for its implementation.

3.2. Harmonised epidemiological indicators (HEIs)

In the context of the modernisation process of meat inspection, and based on advanced knowledge of the prevalence and incidence of the main pathogens in farmed animals, epidemiological indicators first appeared in 2011 within EFSA scientific opinions on HEIs for different farm animal species (EFSA, 2011, 2012, 2013). These opinions aimed to integrate EFSA's scientific opinions on the public health hazards to be covered by inspection of meat (pigs, i.e., swine; poultry; bovines) (EFSA Panel on Biological Hazards [BIOHAZ], 2011b, 2013b; EFSA Panel, 2012a). HEIs were conceived as a key component of the generic framework for carcass safety assurance for biological hazards proposed by EFSA, in the form of a metric (i.e. quantitative key parameters). A HEI is defined as the prevalence or incidence of a hazard at a specified stage of the food chain, or an indirect measure (such as an audit of a farm) of a hazard that correlates to the human health risk caused by the hazard (EFSA, 2011). The basic idea behind the EFSA endeavour was to facilitate comparability and data exchange between MSs by harmonising the concepts and application of epidemiological indicators across Europe. The purpose was to facilitate the categorisation of farms/animals and later, abattoirs, by setting appropriate, specific levels for hazards in animals and carcasses. Ultimately, the HEIs inform the OVs who operate as risk managers at different levels (national, regional, abattoir and farm). Hence, in an implemented RB-MSAS, the information conveyed by the HEIs is used by the FBOs to improve on-farm and abattoir control measures and is used by the OVs to assign a risk level to each farm and abattoir, and to make decisions about whether additional risk mitigation measures are needed to control some specific hazards in/around the incoming animals. Such OV decisions are on slaughter hygiene (e.g. logistic slaughter), slaughter line speed reduction, additional meat inspection procedures, and the use of approved decontamination or inactivation treatments. HEIs are polyvalent and specific to the epidemiological context of the area, region, and country, and can support intensification/adaptation of meat inspection procedures, which are applied more stringently to high-risk animals (Buncic et al., 2019a). The HEIs should be reviewed regularly in light of new information and the data generated by their implementation. However, after ten years since the first EFSA publication on HEIs, based on MSs' experience and recent evaluation, FCI is still lacking adequate and standardised HEIs for the main public health biological hazards identified by EFSA (Bonardi et al., 2021). The exceptions to this are the hazards *Trichinella* and *Salmonella*, that covered by meat inspection of pigs and poultry, respectively (EFSA Panel on Biological Hazards [BIOHAZ], 2011b; EFSA Panel, 2012a), with HEIs that are included in EU respective mandatory monitoring plans (EFSA, 2011, 2012). These HEIs seemed best suited to integrating food-borne hazard controls with modernised pig and poultry meat inspection at slaughter.

3.2.1. Use of HEIs for risk categorisation of farms

To date in the EU, the development and practical implementation of HEIs on farm, during transport and at the abattoir appear as an exceptional circumstance rather than a widespread practice. The MSs' CAs are expected to use HEIs, preferably in collaboration with FBOs, to control housing conditions at farms, to categorise abattoirs, to adapt the meat inspection taking into account priority hazards, and to carry out a risk analysis to support any such decisions. On farms, the monitoring of HEIs is generally performed by auditing, using a questionnaire for husbandry conditions, or by collecting samples (e.g. faeces) for microbiological examination. The sampling strategy can be census sampling (for auditing) or representative sampling (random or systematic) of animals in the epidemiological unit(s) on the farm or of the group of animals that will be slaughtered in one month (EFSA, 2011, 2012; EFSA Panel on Biological Hazards [BIOHAZ], 2011b; EFSA Panel, 2012a). During transport and at lairage, HEIs can be assessed by auditing or by visual inspection (e.g. clean score system). However, not all MSs have defined the requirement for auditing or standardised the auditing of farms, transport, and lairage, or provided sampling plans (Buncic et al., 2019b). The HEIs for specific hazards associated with pigs, cattle, and poultry are described in the Table 2, 3 and 4.

Trichinella monitoring is mandatory at the abattoir level in each EU country, with various percentages of carcasses tested in relation to the status of farms (EU, 2015), while *Salmonella* control programmes at farms are implemented in a limited number of countries, frequently on a voluntary basis (Bonardi et al., 2021). Some European countries have set up programmes for *Salmonella* control in pigs and cattle. These can be divided into two types of approaches: (i) elimination of infection, and; (ii) control and reduction of infection. Sweden, Norway, and Finland have adopted the first approach by virtue of low prevalence on farms, and by using bacteriology as the main detection method (Bonardi et al., 2021). What characterises this type of programme is that if *Salmonella* is detected, stringent measures are applied. These programmes have achieved their goals, as very low levels of *Salmonella*-positive carcass swabs are now seen in all three countries. Conversely, Denmark (Danish Technical Institute, 2022), Germany, The Netherlands, Belgium, Ireland, and the UK adopted the control and reduction approach by implementing a monitoring system based on serology on farms, assigning the farms to risk categories based on their serological profiles, and having specific, targeted control measures. The degree of success is variable, but at the moment, the programmes have not achieved consistent reductions of farm-level prevalence in all of these countries. In the UK the programme was suspended, and in Belgium it is now voluntary (Correia-Gomes et al., 2021). Benefits of EU *Salmonella* control programmes in poultry are reflected in the trends of decreasing *Salmonella* prevalence on farms and on carcasses at abattoirs, as well as decreasing numbers of human salmonellosis cases. Programmes should continue in order to keep meeting the EU targets given in Commission Regulation (EC) No 2073/2005 and subsequent amendments (EU, 2005), but for an effective public health programme, the implementation of measures is needed for other animal species (Antunes et al., 2016; Hugas & Beloeil, 2014; Skarżyńska et al., 2017)

3.2.2. Applicability of HEIs in FCI

The quality of both FCI and HEIs will encourage a multidisciplinary approach, including veterinary-led risk assessment and management on farms and collaboration with the FBOs, to improve not only food safety, but also animal health and welfare. If meat inspection is moving towards visual-only inspection for low risk animals, a crucial step will be producing more robust and reliable FCI that is based on integrated HEIs. This system will streamline the food safety risk-based decisions by the OVs, provide an effective approach to control the main hazards, and facilitate benchmarking and epidemiological comparison for various farming sectors at regional and country levels. But which HEIs can be included in the FCI among those indicated by EFSA for each animal species? Table 5 illustrates the applicability and incorporation of HEIs in a revised form of FCI for pigs, poultry, and bovines.

3.3. Abattoir risk categorisation

Risk categorisation of abattoirs based on their risk reduction performance has been suggested as an important component of RB-MSAS (EFSA Panel on Biological Hazards [BIOHAZ], 2011b). This type of categorisation is the outcome of a food safety management system (FSMS) performance evaluation, based on both the use of the proposed HEIs, and the effectiveness of new tools/methods for detecting pathogens on carcasses. Regarding bacterial carcass contamination, a current assessment tool is based on verification of the HACCP system performance through process hygiene criteria (PHC). For instance, in a cattle abattoir, PHC for pre-chilled beef carcasses includes aerobic colony count, Enterobacteriaceae count, and the presence/absence of *Salmonella* (EU, 2005). However, a wide range of different methods of assessing process hygiene is used in MSs, mainly relying on visual assessment and scoring of practices or microbiological testing (Blagojevic et al., 2021). Moreover, abattoirs do differ in their capacities, technologies, and equipment, as well as in hygiene training, staff motivation, and management (Alvseike et al., 2019; Cegar et al., 2022; Djekic et al., 2016), each of which can affect their differing hygiene performances. The assessment of abattoir performance will also consider the use of key intervention strategies and methods for animal slaughter and carcass handling. Various preventive and control measures (interventions) are available to achieve better performance in animal health and welfare, to meet food safety objectives for chilled carcasses, and to reduce the overall public health risk. They can be based on extrinsic control measures (good manufacturing practice (GMP)/good hygiene practice (GHP)) applied pre-slaughter and/or at the slaughter line (FAO, 2007), as well as hazard-based (or inherent) interventions that are evidence-based, i.e., developed from scientific research to achieve demonstrable and quantifiable reductions in hazard exposures (Costa et al., 2020). These are described in sub-chapter 3.4.1 on risk-based meat inspection methods. The best option to prevent and control priority hazards is the combination of risk categorisations of farms and abattoirs. This combination helps risk managers decide to which abattoirs they should send animals that originate from farms with different risk levels. Here, the ultimate goal is to achieve the set targets for the microbial hazards on the carcasses. High-risk animals should be directed to abattoirs having demonstrated an enhanced ability to control carcass contamination. However, if high-risk animals are slaughtered in an abattoir with a low ability to control carcass contamination, additional slaughter hygiene control measures (e.g. reduction in slaughter line speed) must be implemented, complemented with decontamination treatments (Fig. 2).

Indeed, the risk categorisation of abattoirs provides clear benefits for the CA, which can adjust slaughter methods (e.g. slaughter logistics)

Table 4
HEIs for poultry (EFSA, 2012).

Indicator/Hazard	Food Chain Stage	Analytical/ Diagnostic Method	Specimen	Outcome
HEI 1 *Salmonella* in breeding parent flocks	Farm	Microbiology: detection and serotyping for epidemiological purposes	Pooled faeces	
HEI 2 *Salmonella* in poultry flocks prior to slaughter	Farm	Microbiology: detection and serotyping for epidemiological purposes	Pooled faeces	Batch-level risk.
HEI 3 Controlled housing conditions (CHC) at farms for laying hens and fattening flocks	Farm	Auditing CHC and biosecurity		HEI 1 + HEI 3 = produce Farm-level risk
HEI 1 *Campylobacter* in poultry flocks prior to slaughter	Farm	Microbiology/real-time PCR	Faecal droppings collected 2–3 days prior to slaughter or boot swabs	
HEI 2 *Campylobacter* in CHC at farm for poultry flocks	Farm	Auditing CHC and biosecurity		HEI 1 + HEI 2 = produce Farm-level risk
HEI 3 *Campylobacter*	Farm	Auditing to determine if partial depopulation (thinning) was carried out in the flock sent to slaughter		HEI 1 + HEI 3 = produce Batch-level risk
HEI 1 ESBL/ AmpC [a] producing *E. coli* in elite, grandparent and parent breeding flocks producing chicks for meat production lines	Farm	Microbiology		
HEI 2 ESBL-/ AmpC-producing *E. coli* in incoming 1-day-old chicks for fattening purposes	Farm	Microbiology		
HEI 3 ESBL-AmpC-producing *E. coli* in poultry flocks prior to slaughter	Farm	Microbiology		HEI 2 + HEI 3 = Batch-level risk
HEI 4 CHC	Farm	Auditing CHC and biosecurity		HEI 1 + HEI 2 + HEI 4 = Farm-level risk

[a] ESBL-AmpC: extended-spectrum β-lactamases and AmpC β-lactamases.

Table 5
Applicability of HEIs in FCI for pigs, poultry, and bovines (EFSA, 2011, 2012, 2013).

Species	Relevant HEI information on priority hazard to be included in the FCI
Pigs	*Salmonella* - results of monitoring *Salmonella* in breeding pigs and fattening pigs - result of audit into controlled housing conditions on-farm *Toxoplasma* - results of audit into controlled housing conditions on-farm *Trichinella* - results of audit into controlled housing conditions on-farm - statement and proof of disease free status
Poultry	*Salmonella* - monitoring in breeding parent flocks and in poultry flocks prior to slaughter - results of audit into controlled housing conditions on-farm for laying hens and fattening flocks (including biosecurity) *Campylobacter* - results of sampling of caecal droppings in poultry flocks prior to slaughter (positive or negative classification of flocks) - results of audit into controlled housing conditions on-farm (including biosecurity) - information on partial depopulation of flocks for each slaughter batch ESBL/AmpC-producing bacteria (*E. coli* and *Salmonella*) - results of microbiological testing of pooled faeces from birds on-farm, including paper used in transport boxes - results of audit into controlled housing conditions on-farm - information on use of antimicrobials during the whole lifetime of the flock
Bovine	*Salmonella* - monitoring results of *Salmonella* status of the group(s) of bovine animals containing animals to be slaughtered within one month - Results of audit into on-farm practices and conditions that increase the risk of introducing *Salmonella* to animals, flocks/herds or the farm *VTEC* - results of monitoring the pathogenic VTEC status of the group(s) of bovine animals containing animals to be slaughtered within one month - results of audit into on-farm practices and conditions that increase the risk of introducing VTEC to the farm *Cysticercus* – results of audit on-farm *Mycobacteria* – report on official bovine tuberculosis status of the bovine herd (officially tuberculosis free (OTF) status)

and/or line speed and change the frequency and type of official controls (e.g. audits focusing on specific aspects), with the overall goal of reducing risk to consumers, and achieving a higher level of public health protection. Other benefits include optimising audits conducted by third parties and facilitating export (Antunović et al., 2021). However, key points of any model and system of abattoir risk categorisation are data collection and accessibility, standardized methodology, and criteria for abattoir process hygiene assessment. It is likely that at a country, regional or provincial level in the EU, risk categorisation of abattoirs, where implemented, is based on different methods and parameters depending on the animal species (e.g. pigs, poultry, bovines), the results of official controls, the availability of the FBO's own data, and the organisation of the CA. Article 9 'General rules on official controls', paragraph 1 of Regulation (EU) 2017/625 (EU, 2017a) provides some examples of parameters related to the risk-based official control performed by the CA (Table 6). While the risk-based approaches for ante- and post-mortem procedures have received more global attention in terms of harmonisation, the microbiological criteria used present considerable challenges. For the purpose of consistent and reliable abattoir risk categorisation, further investigation on and standardisation of the levels of indicator microorganisms (e.g. aerobic colony count, Enterobacteriaceae count, and *E.coli* count) on chilled carcasses are needed. These levels are mainly related to the abattoir's process

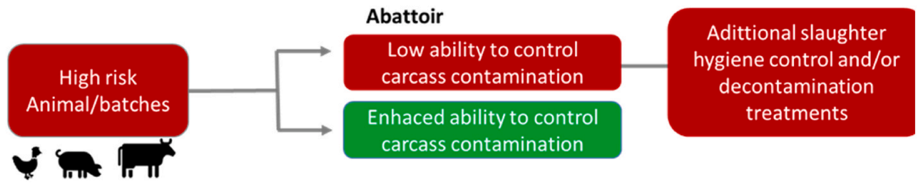

Fig. 2. Abattoir control of carcass contamination.

Table 6

Factors to be considered for abattoir risk categorisation:
- identified risks associated with animals and goods, the FBO's activities, location of the activities or operations of operators, use by the FBO of products, processes, materials or substances - FBO's past records as regards the outcomes of official controls performed on them by the CA, and the FBO's compliance with the rules - the reliability and results of the FBO's own controls that have been performed by the FBO, or by a third party at their request, including, where appropriate, private quality assurance schemes

hygiene, whilst the presence of pathogens can be considerably affected by their pre-abattoir status, i.e. on/in the animals (Cegar et al., 2022). Notably, as for *Campylobacter* in poultry, effective reduction can be successfully achieved within an integrated RB-MSAS, with measures aimed at reducing both the flock prevalence/colony counts (risk-based farm intervention), and the cross-contamination at slaughter and meat processing (including the hygiene criterion). Cross-contamination also occurs at retail and consumer levels, outside the specific remit for OVs discussed herein. Such cross-contamination might be reduced by effective retailer/consumer awareness campaigns.

3.4. Risk-based meat inspection

Most of today's priority biological hazards are bacterial in nature, such as *Salmonella*, *Campylobacter*, *Y. enterocolitica* and VTEC causing the top-four reported zoonoses in humans in Europe. Since these pathogens do not always cause disease in animals, the main risk to consumers is caused by healthy slaughter animals that carry them, i.e. animals that do not show clinical signs at ante-mortem inspection, or do not present visible pathological lesions, and that excrete the bacterial pathogens primarily via faeces. Neither cutting nor palpation is a helpful diagnostic tool in these cases (Berends & Snijders, 1997; Hamilton et al., 2002; Riess & Hoelzer, 2020); on the contrary, they can contribute to cross-contamination with food-borne pathogens within and between carcasses due to insufficient hand and knife hygiene. To increase meat hygiene, stringent GHP and HACCP concepts were introduced in the early 2000s (EC, 2002; 2004a), while subsequent EFSA scientific opinions stated that the Public health risk generated by palpation/incision is likely higher than the public health risk posed by the abnormalities found by this traditional technique (EFSA Panel on Biological Hazards [BIOHAZ], 2011b, 2013b; EFSA Panel, 2012a). Therefore, the omission of palpation/incision and a shift towards visual-only post-mortem inspection for low-risk animals should reduce the spread and cross-contamination of the high-priority and invisible biological hazards, and should have a significant favourable effect on the microbiological status of carcasses (Antunović et al., 2021). Meat inspection with respect to these hazards principally relies on the prevention or reduction of faecal and other contamination in the abattoir environment and on meat during slaughter and carcass dressing. These preventions/reductions come about by an increase in abattoir process hygiene (Blagojevic & Antic, 2014) through the implementation of GMP/GHP and HACCP procedures. Visual-only meat inspection is allowed only for low-risk herds with an appropriate FCI system and pre-harvest controls in place. This was anticipated by Commission Regulation (EU) No 218/2014 for finisher pigs in indoor production (EU, 2014b) and is comprehensively laid down in Commission Implementing Regulation (EU) 2019/627 (EU, 2019b). Under this system, a visual-only inspection of the carcass and its organs is the standard, while palpation and incision should be maintained when there are indications of a possible risk to human or animal health or indications of animal welfare issues, as identified by either the FCI or at ante-mortem inspection. Based on the results of the meat inspection, individual carcasses can be deemed as bearing an increased risk to human health. One way of mitigating this risk is to subject a carcass to decontamination methods such as freezing to inactivate parasites, or organic acid washes to reduce microbial load (Hugas & Tsigarida, 2008). Because the use of decontamination methods can inherently mask poor hygiene practices, carcass decontamination is restrictively regulated in the EU. While Regulation (EC) No 853/2044 (EC, 2004b) stipulates that aside from potable water, other substances that have been approved by the EU Commission can be used to remove surface contamination, only freezing of carcasses for parasite inactivation and lactic acid washes for bovine carcasses are allowed in the EU (EFSA Panel on Biological Hazards [BIOHAZ], 2011a). At the moment, there is no European regulation that allows the use of peroxyacetic acid (PAA) to decontaminate poultry carcasses, but the issue is currently being discussed in the EU (BEUC - The European Consumer Organisation, 2014; BfR, 2017). Overall, the shift from traditional meat inspection involving palpation and incision of all carcasses to a predominantly visual-only system is a viable option to adapt modern meat inspection to the predominant risks associated with the consumption of meat in Europe today (Riess & Hoelzer, 2020), provided the necessary standardisation of appropriate procedures is undertaken. Moreover, future computer imaging technology will offer an interesting solution to avoid manual handling during meat inspection (Buncic et al., 2019b). Compared with traditional meat inspection, stakeholders are more confident in the new meat inspection systems and say the workload is reduced or the same (Antunović et al., 2021). There is no global consensus on methods for risk-based meat inspection. This depends on the time and budget available, as well as the preferred output. Generally, the process follows a tiered approach. First, priority hazard-meat combinations are identified, ideally supported by the information conveyed by the HEIs. Then, the effectiveness of new tools and methods for the detection of carcass contamination is assessed, followed by regular monitoring of the performance of the implemented food safety management system (Zdolec et al., 2022). The risk-based inspection relies on interventions implemented during meat processing to reduce the risk of microbial contamination of carcasses. These interventions can be GMP/GHP-based (proactive) or hazard-based (reactive). The former is founded on empirical knowledge and experience (e.g. cleaning and disinfection of lairage area, hide cleanliness assessment and removal methods, rodding, bunging, knife-trimming, chilling, equipment sanitation), are qualitative in nature, and fall under the prerequisite programmes (PRPs) (EU, 2016). Differently, the hazard-based measures are evidence-based and designed to specifically control priority microbial hazards (i.e. *Salmonella, Campylobacter,* VTEC, *Yersinia, Trichinella, Toxoplasma, Mycobacterium bovis).* Hazard-based measures are interventions that can achieve microbial removal, immobilisation, or inactivation, such as cattle hide chemical washes, beef carcass treatments after dehiding (washes, rinses, and sprays), steam vacuum, pasteurisation, and organic acid washes, and since they are quantitative in nature, they demonstrably reduce the bacteria load. Both strategies are essential and are best applied together in a sequential and coordinated way as a part of the multiple-hurdle approach that aligns well with RB-MSAS's longitudinal and integrated nature (Blagojevic et al., 2021); this combination of strategies achieves consistent reduction effects on both faecal indicator bacteria levels and pathogen prevalence (Antic et al., 2021). For the purpose of risk-based inspection, the CA can set meat safety targets for chilled carcasses, particularly in cases where the FBO is unable to sufficiently reduce risks arising from specific farms/animal batches by using process hygiene alone. The CA also identifies production processes associated with high risks for consumers. Assessment of the effect of interventions in risk-based meat inspection (called process hygiene assessment) requires data on: (i) expected prevalence/levels of microorganisms on the carcasses, e.g., counts of aerobic bacteria, Enterobacteriaceae and/or generic *E. coli*, presence/absence of *Salmonella* (EU, 2005); (ii) sample size; (iii) expected reduction effect in the prevalence/numbers; (iv) possible confounders and risk-of-bias assessment; (v) application of intervention parameters (e.g., duration, temperature, concentration, mode of application). However, with regard to pork processing, for example, consistent data on the efficacy of interventions on indicator organisms and *Yersinia* are lacking (Zdolec et al., 2022). One problem is that intervention studies are normally conducted experimentally, so are often performed under highly controlled but unreal conditions in the laboratory, or under more real field/commercial (abattoir) conditions, prone to be less controlled. However, randomised controlled trials can be considered the "gold standard" for evaluating interventions (Hariton & Locascio, 2018). A recent study assessed and compared the effectiveness of interventions in carcass MSAS at the pre-slaughter and slaughter stages for cattle, pigs, sheep, and broiler chickens. The study showed the best effects in reducing the number of bacteria were obtained by using hazard-based interventions such as pasteurisation treatments with hot water and/or steam, or these in combination with organic acid washes (Antic et al., 2021). However, there are still data gaps in measuring the efficacy of interventions, and there is a need for further research on other environmental, social, and economic factors. All this knowledge is needed to guide risk management decisions toward a well-functioning and effective RB-MSAS. Future opportunities to improve the detection of carcass contamination and gross pathological lesions, and to advance RB-MSAS, will rely on the use of novel vision systems, such as non-invasive imaging techniques (e.g. optical, ultrasound, tomographic, thermal).

4. Training in RB-MSAS

Performance of official controls strongly depends on the availability of well-trained staff. Regulation (EU) 2017/625 states that appropriate and dedicated training should be provided to OVs by the Commission, CAs, or delegated bodies (EU, 2017a). This training provides staff who perform official controls with the necessary competencies and allows them to stay up-to-date in their area of expertise through regular training as necessary. Commission Delegated Regulation (EU) 2019/624 lists the specific areas of expertise expected from OVs in the meat sector and specifies a minimum practical training period of 200 h (EU, 2019a). In the scientific opinions on HEIs for pigs, poultry, and bovines (EFSA Panel on Biological Hazards [BIOHAZ], 2011b, 2013b; EFSA Panel, 2012a), EFSA recommends organizing training to ensure the HEIs are applied uniformly. Table 7 summarises all EU regulations currently in force that pertain to OV training. Currently, there are considerable differences between national systems within Europe, depending on the level of implication of RB-MSAS, the FCI system used, and existing trade agreements with third-party countries. In spite of the fact that Day One Competencies for Veterinarians are supported by the European Directive 2005/36/EC, and subsequent amendments (EC, 2005), more attention should be focused on practical training in official controls in the undergraduate veterinary curriculum (Maijala & Korkeala, 2008; Seguino et al., 2021). Currently, RB-MSAS is raising new challenges to training, and there are several important knowledge gaps regarding training of the OVs within the EU. There is no overview available on the different training programmes for OVs in MSs, and there is no internationally coordinated training programme. There is no information available on how the requirements for OV training within the EU regulations (Table 7) are implemented in the different MSs. Accordingly, features required by Commission Delegated Regulation (EU) 2019/624 (EU, 2019b), such as the establishment of exchange programmes for staff amongst MSs to ensure uniform conditions for the implementation of the EU rules, as well as the requirement to mutually recognise OV education to allow for mobility of OVs between MSs, are poorly implemented.

Considering these knowledge gaps, there is a need to evaluate the OV training systems in the different MSs. In parallel, all stakeholders should be involved in determining specific training needs for OVs in individual countries. This combined information could then be used to create tailored, modular training systems that can be implemented across the MSs. Potential providers of appropriate training for OVs are CAs, national and international professional associations, universities, and FBOs. Language differences and confidentiality requirements implemented by FBOs are potential barriers to the accessibility of training materials across Europe. However, to enable integrated RB-MSAS, and a harmonised FCI data system, a concerted effort towards providing OVs across Europe with a comprehensive understanding of RB-MSAS is

Table 7
Current EU regulations on official veterinarian (OV) training.

Regulation and EFSA scientific opinions	Title	Relevant sections pertaining to OV training
(EU) 2017/625	On official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products	Article 5 no 4 a-c, Article 18 no 3, Article 81
(EU) 2019/624	Qualifications for OVs and requirement for continuing education	Appendix II: Chapter I, Chapter II
(EC) No 852/2004	On the hygiene of foodstuffs	Chapter XII[a]
EFSA Journal 2011; 9(10): 2371 (pigs) EFSA, 2011	Scientific Opinion on the public health hazards to be covered by inspection of meat (swine)	"Member States are invited to organize training to ensure harmonised implementation...." "It is recommended that the Commission and the Member States organize training to ensure harmonised implementation of the monitoring and inspection requirements."
EFSA Journal 2012; 10 (6):2764 (poultry) EFSA 2012	Technical specifications on harmonised epidemiological indicators for biological hazards to be covered by meat inspection of poultry	"Member States are invited to organize training to ensure harmonised implementation..." "It is recommended that the Commission and the Member States organize training to ensure harmonised implementation of the monitoring and inspection requirements for the HEIs."
EFSA Journal 2013; 11 (6):3276 (bovines) EFSA 2013	Technical specifications on harmonised epidemiological indicators for biological hazards to be covered by meat inspection of bovine animals	"Member States are invited to organize training to ensure harmonised implementation" "It is recommended that the EC and the MSs organize training to ensure harmonised implementation of the monitoring and inspection requirements for the HEIs."

[a] This older regulation does not pertain to OV training but states the FBOs are responsible for training personnel involved in HACCP.

indispensable.

5. Challenges for the OV under the RB-MSAS

The scientific and legislative changes of the last two decades, combined with new epidemiological, economic, technological, and scientific contexts (Table 8), radically changed the way risk-based meat inspection has to be carried out by the OV in the framework of the RB-MSAS. The RB-MSAS raises new professional challenges for the OV, but also provides the basis for the OV to make sound, well-informed meat safety decisions. Current challenges include the diverse socio-economic and cultural conditions existing among EU MSs, a lack of proper definition of the OV's roles, responsibilities, and competencies, as well as a lack of a training roadmap towards successful implementation of RB-MSAS. Indeed, the OV, as risk manager, is required to update, advance, and optimise their knowledge on current, most pressing issues, such as sustainability, animal health, animal welfare, fraud prevention, and AMR, and to champion new technology and innovation. These needs can be met by designing a new OV training programme to fill the gaps in the key components of RB-MSAS: FCI, HEIs, risk-based meat inspection, and additional/reactive interventions. Further challenges in OV training include the roles of third-party Inspections and private control systems and the coordination with other professionals, e.g. auxiliaries and plant staff at abattoirs and meat processing plants.

Numerous knowledge gaps are still present in the increasingly complex meat safety system that includes food safety, animal health, animal welfare, fraud prevention, sustainability, mitigation of AMR, and sustainability, so further scientific research is needed to fill them (Vågsholm et al., 2020). Potential solutions can be envisaged in effective on-farm monitoring with reliable and punctual information regularly conveyed to the abattoir by means of FCI. Key information might derive, for instance, from results of multi-serology testing of priority hazards (e.g., *Salmonella*, *Yersinia*, *T. gondii* in pigs), which would enable the OV at the abattoir to assign a risk level to incoming animals and to carry out an *ad hoc* risk-based meat inspection. Further development of post-mortem inspection methods will include the use of imaging technologies, based on cameras and computerised analysis, to detect pathological lesions, abnormalities, and contaminants of carcasses and viscera on slaughter lines (Park et al., 2004). Several advantages arise from using these technologies: improvement of feedback to farmers about diseases present; the avoidance of manual handling of meat during inspection, and; prompt adoption of mitigation actions. Another direction for future work of the OV is the improvement of the abnormality recording system by using an automated computer system located at inspection points to identify and record post-mortem conditions (McKenna et al., 2020). For the transition to a fully integrated and properly functioning RB-MSAS, it is of paramount importance to define new OV competencies and to develop related OV skills for the enhancement of food safety, animal health and welfare, public health, and the environment. Aside from implementing efficient regulatory controls, the OV will operate as a bridge linking national regulatory authorities with the meat industry operators to assure the most cost-effective contribution to public health. All this signals the need to revise the current OV training programme, as it needs to incorporate new tools and methodologies for the implementation of the RB-MSAS. Among them, digitisation might prove to be a future key, as it enables the OV to query larger and more complex databases and to analyse and predict the associations between hazards and food.

Table 8
The multidimensional context and drivers of future RB-MSAS.

Context	Drivers
Epidemiologic	Globalisation, changes of animal health status lead to an increasingly complex food safety environment with new food safety hazards, including environmental contaminants and residues
Technological	The deployment of emerging technologies in different areas of the meat sector requires close collaboration between farmers and veterinarians: e.g., precision livestock farming uses biosensors to early detect animal health and welfare problems; camera-based technologies that use computerised vision systems to detect carcass contamination and gross pathologies post-mortem, which are mainly developed and used in the poultry industry
Socio-economic	The unprecedented development of the EU meat sector towards intensified farming with increased productivity led to a close link between animal health, animal welfare and concern about food safety and quality and sustainable waste management.
Scientific	New scientific evidence (ref: EFSA scientific reports) supports the shift towards the evidence (risk)-based approach of the official control system and FBOs' food safety management programmes.

6. Conclusions

The RB-MSAS proposed by EFSA and supported by related scientific opinions aims to revise and modernise the European meat safety system to improve public health. However, its full implementation and fine-tuning require the overcoming of numerous gaps pertaining to research, roles, responsibilities, positioning (e.g. local, global or both), and training of the OV as risk manager, along with increased FBO awareness of their own roles and responsibilities. The main prerogatives of RB-MSAS revolve around a rapid exchange of information with bi-directional information flow through the farm-to-fork continuum. This integrated RB-MSAS allows the harmonised implementation of the epidemiological indicators and will have minimum monitoring and inspection requirements. The successful implementation of RB-MSAS to reduce the presence of biological hazards in the meat production chain also relies on: (i) organisation and trust between operators and decision makers; (ii) close collaboration of relevant stakeholders; (iii) risk analysis training; (iv) rapid and effective diagnostic aids, and; (v) the implementation of novel and cost-effective tools. The OV's proficiency in RB-MSAS requires a high level of competence in meat inspection that will be reached with education and practical training in epidemiology, risk assessment, and the use of FCI/HEIs and new technologies. While a RB-MSAS is designed to improve food safety and public health, and animal health and welfare, additionally it can contribute to economic gains on farms through reduced costs of treating diseases and lower production losses, and can enhance retailers' and consumers' trust in safe food. There is a remarkable global buy-in to risk-based frameworks, and a clear value for the OV as risk manager to assess and effectively control priority hazards, and to achieve continuous improvement of public health. Finally, to fully implement RB-MSAS, the strong commitment of all actors in the food chain to gradual and consistent change in the proper allocation of financial, human and technical resources is needed.

Declaration of competing interest

All authors report that they do not have any conflict of interest.

Data availability

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

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