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Review

Drivers, opportunities, and challenges of the European risk-based meat safety assurance system

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ABSTRACT

The traditional meat safety system has significantly contributed to public health protection throughout the last century. However, it has been recognised that this system suffers many flaws – the main being its limited ability to control the currently most important meat-borne hazards. The European Food Safety Authority evaluated meat inspection in the public health context, prioritised meat-borne hazards and proposed a generic framework for a new, risk-based meat safety assurance system. The proposed system aims to combine a range of preventive and control measures, applied at farms and abattoirs and integrated longitudinally, where official meat inspection is incorporated with producers' food safety management systems into a coherent whole. The modernisation process has recently started as a direct result of changes to relevant legislation in the European Union. Many challenges have been experienced while many opportunities are foreseen. More focus on targeted and risk-based inspection along the supply chain as well as use of new technologies may be a cost-effective and feasible way forward. Practical implementation of the system is expected to be a slow and careful process followed by thorough development, fine-tuning, and testing of practical feasibility and general impacts. Further progress that will lead to the full implementation is dependent on intensive research to fill knowledge gaps, enhance education and training and foster close collaboration of all the new system's stakeholders.

1. Traditional meat safety system and its need to change

Meat safety has been of interest since humans first became aware of a direct link between their health and animal health. Written proof of this connection can be found in ancient scripts and, hence, meat safety might be considered as a discipline since then. Progress in medicine led to the beginnings of inspection of slaughter animals during the medieval period in Europe. By the mid 19th century, a meat inspection system, now referred to as traditional meat inspection, had been developed (Ostertag, 1899). At that time, zoonoses such as tuberculosis, brucellosis

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and cysticercosis were prevalent and meat inspection targeted them - meaning it was, in its nature, risk-based. Meat safety since then continued to lean on veterinary ante- and post-mortem inspection that detect hazards causing clinical signs or gross lesions in slaughter animals using visual inspection, palpations, incisions and additional tests. Meat inspection contributed invaluably to public health protection from macroscopically visible zoonoses through the last century (Edwards et al., 1997).

Healthy slaughter animals, i.e. those that do not show clinical signs or gross pathological lesions, often carry zoonotic, microscopically visible hazards such as *Campylobacter* spp., *Salmonella enterica*, human pathogenic *Escherichia coli* and *Yersinia enterocolitica* (agents causing the top-four reported zoonoses in humans in Europe; EFSA/ECDC, 2019) in their digestive tract or on their skin. As these hazards are undetectable by traditional meat inspection, meat safety with respect to them relies on prevention or reduction of faecal and other contamination, including from the abattoir environment to meat during slaughter and carcass dressing, i.e. abattoir process hygiene (Blagojevic & Antic, 2014). This is assured by implementing Good Manufacturing and Hygienic Practice (GMP/GHP) and Hazard Analysis and Critical Control Point (HACCP) procedures from the point of receiving animals for slaughter until chilling of the carcasses. Chemical hazards, such as residues of authorised veterinary medicines, prohibited substances and industrial contaminants, might also be present in apparently healthy animals and, consequently, in meat thereof. The presence of both microbiological and chemical hazards can only be confirmed through laboratory analyses that came gradually into play during the 20th century (Alban et al., 2018; Custer, 2014). Therefore, meat inspection and abattoir process hygiene are traditionally complemented with additional analyses to help ensure carcass meat safety.

Veterinary public health and meat safety challenges have changed during the 20th century along with the changes to the structure of meat production. Livestock production is becoming increasingly specialised, implying only one species per farm. Biosecurity has improved as many animals are raised indoors. Eradication and control programmes have been put in place, leading to freedom from diseases such as brucellosis and bovine tuberculosis in some countries (Buncic, 2006). Also, concerns about harmful chemicals in meat have increased (Alban et al., 2020). All of this has changed the impact of these previously important, macroscopically visible hazards. Thus, although traditional meat controls are resource-intensive, their food safety impact is now limited. Therefore, it became clear that meat inspection had been a success, but the way it was undertaken and its goals were outdated. The idea that, in its traditional form, meat inspection is no longer adequate to protect public health – although it is still useful from animal health and welfare surveillance perspectives and serves for removal of grossly abnormal or contaminated products from the meat chain – matured in scientific circles during the 1980s and 1990s (Berends et al., 1993; Hathaway & McKenzie, 1991). Calls were made for official meat inspection to be revised and made fit-for-purpose again. The opinion was that traditional meat inspection now had many flaws: (1) it was no longer risk-based and served for quality control rather than public health purposes, (2) it was not validated regularly, and the static approach ("one-size-fits-all") was not flexible to reflect differences in the epidemiological status between regions and countries (3) post-mortem procedures (e.g. incision of lymph nodes), could increase cross-contamination between different organs and consecutive carcasses, mediated by mandatory manual handling, (4) organoleptic judgments taken about diseases, abnormalities and contamination were subjective, (5) lesions in carcasses/organs resulting from an infection occurring months before slaughter often led to condemnation, although the food safety risk was negligible, if present at all (hence, the non-flexible interpretation of the traditional meat inspection legislation produced unnecessary condemnation and food waste), and (6) it was mainly based on final product control rather than considering the whole meat chain. Also, testing every carcass for all relevant hazards that could only be detected through laboratory analyses was not cost-effective, and nor did it guarantee the absence of hazards from non-sampled parts due to the heterogeneous distribution of hazards on the meat.

To mitigate these outlined flaws, revision of the traditional meat safety system became necessary to ensure the focus is placed on the most relevant hazards that cause meat-borne illnesses today, in a cost-effective way. This paper aims to present the evolution of meat inspection from the traditional system accompanied by end-product testing to a modern, risk-based meat safety assurance system (RB-MSAS) for the three main meat producing animal species in Europe. Moreover, the drivers of this process are described along with the opportunities and challenges the changes will bring.

2. Modernisation of Europe's meat safety system

The modern meat safety system is: (1) risk-based (focused on the high-risk hazards with the aim of reducing the overall meat safety risk), (2) longitudinally integrated (multiple interventions or measures along the food chain are necessary to achieve required meat safety goals), and (3) flexible and dynamic (adaptable to changes while it still fulfils functional demands). The main responsibility for meat safety is now placed on food business operators (FBOs), i.e. meat producers, while the competent authorities (CAs) have advisory and auditory roles in official controls, along with their role of acting if FBOs do not comply.

A wide, integrated approach to food safety and public health is a century-old idea from pioneers such as Prescott (1920), Meyer (1931) and Wilson (1933). Their strategies were not implemented until the 1960s when HACCP-based procedures were introduced. During the 1980s, the pioneers' philosophies were combined with HACCP into the Longitudinal Integrated Safety Assurance system (Mossel, 1989). HACCP has mostly been an industrial food safety system, but Mossel advocated for a wider scope integrating animal health and welfare, and furthermore, measures from the environment to consumers with information flowing up and down the value chains (Buncic, 2006).

2.1. Work of international organisations towards RB-MSAS

Development and improvement of the traditional meat controls have been a focus of international organisations in the fields of trade, food safety, and public and animal health for decades. The World Trade Organization Agreement on the Application of Sanitary and Phytosanitary Measures (WTO, 1995) stressed the importance of harmonisation, equivalence, risk assessment, adaptation to regional conditions and transparency in food controls for facilitating trade.

The involvement of the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) in meat hygiene dates from the 1950s, when the first joint FAO/WHO Technical Report on meat hygiene was issued (WHO, 1955). The role of meat inspection was recognised in terms of providing wholesome meat for consumption, as well as its contribution to livestock disease control. From that time, several joint FAO/WHO expert initiatives on meat hygiene, and chemical and microbiological hazards stressed the importance of sound science and risk assessment principles in food/meat safety. A strategic, 10-year plan for food safety and food-borne zoonoses, adopted by WHO (2013), foresees evidence-based control measures along the food chain will decrease food-borne risks, and will strengthen risk-based, integrated national food safety systems. The FAO issued technical guidance specifying principles and application of risk-based meat inspection (FAO, 2019), primarily aimed at low- and medium-income countries. The document reflects the responsibilities of CAs for safeguarding food safety and fair food trade and recommends the farm-to-plate approach in application of control measures. Risk-based meat inspection should be part of the integrated approach to the food chain, including upstream (farm-to-abattoir) and downstream (abattoir-to-farm) exchange of information. The principles and their application are given as guidance that serves CAs and meat inspection services to design relevant protocols, support decision-making, and establish policies and standards that facilitate international trade. Both organisations continue to contribute to development of risk-based meat controls; this is confirmed with the recent revision of control of meat-borne parasites (FAO/WHO, 2020).

Codex Alimentarius develops international food standards, guidelines and codes of practice, contributing to protect public health and ensure fair trade practices. A Code of Hygienic Practice for Meat was developed by the WHO/FAO Codex Committee on Meat Hygiene (CAC, 2005). The Code constitutes the primary international standard for meat hygiene and incorporates a risk-based approach for applying sanitary measures throughout the meat chain. In general, the starting point is that meat should be safe to eat and otherwise suitable for human consumption. The basic elements are as follows: (1) meat inspection should be risk- and science-based, (2) the entire chain from primary producer to consumer should be involved, (3) HACCP principles should be applied to the widest possible extent, (4) meat inspection should be adapted to the status of individual countries or regions with regard to animal and public health, and (5) there should be a clear division of responsibilities between FBOs and CAs.

The World Organisation for Animal Health (OIE), which is developing international standards primarily designed to prevent the introduction of pathogens to animals and humans through trade, considers that meat inspection is the primary responsibility of veterinary services. The OIE recommends that meat inspection protocols should be risk-based while food safety management systems should be developed in accordance with international norms and cover the major hazards important for both livestock and public health (OIE, 2019). Priority in meat inspection protocols should be given to addressing microbiological contamination of meat, as this is the most important source of hazards for consumers, while still taking into account gross abnormalities detected by ante- and post-mortem inspection.

2.2. Work of the European Commission and the European Food Safety Authority towards RB-MSAS

The weaknesses of the traditional meat inspection system are well recognised in the European Union (EU), where significant actions have been initiated to review and modernise meat inspection, moving it to a more risk-based approach. The groundwork for the modern food safety system in the EU was completed in 2000 with publication of a White Paper on Food Safety (Anon, 2000), which lays out the concepts of the integrated approach to food safety. In line with this, the EU General Food Law (Anon, 2002) set out the principles and requirements for regulation in the area of food and for the establishment of the European Food Safety Authority (EFSA). Its first key message was that official decisions should be based on risk assessments that are independent, objective, transparent and based on available scientific data. Hereby, it was thought consumers would have more confidence in the decisions made. A second key message was that FBOs would take full responsibility for the food they place on the market. Third, a food production chain perspective was recommended.

The resulting legislation, called the "Hygiene Package", became applicable from 2006 (Anon, 2004a, b, c, d), and it mandated implementation of GHP and HACCP principles. It laid down general hygiene requirements for FBOs at all stages of the food chain including primary production, and more specific hygiene requirements to be followed by FBOs when handling food of animal origin. It also introduced the concept of food chain information (FCI), covered the meat inspection procedures and suggested use of risk assessment principles when considering changes in food inspection. Finally, it regulated organisation of official control systems so as to integrate controls at all stages of production and in all the sectors concerned, using farm-to-fork principles. Certain meat inspection changes were allowed if the risk assessment showed the change would not jeopardise food safety, animal health or animal welfare. Initially, such changes were only allowed for finishing pigs raised under controlled housing conditions and calves slaughtered at 6 weeks of age (Anon, 2004c). Besides visual-only inspection (VOI), other alternative meat inspection procedures, such as serological or other tests, were allowed if they ensured a level of protection at least equal to that of the traditional procedures. A wide range of implementing measures was adopted in the following years on the basis of the Hygiene Package – the main ones were for microbiological criteria (Anon. 2005a) and *Trichinella* testing (Anon, 2005b).

In 2009, the European Commission mandated EFSA to assess the impact of revising the meat inspection system in the EU. Briefly, EFSA's mandate was to: (1) identify and rank the main biological and chemical risks for public health that should be addressed by meat inspection, (2) assess the strengths and weaknesses of the traditional meat inspection methodology and recommend possible alternatives, (3) recommend fit-for-purpose methods that met the overall meat inspection objectives for relevant hazards not covered by traditional inspection, and (4) recommend adaptations of inspection methods and/or frequencies that would provide an equivalent level of protection. The work was done with a focus on the impact on food safety, animal health and animal welfare, whereas meat quality was not considered. EFSA opinions for pigs, poultry and cattle (EFSA, 2011a; 2012a; 2013a) formed the basis for legislative changes that would lead towards RB-MSAS in the EU. Prioritization (Table 1) of biological hazards was based on incidence and severity of human disease and the strength of evidence that meat from respective animal species is an important risk factor for human disease. Chemical hazards were ranked according to the outcomes of the national residue control plans, the toxicological profile and the likelihood of the occurrence of residues/contaminants in the respective animal species. Besides hazard prioritization and pointing out the flaws and virtues of the traditional meat inspection system, EFSA proposed a generic framework for a new, RB-MSAS that incorporates official meat inspection with food safety management systems managed by FBOs into a coherent whole (Fig. 1).

Subsequently, the European Commission initiated amendments of the meat inspection regulations on the basis of EFSA's opinions, although addressing only some of the EFSA recommendations. In 2014, the first such regulation came into force and was on VOI in pigs, following on from the first EFSA meat inspection opinion (EFSA, 2011a). VOI became applicable to all pigs irrespective of age and production system but on the condition that a FCI system is in place, requiring, among other factors, that livestock producers inform abattoirs prior to delivery about the health status of the animals to be slaughtered. If the FCI analysis or ante- or post-mortem inspection indicates a risk, then the animals are further subjected to traditional inspection involving palpation and incisions of relevant organs (Anon., 2014b). Moreover, the process hygiene criterion (PHC) for *Salmonella* in pig meat was made more stringent, reducing from five to only three positive samples allowed out of 50 tested (Anon, 2014a). Finally, there is no longer a

Table 1
Priority hazards as ranked by EFSA (2011a, 2012a, 2013a).

Species	Biological hazards	Chemical hazards
Pigs	*Salmonella enterica*	Dioxins
	Yersinia enterocolitica	Dioxin-like polychlorinated biphenyls
	Toxoplasma gondii	Chloramphenicol
	Trichinella spp.	
Poultry	*Campylobacter* spp.	Dioxins
	Salmonella enterica	Dioxin-like polychlorinated biphenyls
	ESBL-AmpC gene-carrying bacteria	Chloramphenicol
		Nitrofurans
		Nitroimidazoles
Cattle	Pathogenic *Escherichia coli*	Dioxins
	Salmonella enterica	Dioxin-like polychlorinated biphenyls

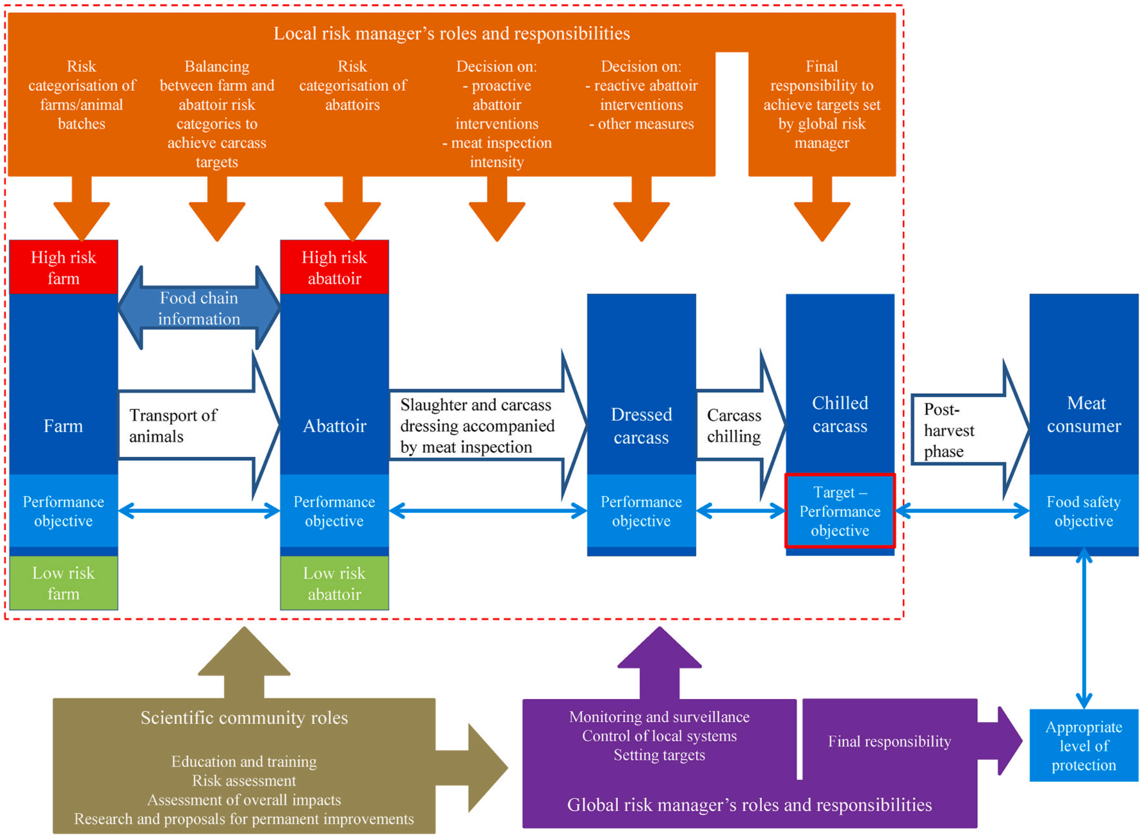

Fig. 1. Generic outline of the risk-based meat safety assurance system (adapted from EFSA, 2011a; 2012a; 2013a).

requirement for *Trichinella* testing for pigs raised under controlled housing conditions (Anon., 2015). EFSA's meat inspection opinion on poultry (EFSA, 2012a) identified *Salmonella* and *Campylobacter* as high priority hazards. Following on that, in 2017, PHC for *Campylobacter* in broiler carcasses were introduced (Anon., 2017b) to amend the older regulation on microbiological criteria (Anon. 2005a).

From 2017, food controls became regulated by Regulation (EU) 2017/625 (Anon, 2017a) that offers more dynamic and flexible options for several livestock species. From December 2019, its implementing acts came into force, in particular Regulation (EU) 2019/627 specifying uniform practical arrangements for conducting official controls on products of animal origin intended for human consumption (Anon, 2019). The Regulation is based on the most recent relevant information available and scientific evidence from EFSA opinions. This Regulation enables implementation of different approaches to post-mortem meat inspection provided certain criteria are met and the approach is based on a scientifically sound risk assessment.

3. RB-MSAS components and development

A risk analysis- and food chain-approach to meat safety creates the need for a longitudinal and integrated RB-MSAS. Such a risk management system implies selecting and implementing measures to reduce meat safety risks to acceptable levels based on the results of risk assessment (CAC, 2005). The effectiveness and appropriateness of the risk management measures need to be reviewed regularly to continually improve public health (WHO/FAO, 2006).

The meat safety assurance system described by Berends and van Knapen (1999) considered the entire farm-to-fork chain. Although the risk to public health generally occurs when food is consumed, RB-MSAS as elaborated by EFSA (2011a, 2012a, 2013a) is focused on the safety of chilled carcasses in abattoirs. In EFSA's concept, the rest of the meat chain (i.e. post-harvest) is considered "fixed", and chilled carcass safety is used as a proxy for meat consumers' exposures to hazards. The system is expected to be prone to changes in the importance of meat-borne hazards while flexibility is allowed in achieving the system's goals.

3.1. RB-MSAS concept/scope and targets

RB-MSAS combines a range of preventive and control measures applied at both farms and abattoirs, longitudinally integrated into a coherent whole. Preconditions for a successful RB-MSAS are the traceability of animals and meat, collection and analysis of the FCI needed for making risk management decisions, and robust monitoring systems for biological and chemical hazards. The entire system is coordinated by the risk managers who will have to choose and balance which control options will be applied to ensure the hazard-based targets for chilled carcasses are achieved and to generate the overall most cost-effective contribution to public health (Fig. 1).

A prerequisite for RB-MSAS' functioning is setting performance objectives (PO) that FBOs are expected to meet in specific phases of the meat chain. The minimum POs must be set by official regulators, while FBOs can set stricter objectives. The POs are maximum prevalences or concentrations of selected indicators or hazards. The POs on chilled carcasses will be linked with the targets in earlier phases of the meat chain (e.g., dressed carcases before chilling or farm-level targets), in later phases (e.g., batches of trimmed or minced meat), and at the moment of meat consumption (food safety objective; FSO). Ultimately, POs are linked with the level of protection that is deemed appropriate by the country establishing control measures to protect human health within its territory (appropriate level of protection; ALOP). ALOP can be directly derived from risk assessment results and relates to the current public health status in the food safety context, but can change over time. Specifically, it is expected that RB-MSAS will lead to improved public health and, hence, ALOPs could be stricter in future. The ALOP/FSO/PO concept, although seemingly not much in use, offers an explicit and advantageous link between risk management aims and science-based risk mitigation measures along the food chain.

Based on the above, RB-MSAS can be defined as a "flexible and dynamic system comprising all control measures applied at pre-harvest and harvest phases of the meat chain that contribute to the performance objective set for chilled carcasses".

3.2. Pre-harvest controls

Key concepts for interventions at herd level are controls of the purchase and flow of animals, in particular at the top of the breeding pyramid, control of feed, internal and external biosecurity, and categorisation of herds that are carriers of specific pathogens. Intervention at herd level might also contribute to more sustainable and "clean" production, while also solving some general problems connected to the environment by avoiding recycling of zoonotic hazards like *Salmonella* at farm level.

Finland, Norway and Sweden have documented that successful intervention of *Salmonella* in cattle, pigs and poultry at herd level is possible. Heat-treatment of feed and starting with breeding animals free from, for example, *Salmonella* at the top of the breeding pyramid have probably been the most important measures. The tradition of cooperation between the farmers, abattoirs and the food safety authorities has been crucial. The food safety authorities follow up on positive herds to prevent transmission to other herds, humans and food by prohibiting the purchase and transportation of animals and foods from infected farms. The food safety authorities also demand sampling until the herd is documented free from the zoonotic hazard; sampling of herds which have been in contact with the infected herd is also demanded (Nesbakken et al., 2019).

Some countries have successful programmes for intervention of *Campylobacter* in broilers. Many surveillance programmes are based on flock categorisation and testing for *Campylobacter* prior to slaughter, so carcasses from positive flocks are heated or frozen prior to sale in order to reduce the potential for exposure of humans (Hofshagen and Kruse, 2005). Studies also indicate it is possible to establish clusters (health and breeding pyramids) of pig herds free from zoonotic hazards other than *Salmonella*. One such example is specific pathogen free (SPF) pigs that are also free from *Yersinia enterocolitica*, showing that the same measures used to prevent animal diseases might also provide pork free from zoonotic agents (Nesbakken et al., 2007). Some of these SPF herds were even free from *Campylobacter* spp. (Kolstoe et al., 2015). However, such strategies have to be evaluated in a cost-benefit context dependent on the impact on public health, agent, the spread of infection and feasibility.

Risk categorisation of farms is an important component of the RB-MSAS and is based on extended use of FCI and harmonised epidemiological indicators (HEIs). FCI, consisting of epidemiological, herd health and production data, is an important tool for recording and categorizing herds, and it is a basis for control measures in the meat chain. HEI is defined as the prevalence or incidence of the hazard at a certain stage of the food chain or an indirect measure of the hazard that correlates to the human health risk caused by the hazard. To facilitate categorisation of farms/animals and, later, abattoirs, and to set appropriate specific hazard-based targets in animals or carcasses, the HEIs shown in Table 2 have been proposed by EFSA (2011b, 2012b, 2013b).

3.3. Harvest controls

Under normal commercial practice, interventions must be implemented as an integral part of abattoir process hygiene. Abattoir interventions applied pre-slaughter and on the slaughterline are, in their nature, GHP- and hazard-based measures (FAO/WHO, 2016). GHP-based measures are often founded on empirical knowledge and experience. Examples comprise cleaning and disinfection of lairage-to-stunning areas, hide or pelt removal methods, bunging, knife-trimming, chilling, equipment sanitation, etc. They sometimes have indirect impact on public health risks, for example bunging of pig carcasses on human yersiniosis (Nesbakken & Skjerve, 1996). Such measures also serve as pre-requisites to, and complement, the hazard-based interventions that are evidence-based, i.e., developed from scientific research to specifically control certain hazard(s). The examples include a range of different skin and carcass interventions mostly aiming at microbial removal, immobilisation or destruction, and they provide demonstrable and quantifiable reductions in hazard loads (FAO/WHO, 2016). Considering that animal coats are among the main sources of carcass microbiological contamination, interventions targeting them, complemented by strict adherence to clean animal policies, are attracting more attention (Antic et al., 2011). Animal coat interventions can be seen as a proactive approach in dealing with sources of contamination, versus carcass treatments (pasteurisation with hot water or steam, and spraying with organic acids and other chemicals), which are usually applied after contamination events, and are reactive (Antic, 2018). Both strategies are essential and best applied together in a sequential and coordinated way as a part of the multiple-hurdle approach, which aligns well with RB-MSAS's longitudinal and integrated nature. Abattoir interventions are envisaged in the RB-MSAS and can be used whenever needed to accomplish goals and targets (e.g.,

Table 2
Examples of the proposed harmonised epidemiological indicators for priority biological hazards with potential for farm and abattoir risk categorisation (EFSA, 2011b; 2012b; 2013b).

Stage	Pigs	Poultry	Cattle
Farm	Auditing of controlled housing conditions (with specifics for some pathogens, i.e. cats/ *Toxoplasma*); Officially recognised *Trichinella* free status; *Salmonella* status of breeding and fattening pigs prior to slaughter; *Toxoplasma* infection status of breeding pigs from officially recognised controlled housing conditions and all pigs from non-officially recognised controlled housing conditions; *Trichinella* status of free-range and backyard pigs and pigs from non-officially recognised controlled housing conditions; *Trichinella* status of wildlife.	Auditing of controlled housing conditions; *Salmonella* status of breeding and flocks prior to slaughter; *Campylobacter* status of flocks prior to slaughter; ESBL-/AmpC-bacteria status of breeding flocks, 1-day-old chicks and flocks prior to slaughter; Use of partial depopulation in the flock (*Campylobacter* relevant); Use of antimicrobials during the whole lifetime of the flock (ESBL-AmpC bacteria relevant).	Auditing of on-farm practices and conditions including of practices which increase the risk of introducing *Salmonella* and pathogenic *Escherichia coli* into the farm (e.g. purchase policy); *Salmonella* and pathogenic *E. coli* status of animals intended for slaughter.
Abattoir	*Salmonella* status of ileal contents; *Yersinia* status of tonsils or rectal content; Auditing of head separation after slaughter (*Yersinia* relevant); *Salmonella* and *Yersinia* status of carcasses before and after chilling.	*Campylobacter* counts in caecal content; Detection of *Salmonella* and enumeration of *Campylobacter* and ESBL-/AmpC-producing *E. coli* in carcasses after chilling.	Hide cleanliness status; *Salmonella* and pathogenic *E. coli* status of slaughtered animals' hides; *Salmonella* status of lymph nodes; *Salmonella* and pathogenic *E. coli* on carcases before and after chilling.

when an abattoir is unable to sufficiently reduce risks arising from specific farms/animal batches by using process hygiene alone). Another example is when intramuscular parasites are not mitigated on-farm or by meat inspection; freezing carcasses is foreseen as a possible abattoir intervention to eliminate these hazards (EFSA, 2011a).

The EU legislation allows the use of treatments to "remove surface contamination" during slaughter, following appropriate consideration and a risk assessment by EFSA, and approval of such treatments by the regulatory authorities (Anon, 2004b; EFSA, 2010a). Currently, only potable water for carcasses treatments i.e., hot water washing and steam pasteurisation (Anon, 2004b), and lactic acid spray washing of beef carcasses are permitted for use in European abattoirs (Anon, 2013). Lactic or acetic acid use on pork carcasses could follow on from the recent positive EFSA opinion (EFSA, 2018). Decontamination using hot water is in place in Denmark, targeting pigs from herds with an unacceptably high *Salmonella* prevalence (Alban & Sørensen, 2010). Nevertheless, such interventions are not common in Europe. In the USA, on the other hand, interventions for animal coats, particularly cattle hides, and carcasses are integrated within an intervention-based HACCP system (Buncic & Sofos, 2012).

Risk categorisation of abattoirs, based on their risk reduction performances, is also an important component of the RB-MSAS. Used in conjunction with farm risk categories, it enables risk managers to balance the level of risk in order to achieve carcass targets. Resultant risk manager decisions include establishing to which abattoirs animals from different risk-level farms will be sent or whether additional risk mitigation measures are needed (e.g. logistic slaughter, slaughterline speed reduction, carcass decontamination treatments). Determination of abattoir risk categories is also important to identify those premises requiring more stringent auditing practices and/or technology improvements. Various methods of assessing the process hygiene of abattoirs are used in different countries. These methods mainly rely on visual assessment and scoring of abattoir practices (Røtterud et al., 2020) or microbiological testing (Alvseike et al., 2019; Milios et al., 2014) and serve to verify GMP/GHP and HACCP. EU PHC for carcasses (Table 3) are in place to assess abattoir process hygiene, while several proposed HEIs can be used for abattoir risk categorisation (Table 2).

3.4. Impact of changes and alternatives to traditional meat control methods

The main drivers to changing the traditional meat safety system are to improve the cost-effectiveness of the meat controls and to reduce the burden of public health hazards. It is necessary to validate whether the new RB-MSAS accomplishes its main goal, i.e., to be at least equal to the traditional system with respect to food safety in all segments, but preferably leading to better risk reduction and resource allocation. Both meat inspection and abattoir process hygiene, which were cornerstones of the traditional system, will be maintained in the new RB-MSAS, although complemented by conventional or alternative testing methods. Development and application of alternative procedures able to replace some of the traditional ones are important for proper functioning and permanent improvements to RB-MSAS. This will close gaps and provide equal or even higher levels of protection more efficiently and objectively.

Table 3
EU process hygiene criteria (Anon, 2005a).

Carcass	Microorganism	Limit (unsatisfactory results[a] if exceeded)
Cattle/pig (before chilling)	Aerobic Colony Count	5.0 $\log_{10}$ cfu/cm^2 (daily mean log of 5 carcases sampled by destructive method)
	Enterobacteriaceae Count	2.5 (cattle)/3.0 (pigs) $\log_{10}$ cfu/cm^2 (daily mean log of 5 carcases sampled by destructive method)
	Salmonella	Presence in 2 (cattle)/3 (pigs) out of 50 swabbed carcases
Broiler (after chilling)	*Salmonella*	Presence in 5 out of 50 pooled samples
	Campylobacter	15[b] out of 50 pooled samples carcases with >1000 cfu/g

[a] Improvements in slaughter hygiene and review of process controls for indicators with additional review of biosecurity measures in the farms of origin for pathogens needed.
[b] 10 from January 1, 2025.

3.4.1. Risk-based meat inspection

Meat inspection changes are driven by needs for greater cost-efficiency and avoidance of cross-contamination. Hence, the inspector's time, saved by omitting unnecessary manual handling, could be used to enhance pre-slaughter risk assessment by better use of FCI or to focus on audits and control of abattoir process hygiene. Less manual handling might also reduce the exposure of meat inspectors to occupational hazards (Fredriksson-Ahomaa, 2014). Therefore, VOI of low-risk animals, based on properly functioning FCI for risk categorisation of animals arriving at slaughter, is an example of risk-based meat inspection. More stringent inspection procedures comprising palpations or incisions can be applied to high-risk animals. VOI was foreseen in the EU legislation from 2004 (Anon, 2004c) for poultry and indoor-raised finisher pigs, and for all low-risk pigs from 2014 (Anon, 2014b). The recent meat inspection Regulation (Anon, 2019) reduced manual inspection procedures for cattle; however, it is still far from completely VOI (Table 4).

Numerous studies have been performed in Europe to assess risks related to the switch of traditional inspection to VOI. In Denmark, a series of risk assessments was undertaken from 2006 to 2020 to study the detailed impact of omitting the various incisions and palpations of the organs listed in the earlier meat inspection Regulation (Alban et al., 2021). Results implied it was possible to assess what could be missed, how often and what the consequences of this might be on meat safety. The conclusion was that omission of the incisions and palpations on finishing pigs raised indoors were not associated with any increased risk. Several studies in the United Kingdom (Blagojevic et al., 2015; Hill et al., 2013) and Italy (Ghidini et al., 2018) came up with a similar conclusion. Nonetheless, meat inspection objectives other than public health protection should not be neglected. VOI might lead to reduced detection of some animal health hazards and meat quality issues, and less useful feedback to the farm of origin.

Bovine cysticercosis inspection is an example of how meat inspection can be modernised and made flexible, thus transforming into an appropriate component of RB-MSAS. Research had shown that the probability of young bovines, <24 months old, harbouring cysticerci was very low (Calvo-Artavia et al., 2012). Omitted or reduced incisions result in a further decrease of detection sensitivity from the already low sensitivity of traditional meat inspection (Blagojevic et al., 2017; Jansen et al., 2017). Serological tests as an alternative to meat inspection incisions were possible from 2006 (Anon, 2004c), but their use was hampered by the additional costs. Nonetheless, the meat inspection Regulation from 2019 (Anon, 2019) recognises the actual risks of cysticerci in various cattle categories. The Regulation states that masseters in cattle younger than 8 months old, or 20 months old if reared without access to pasture during their whole life, do not have to be incised (Table 4). Moreover, the Regulation foresees ending masseter incisions for older categories of cattle provided the following conditions apply in the country or region: (1) a specific serological test is used, (2) the animals have been raised on a holding of provenance officially certified to be free of cysticercosis, or (3) either the prevalence is less than one in a million with 95% certainty, or no cases were found in slaughtered cattle in the last 5 years (or 2 years with the negligible risk supported by a risk analysis carried out by the CA; according to Axelsson and Kautto (2020) this is now expected to be implemented in Sweden).

Another example of risk-based meat inspection implemented in the EU relates to trichinellosis in pigs. Pigs raised under controlled housing conditions, i.e. compartments, do not need to be tested for *Trichinella*

Table 4
Meat inspection procedures of cattle and pigs before (Anon. 2004c) and after meat inspection regulation changes (Anon, 2019).

Subject of inspection	Cattle								Pigs			
	Young before[a]		Young after[b]		Older before[a]		Older after[b]		Before		After	
	M	A	M	A	M	A	M	A	M	A	M	A
Head	V		V		V		V		V		V	
Mouth	V		V		V		V		V		V	
Throat	V		V		V		V		V		V	
Fauces	V		V		V		V	P	V		V	
Retropharyngeal lymph nodes	I		P	I	I		I					
Submaxillary lymph nodes					I			I	I			I
Parotid lymph nodes					I			I				
Masseters					I		I					
Tongue	P			P	V + P			P	V		V	
Lungs	V + P + I^c		V + P	I^c	V + P + I^c		V + P	I^c	V + P + I^c		V	P + I^c
Trachea	V + I^c		V	I^c	V + I^c		V	I^c	V + I^c		V	I^c
Main branches of bronchi	I^c			I^c	I^c			I^c	I^c			I^c
Mediastinal lymph nodes	I		P	I^c	I		I		P			P
Bronchial lymph nodes	I		P	I^c	I		I		P			P
Oesophagus	V		V		V		V		V		V	
Heart	V + I		V	I	V + I		V + I		V + I		V	I
Pericardium	V		V		V		V		V		V	
Diaphragm	V		V		V		V		V		V	
Liver	V	I	V		V + P + I		V	P + I	V + P		V	P
Hepatic lymph nodes	V	I	V		V + P		V	P	V + P		V	P
Pancreatic lymph nodes	V		V		V + P		V	P	V		V	P
Gastrointestinal tract	V		V		V		V		V		V	
Mesentery	V		V		V		V		V		V	
Gastric lymph nodes	V + P	I	V	I	V + P	I	V + P	I	V + P	I	V	P + I
Mesenteric lymph nodes	V + P	I	V	I	V + P	I	V + P	I	V + P	I	V	P + I
Spleen	V	P	V	P	V	P	V	P	V	P	V	P
Kidneys	V	I	V	I	V	I	V	I	V	I	V	I
Renal lymph nodes		I		I		I		I		I		I
Genital organs					V		V		V		V	
Udder					V + I^c	P + I	V	P + I^c	V		V	
Supramammary lymph nodes					V + I^c	P + I	V	P + I^c	V + I		V	I
Dressed carcass	V		V		V		V		V		V	
Pleura	V		V		V		V		V		V	
Peritoneum	V		V		V		V		V		V	
Umbilical region	V + P	I	V	P + I					$(V + P)^d$	I^d	V^d	$(P + I)^d$
Joints	V + P	I	V	P + I					$(V + P)^d$	I^d	V^d	$(P + I)^d$

V: visual inspection; P: palpation; I: incision; M: mandatory procedures; A: additional procedures (if there are indications of a possible risk to human health, animal health or animal welfare, based on FCI analysis and additional epidemiological data or other data from the farms, and/or ante-mortem inspection findings, and/or animal welfare rule compliance checks, and/or post-mortem inspection findings by mandatory procedures); [a]age limit was 6 weeks (Anon. 2004c); [b]age limit is 8 months or 20 months if reared without access to pasture land during their whole life in an officially tuberculosis-free country or region (Anon, 2019); [c]not necessary if excluded from human consumption; [d]only in piglets.

anymore, due to absence of findings of *Trichinella* in compartments (Anon., 2015c). A set of requirements for a herd to be recognised as being from controlled housing conditions is listed in the Regulation. Auditing can be conducted either by the CA or by a third-party independent auditor, as described by Alban and Petersen (2016). This highlights the usefulness of the concept of farm risk categorisation.

3.4.2. *Alternative approaches and technology*

Emerging technologies have constantly been introduced to meet new challenges. The demand for increased productivity, including improved quality and reduced waste, drives development into larger factories and volumes, and further into automation. Most automation approaches have been expensive, inflexible and lack robustness. However, reduced costs and increased capabilities of automation solutions have been emerging trends (Pratt, 2015). Also, high performance tests are wanted, but there will always be trade-offs between sensitivity, specificity, cost and volume of analyses.

As an example, these challenges and technological options led to the suggestion of the meat factory cell (MFC). It was intended as a more relevant future platform for automation in small scale factories, but it also has had positive impacts on hygiene and meat inspection (Alvseike et al., 2018, 2020). MFC removes the muscle masses first; the four legs, the loin including head and tail, the viscera in one piece, and finally the sides and ribs. This results in reduced risk of faecal contamination, holistically presented carcasses for meat inspection and smaller cuts available for targeted sensing and diagnostic tools.

Specific tools influence hygiene and speed of abattoir processes. The human sensory and locomotive systems and the human brain, adjusted to learn, are extremely valuable "tools", impossible to copy. However, engineered tools have other strengths: most relevant to meat safety are electromagnetic and sound wavelengths to penetrate tissues (X-rays, ultrasound, etc.), the ability to filter wavelengths for different purposes, machines' compliance to procedures, computers' calculations of complicated algorithms, memory, documentation of operations, and, finally, machines do not get tired.

Vision systems use cameras and computerised image analysis to detect pathological lesions, other abnormalities and contamination affecting meat safety and quality, and animal health and welfare (Blömke et al., 2020; Park et al., 2004). Hence, vision and other sensor systems have great potential in future ante- and post-mortem inspection as well in other RB-MSAS components.

Meat juice serology is useful for mass surveys of infections and the occurrence of subclinical infections animals and has potential to be used in risk categorisation of farms/animals (Felin et al., 2019; Loreck et al., 2020; Meemken et al., 2014). In Denmark, a partly automated ELISA set-up continuously surveys *Salmonella* herd-levels in finishing pigs, and the results are used monthly to assign herds into three risk categories (Alban et al., 2012). Another potential area is serologic monitoring for

Toxoplasma gondii in outdoor pigs, which are known as a higher risk than indoor pigs (Olsen et al., 2020). Also, automatically measuring serum acute phase proteins, the levels of which change in animals suffering from infection, inflammation or stress, could be useful in RB-MSAS (Blagojevic et al., 2011; Gutierrez et al., 2015).

Molecular epidemiology has become a central reactive tool to investigate disease outbreaks caused by biological hazards. Genetic tests can distinguish between strains and help hypothesise the origin of infections. The technology of whole genome sequencing is becoming increasingly affordable and portable, and could, in the future, contribute to both FBOs' and CAs' preparedness and risk management of outbreaks (Nastasijevic et al., 2017). Different generations of chromatography and spectroscopy have gradually improved the sensitivity of chemical analysis methods. Chemical hazards are, today, surveyed in spot test programmes where advanced and expensive analyses are undertaken by central laboratories. This reflects a trade-off between costs, the very low concentrations relevant to public health, competence demands and the low frequency of unacceptable levels. Available sensor technologies exist for continuously monitoring some chemical hazards (Yaroshenko et al., 2020). A challenge in this regard is that with ever better methodology and analytical sensitivities, risk-based acceptance limits are needed instead of requiring absence of the hazard.

RB-MSAS could well benefit from fast, cost-effective and reasonably sensitive technologies for continuous monitoring earlier in the value chain. The examples above show that artificial intelligence solutions are available to assist and improve decision making on objective information. However, if they are not handled systematically, data from sensors and diagnostic tools are useless. Data analysis and documentation are fundamental to ensure pay-back from surveillance and control programmes.

Transparency and traceability in the, nowadays complex, meat supply chain are essential to guarantee safety and quality. Intensified information exchange and integrated information systems involving all chain actors are needed to achieve transparency (Trienekens et al., 2012). FBOs are expected to track their commodities one link upstream and downstream in their value chain. In support of this, block-chain technology solutions for food traceability from farm-to-plate have recently been launched (Kamath, 2018). Such solutions will enable changes of information once uploaded in a block; however, they do not provide any guarantee that the information entered is correct.

4. Experienced and foreseen drivers, opportunities and challenges of the RB-MSAS

Harmonised meat controls system throughout Europe and their equivalent globally would be ideal, as it would help ensure fair competition between FBOs and proper official checks by CAs. However, even if it were possible to develop a one-size-fits-all system, it would not lead to reasonable resource allocation. Therefore, fit-for-purpose systems based on the general principles described above, but with locally tailored specifics is our philosophy behind a successful RB-MSAS.

4.1. Positions of relevant stakeholders

Implementation of RB-MSAS could be seen as a disruptive innovation and will, thus, likely face opposition from various stakeholders. Considering the aims of public health improvement and long-term economic savings, it is expected that all stakeholders should be in favour of the modernisation. However, this is not always the case.

One of the drivers behind meat inspection and overall meat safety assurance changes is competition, leading to lower marginal gains. This implies the FBO is focused on cutting costs by avoiding unnecessary activities. Still, the FBO must ensure the food placed on the market is safe, which protects the reputation of the product and, thereby, continued market access for the FBO. In general, large abattoir companies have been in favour of meat inspection modernisation, whereas smaller ones have been less interested (Bækbo et al., 2015). This is most likely because the smaller abattoirs cannot necessarily see a business case, but only extra costs. This could, to some extent, indicate that the new food production systems implemented have been designed to fit the needs of large companies. On the other hand, in many cases, small scale producers encounter less strict rules and fewer restrictions to local distribution chains, likely because the possible public health implications are perceived by the CAs as limited.

Many meat inspectors have expressed concerns about the changes to come (Bækbo et al., 2015), pointing out inadequacies of VOI (Laukkanen-Ninios et al., 2020). It can be argued that this is, firstly, because of their frustration on being told that some techniques, such as incision, are no longer necessary and are no longer considered to ensure food safety, even though meat inspectors have been making them for many years. Secondly, meat inspectors could have concerns for their job security. It is part of the story that the European Commission's proposal for a new pig meat regulatory framework based on EFSA's risk assessment was adopted by the European Parliament despite a group of Members of Parliament trying to stop the reform by arguing that the changes "could lead to another food safety scandal". This shows there is still great opposition to modernisation of meat controls in Europe, and the resistance is probably greatest among veterinarians in central Europe (Bækbo et al., 2015).

Consumers expect meat to be safe and they are becoming increasingly interested in the origin of the meat, so this requires production and control to be transparent to assure consumers' trust. However, their perception of risks might not correspond to the objectively measured risk. An example is higher concern among consumers for chemical residues than for food poisoning from bacteria (EC/EFSA, 2019). Still, consumer opinion is important in setting regulatory food safety standards. In addition, food fraud is an important consumer concern that is likely to gain more prominence in the future. Newly raised consumer concerns such as sustainability, wholesomeness and animal welfare have gained considerable weight. It is unknown how these consumer concerns will influence future meat safety systems. Finally, varying consumer reactions to modernisation of meat inspection have been noted so far, from hardly any reaction in Denmark to a more negative reaction in Germany (Bækbo et al., 2015).

4.2. Gaps and conflicting aims in RB-MSAS

The risks that RB-MSAS handles are complex and require fit-for-purpose solutions. This is confirmed by different aims that the risk manager has to handle during meat inspection: its findings and consequent actions have implications for food safety, but also sustainability, food quality, animal health, animal welfare, fraud and even antimicrobial resistance (AMR) (Vågsholm et al., 2020).

Good examples of this complexity are wooden breast in broilers or skin wound in slaughter pigs. These conditions present no meat safety risk, but the meat has visibly impaired quality. Partial condemnation of affected carcasses increases food waste and, thus, impairs food security and sustainability, but ensures consumers eat meat of good quality and not inflammatory or damaged tissues. The difficult question is how the risk managers should handle this dilemma. Nevertheless, detection of these problems clearly indicates animal welfare problems in primary production, and risk managers should act to also mitigate these problems.

Currently, meat inspection cannot work as a control point for AMR in the meat chain. This is a major gap in the current system, as AMR spreads through foodstuffs to consumers, or becomes prevalent in those handling animals or meat, and could be a major concern in the coming years. Having on-farm AMR monitoring procedures with results included in the FCI would enable the risk manager to take mitigation actions to avoid transmission of AMR pathogens to consumers and to those handling animals or processing meats. Additionally, the system of feedback to the farm, regarding lesions detected during ante- and post-mortem inspection, contributes to continuous improvement towards healthier herds that have fewer demands for antimicrobial treatments.

4.3. Legislative obstacles and possibilities

CAs are positioned within the FBOs by law, having access to any FBOs' documentation, system, or premises. CAs are empowered to interpret legislation, but if the legislative demands are not knowledge- or science-based or their interpretation is incorrect, the CA's efforts will not be allocated to the most critical challenges, and finally, will not be risk-based. Also, the legislative demands have been considered as the common lowest denominator, while customer and societal/political demands and industry standards are considered increasingly important. Therefore, meat control legislation must evolve to be relevant upfront. The vision of RB-MSAS demands innovation-friendly legislation, resulting in a trustworthy system that constantly improves its productivity, i.e., safer food for the resources invested. Where legislation defines how the processes will be undertaken, this could unintentionally halt disruptive innovations and restrict the scope for improvement. Therefore, normative descriptions should be reduced to an absolute minimum, and instead, functional demands or output-based criteria are needed; i.e., what the FBOs should achieve in terms of food safety, not how it is achieved.

Central demands are aesthetic opinions; for example, carcasses should be free from visible faecal contamination since faeces is the main source of the most important meat-borne hazards. It may be a fine overall vision, but in reality "free" or "zero-tolerance" is difficult to achieve in practice and leaves space for subjective opinions and different conditions. Instead, demands need to be realistic and based on objective targets. Furthermore, the requirement for FCI was launched as a legislative demand, but without clear definition of what FCI is, how seamlessly it should flow and who should own the necessary infrastructure within the FBOs' premises. Now, when all these questions have found their solutions, there is still no requirement detailing how FCI should be analysed and utilised. Analyses of FCI should not be arbitrary but harmonised with automated algorithms including predefined thresholds and ambitions (Ward & Carpenter, 2000). Implementation of FCI systems has, thus, been slow in Europe, the original intentions for its use have largely not been achieved to date, and it has been underdeveloped and underutilised (Buncic et al., 2019).

On the other hand, future changes and innovation of RB-MSAS are likely. As the levels of risk of meat safety hazards or the hazards themselves change with time, dynamic and flexible legislation is a prerequisite of this risk-based system. The current EU legislation on official food controls (Anon., 2017a; Anon, 2019) offers possibilities for trying out novel approaches in meat safety assurance. Furthermore, according to these regulations, when updating legislation, including adopting delegated and implementing acts, the EU will take note of experience gained by CAs and FBOs during their application of HACCP-based procedures, and of scientific and technological progress. Besides, there is room for completing pilot trials of different meat inspection arrangements ("alternatives") that should give at least equivalent meat safety as the traditional system, using the results from third party inspections and private control systems, and implementing changes in division of tasks between official veterinarians and assistants.

4.4. Variations between European countries

The history of Europe has resulted in diversified structures, rules and cultures. The diversity in the European countries is huge, including the incomes and costs, division of labour, financing, employment and organisation of authority bodies. The conditions for meat production are also different depending on climate, scale, ownership and the epidemiological status of a wide range of zoonoses and animal pathogens. Some countries are mainly meat exporters while other countries aim at a level of self-sufficiency. Furthermore, within Europe, there is a large variation in livestock and abattoir systems – from countries with a plethora of small farms and abattoirs slaughtering several species a day, to countries with large units typically farming intensively, delivering their animals to specialised abattoirs only slaughtering one species, which they are licensed to export globally. This also implies a huge variation in industrial hygiene standards, distribution systems, societal infrastructure and institutions (Pinillos, 2008).

All these factors influence the incentives and the interest in how a safe meat supply can be provided, the meat safety system's modernisation needs, and willingness to modernise at national level. A principal solution is to define a common basic approach which could be based on today's procedures, even though practises vary considerably in Europe. Then, the FBOs and suppliers should have liberal opportunities to alternatively organise the work and develop approaches and tools, as long as the objective targets are met.

4.5. Meat trade with overseas countries

European meat exporters target non-European countries; also, the European Economic Area is an attractive high-end market for countries in the Americas, Africa, Oceania and Asia. Meat safety systems of exporting countries are considered during meat import, and export is possible only if appropriate safety systems are documented. Although meat inspection and process hygiene are based on common general principles (CAC, 2005), they vary practically, which can impose trade obstacles. The European meat safety system's differences with overseas countries are more pronounced than intra-European differences. RB-MSAS modernisation sometimes limits trade and *vice versa*. Examples are the European meat export obstacles to applying RB-MSAS with VOI or exemption of *Trichinella* testing. Also, carcass decontamination with chemical agents not permitted in Europe limits meat import from overseas countries.

Certain adjustments of European RB-MSAS towards harmonisation with overseas meat safety assurance systems and *vice versa* are needed to overcome the obstacles. If particular system components or controls work well abroad, these might be tested and later implemented as being better than their home-grown counterparts. For example, EFSA compared equivalence of the Australian abattoir monitoring programme with European requirements (EFSA, 2010b). Also, VOI has recently been considered in pigs in the USA (Riess & Hoelzer, 2020). However, due to different risk perceptions and cultures, full harmonisation might not be achievable.

4.6. Risk- and cost-benefit considerations

The change from traditional towards RB-MSAS overall involves reduced costs related to traditional inspection activities, and extra costs related to new technologies and activities in the form of monitoring and auditing programmes. The change was due to the perception that the benefit of reducing cross-contamination outweighs the value of additional findings potentially discerned by traditional inspection. However, the reduction in contamination due to replacing traditional inspection with VOI could be minor compared to the overall contamination generated on the slaughterline. Still, VOI offers the possibility of having fewer people physically involved at slaughter.

For example, in pigs, no routine incisions into the mandibular lymph nodes and no routine opening of the heart imply less work on the slaughterline. Similarly, no requirement for manipulation of the plucks and the intestines opens up the option of one person inspecting plucks hanging over the intestines, instead of two people inspecting these organs. The latter would require economic investment in reorganisation of the slaughterline. So far, it is expected that mainly the large pig abattoirs will lower their inspection costs by replacing traditional inspection with VOI (Bækbo et al., 2015). The omission of *Trichinella* testing of pigs raised on farms applying controlled housing conditions is used widely in abattoirs that are not intending to export outside the EU. This causes direct savings. However, the large abattoirs are still testing due to export requirements. Also, auditing is needed for a farm to be recognised as applying controlled housing conditions, and the auditing costs are paid by the producer (Alban & Petersen, 2016). Similarly, for the product standard related to the meat, the abattoirs cover the costs.

In cattle, the legislation now offers less intense post-mortem inspection of calves up to the age of 8 months or 20 months if they are raised indoors. It is still too early to assess the economic potential of the savings, but according to Calvo-Artavia et al. (2012), savings may be related both to less work and a higher price for the masseter meat associated with omission of the routine incisions. Abattoirs that implement this risk-based inspection need to be able to sort animals arriving at the abattoir according to their age, based on FCI. Moreover, inspection work must be planned to ensure the required number of inspectors is present. Without that, no cost saving related to inspection itself can be expected.

4.7. Risk management considerations

The general approach related to the modernisation process is evidence-based, so data must be collected from animals on-farm, and from carcasses and meat at abattoirs. A food chain view is applied, enabling assessment of the effects of changing different inspection elements on the final outcomes (prevalences of hazards on/in meat). All this has generated knowledge about how the changes can be implemented without jeopardising food safety, animal health or animal welfare. Moreover, the slow speed of change has enabled consumers, meat inspectors and trade partners to gain confidence in the changes. Consequently, it is expected the move towards RB-MSAS will lead to more proportionate risk management with better cost-benefit ratios, due to a better understanding of what is needed, where it is needed, and how to perform what is needed. Such an approach could be called risk-based assessment and management. Finally, according to the EU General Food Law (Anon, 2002), the precautionary principle can be used when there is doubt about a specific issue. Nonetheless, the evidence-based approaches described above have limited the need for using the precautionary principle.

5. What will the future hold?

Further research, including baseline studies, needs to fill numerous knowledge gaps that will lead to fine tuning RB-MSAS and its full implementation in practice. Research might include collecting data for better evidence-based rankings for specific hazards (including periodically revisiting each ranking), investigating approaches and collecting further data for farm and abattoir risk categorisations, developing modern technical solutions, conducting source attribution and epidemiological studies, running comparative exposure assessments, and preparing structured expert opinions. To put specific system components in place that will contribute to revision of relevant legislation, the European Commission will need inputs from CAs and FBOs as well as further scientific inputs from EFSA, while EFSA will need inputs from the scientific community.

Due to the complexity and multitasking, defining different roles, responsibilities and clear rationales are crucial for proper functioning and fulfilling RB-MSAS's goals. The new risk managers are expected to play a pivotal role in RB-MSAS, but their positions are not yet established. Precise definitions of their roles and responsibilities must be accompanied by integration with and/or transformation of the current meat safety risk managers (a possible scenario is shown in Fig. 1). Also, it is important to define at what level they should act, i.e., local (e.g. FBO level), global (e.g. national level), or at both these levels. Also, their competencies need to be clearly outlined as well as who should employ them – CAs or FBOs. At the moment, it is assumed that only veterinarians have sufficient competencies to act as local risk managers in RB-MSAS. They will have to be properly trained and their performance monitored. Practical training in epidemiology, risk assessment and the use of FCI/HEIs will be crucial. Also, all other parties involved, including official meat inspection auxiliaries, abattoir staff and farmers, need to be trained in the skills required for this system to operate properly. Proper education/training would lead individuals to understand the system and probably change the minds/attitudes of any reluctant stakeholders that need to collaborate within it. Finally, for it to properly function, RB-MSAS's cascade nature demands the full commitment of all involved parties.

Numerous internationally recognised standards, private meat safety management systems covering food safety and animal health and welfare, and traceability requirements are in place in the meat industry (Henson & Humphrey, 2009). These private standards complement the EU legislation in terms of food safety and could be a component or a primer for RB-MSAS. In the interests of fair competition in the meat sector and more efficient regulatory controls across Europe, different existing meat safety systems should be aligned with RB-MSAS gradually, to the greatest extent possible.

Cost-effective and flexible monitoring programmes for biological and chemical hazards (especially priority ones) in the meat chain are needed to verify whether the RB-MSAS is accomplishing its main goal: improving meat safety and public health. The two monitoring systems (biological and chemical) are already in place (Anon, 1996; Anon, 2003), but it is important to continuously update them for better harmonisation among countries, fill gaps about novel potentially important hazards, provide cost-effective programmes, etc. It is expected that successful implementation and functioning of the RB-MSAS will ultimately lead to lowering the human burden of disease from meat-borne hazards. Therefore, continuous efficiency monitoring that includes assessment of the public health and socioeconomic impacts is needed for evaluation and proper functioning of the RB-MSAS.

Finally, strengthening the links between academia, CAs, and FBOs is a cornerstone of functionality of the new system. Aiming to facilitate this process across Europe and beyond, recently a network of researchers and regulatory and meat industry representatives has been established through the COST Action, RIBMINS (ribmins.com). The network aims to combine and strengthen European-wide research efforts on modern meat safety controls. It consists of five working groups on: (1) scope and targets of meat safety assurance, (2) farm-level controls and risk categorisation, (3) abattoir-level controls and risk categorisation, (4) impact of changes and alternatives to the traditional meat safety system, and (5) training, communication and monitoring.

6. Conclusion

The revision and modernisation of the European meat safety system is triggered by science and the livestock and meat industry's need for cost-effectiveness but is dependant on different political and socioeconomic interests. The switch from a traditional to a modern system is an evolution – not a revolution – and, thus, is a slow, carefully guided process, driven by inputs from different stakeholders. It brings many opportunities to improve public health in a cost-effective way, while numerous challenges are associated with the process. Clearly, further developing and fine-tuning RB-MSAS will be an ongoing journey, not a destination. Full implementation is dependent on close collaboration of all the new system's stakeholders and will involve intensive research to collect data and fill knowledge gaps as well as ongoing education and training.

Declaration of competing interest

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

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