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Implementation of harmonised epidemiological indicators (HEIs) for pigs – A Europe-wide online survey

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ABSTRACT

In 2011, the European Food Safety Authority (EFSA) introduced harmonised epidemiological indicators (HEIs) for pigs to be utilised as part of the risk-based meat inspection within the meat safety assurance framework. However, the application of HEIs is not regulated by law. HEIs enable risk categorisation of farms regarding the main foodborne biological hazards associated with pigs and pork in Europe: *Salmonella*, *Yersinia enterocolitica*, *Toxoplasma gondii*, *Trichinella* and *Cysticercus cellulosae*. A questionnaire was developed to evaluate the current implementation of HEIs for pigs in Europe and was targeted at official veterinarians and food business operators experienced or involved in the official monitoring and surveillance at abattoirs. The study examined which of the HEIs for pigs were applied by asking for i) the corresponding private and/or official monitoring and surveillance systems (MoSSs) in place, ii) the stages at which the testing was conducted, iii) the diagnostic methods and iv) the sample materials used. In general, 88% of the respondents stated monitoring for *Salmonella*, 10% for *Yersinia enterocolitica*, 2% for *Toxoplasma gondii*, 90% for *Trichinella* and 31% for *Cysticercus cellulosae* was in place. In most cases, MoSSs for *Salmonella*, *Trichinella* and *Cysticercus cellulosae* were in place at abattoir level. Monitoring for these pathogens at abattoir level is already regulated by EU legislation. When corresponding HEIs for a regulated pathogen existed, they largely overlapped with the testing regime of the MoSSs. HEIs for the same pathogens that focus on a different stage of the food chain were mostly declared by respondents to not have been implemented; the same situation was found with HEIs for the other pig-associated hazards, *Yersinia enterocolitica* and *Toxoplasma gondii*. The results also revealed some alarming inconsistencies in the mandatory monitoring prescribed by EU regulations. Some respondents demonstrated a lack of understanding regarding diagnostic procedures, failing to correctly match diagnostic methods with the appropriate sample materials or vice versa. While HEIs provide valuable data, especially in terms of a novel risk-based meat safety assurance system, this survey showed that they are currently underutilised for pigs in Europe.

1. Introduction

In 2005, the principles of risk-based meat inspection were outlined in the European Union (EU) in line with Regulation (EC) No 854/2004 (European Commission, 2004), and today, visual meat inspection of pig carcasses is performed as the standard practice (Regulation (EU) 2017/625, 2019/627) (European Commission, 2017, 2019). Previously required palpations and incisions are now only performed if a specific risk is apparent from food chain information (FCI) or from results of ante- or post-mortem inspections or both (Regulation (EU) 2019/627) (European Commission, 2019). The objective of this paradigm shift was to reduce the risk of cross-contamination, which is higher when carrying out compulsory palpation and incision (EFSA Panel on Biological Hazards, 2011). In addition, the most common pig-associated zoonotic pathogens in Europe cannot be detected by these techniques, as pigs are usually asymptomatic or sub-clinically infected (Fredriksson-Ahomaa, 2014). The European Food Safety Authority (EFSA) proposed a general framework regarding the risk of biological hazards to be covered by meat inspection of pigs (EFSA Panel on Biological Hazards, 2011). At the same time, EFSA proposed "technical specifications on harmonised

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epidemiological indicators for public health hazards to be covered by meat inspection of swine" (EFSA, 2011) to be utilised as part of the risk-based meat inspection within the meat safety assurance framework. A harmonised epidemiological indicator (HEI) is defined by EFSA as the "prevalence or incidence of the hazard at a certain stage of the food chain or an indirect measure of the hazards (such as audits of farms) that correlates to a human health risk caused by the hazard" (EFSA, 2011). HEIs can contribute to mitigate the risk of foodborne hazards associated with pigs through supporting the choice of appropriate interventions, especially in adapting ante- and post-mortem inspections (EFSA, 2011). HEIs allow risk categorisation of farms according to their risk exposure and of abattoirs according to their ability to control and reduce the risk. Additionally, HEIs can be used to set targets for final chilled pig carcasses (EFSA, 2011). Depending on the purpose and epidemiological situation, national risk managers should decide on the most appropriate indicator(s) to be used, either individually or in combination, at national, regional, abattoir or farm level (EFSA, 2011).

1.1. Harmonised epidemiological indicators for hazards in pigs

The EFSA opinion on swine meat inspection identified six foodborne biological hazards to public health associated with pigs and pork: *Salmonella*, *Yersinia (Y.) enterocolitica*, *Toxoplasma (T.) gondii*, *Trichinella*, *Cysticercus (C.) cellulosae* (the larval stage of *Taenia (T.) solium*) and mycobacteria (EFSA, 2011). For each of the pathogens, at least one HEI is proposed to detect and address the respective hazard. There are specifications regarding the diagnostic method and sample material, both of which define monitoring and inspection requirements (Figs. 1–5). Since the monitoring and diagnostic criteria are predefined (harmonised), HEIs provide comparable epidemiological data on these pathogens from the EU member states (MSs). Hence, when possible, the criteria for the HEIs were based on monitoring activities already legally regulated in the EU (EFSA, 2011).

1.2. Relevant EU legislation and implementation of HEIs

In Europe, there is no legal obligation to implement HEIs. However, for some of them, corresponding EU regulations exist. According to the Zoonoses Directive 2003/99/EC, EU MSs are obligated to collect relevant and comparable data on the zoonotic agents listed in Annex I, Part A, including *Salmonella* and *Trichinella*, and on foodborne outbreaks caused by these hazards (European Commission, 2003). The monitoring is based on the systems that are in place in the MSs. All MSs submit annual reports to the European Commission (EC) that contain results of examinations for the abovementioned hazards. Annex I, Part B concerns pathogens, including *Y. enterocolitica* and *T. gondii*, that only have to be monitored if necessitated by the epidemiological situation (European Commission, 2003). Regulation (EC) No 2073/2005 requires food business operators (FBOs) to implement a testing strategy (self--monitoring) to ensure strict accordance of foodstuffs with the predefined microbiological criteria (European Commission, 2005b). For *Salmonella* in pigs, a process hygiene criterion (PHC) is defined for carcasses after dressing and before chilling at the abattoir and which is consistent with *Salmonella* HEI 6 (Fig. 1). The PHC indicates "the acceptable functioning of the production process" (European Commission, 2005b) which the competent authorities (CAs) verify (European Commission, 2019). In addition, Regulation (EU) 2019/627 prescribes official controls and laboratory testing for *C. cellulosae* and *Trichinella* (European Commission, 2019), the latter being specifically regulated in Regulation (EU) 2015/1375 (European Commission, 2015). For *Trichinella*, compulsory testing of pig carcasses must be conducted, which is consistent with *Trichinella* HEI 1, 2 or 4 (Fig. 4), unless a derogation applies. For *C. cellulosae*, the regular meat inspection embodies the minimum requirement for the examination for cysticercosis in pigs, which partly coincides with *C. cellulosae* HEI 1 (Fig. 5) (European Commission, 2019). At present, no EU regulations concerning systematic monitoring or other control requirements for *Y. enterocolitica* or *T. gondii* exist. Official

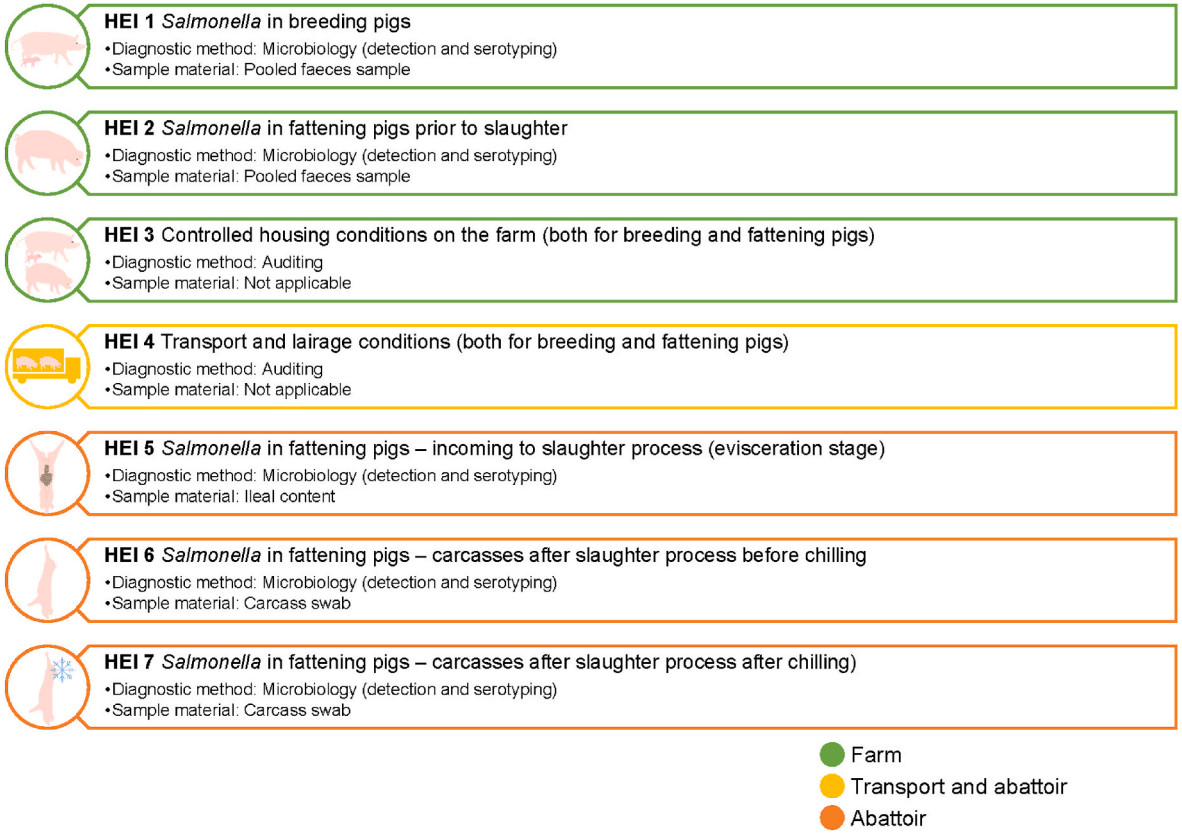

Fig. 1. Proposed HEIs for *Salmonella* in pigs according to EFSA (2011).

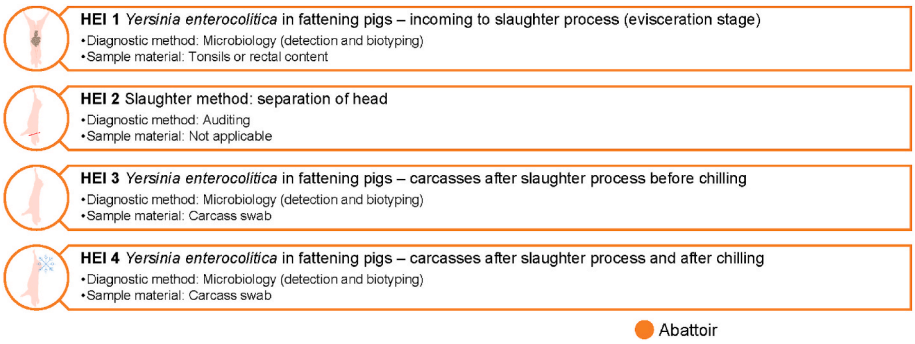

Fig. 2. Proposed HEIs for *Yersinia enterocolitica* in pigs according to EFSA (2011).

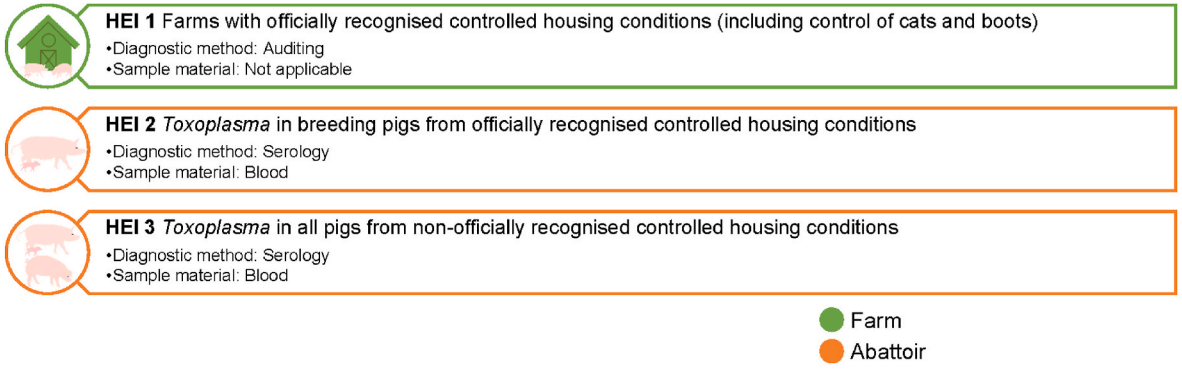

Fig. 3. Proposed HEIs for *Toxoplasma gondii* in pigs according to EFSA (2011).

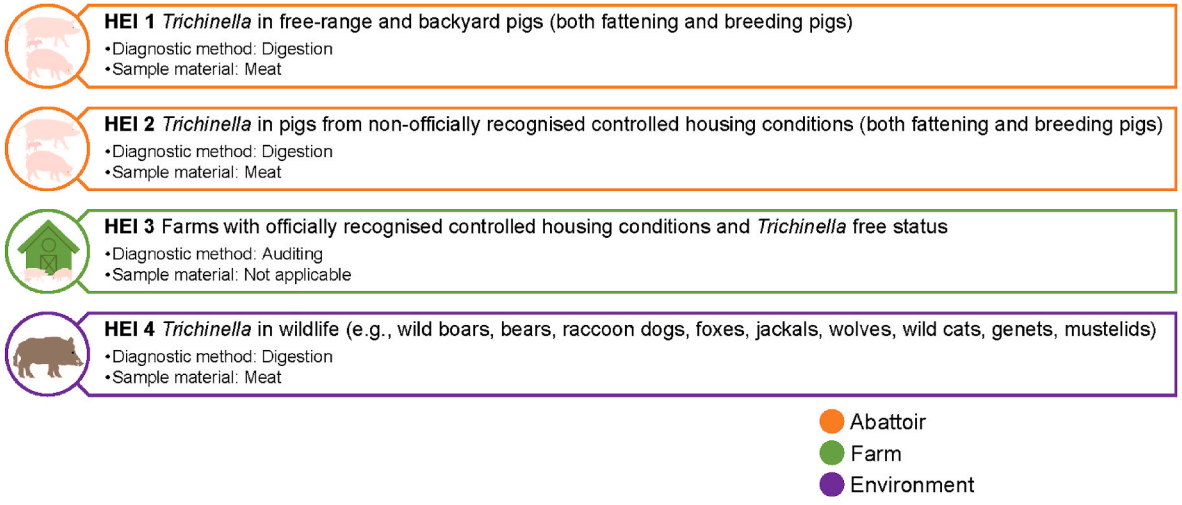

Fig. 4. Proposed HEIs for *Trichinella* in pigs according to EFSA (2011).

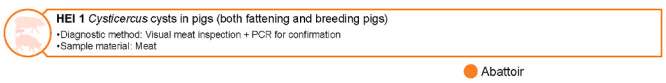

Fig. 5. Proposed HEI for *Cysticercus cellulosae* in pigs according to EFSA (2011).

control plans for pigs are implemented exclusively at abattoir level in the EU and only for *Salmonella, Trichinella* and *C. cellulosae*. Some EU MSs have control programmes for *Salmonella* in pigs in place that focus mainly on farm level control, but they were implemented long before the introduction of HEIs and are not mutually harmonised (Bonardi et al., 2021). The existence of HEIs and their purpose seem to be rather unknown among national risk managers, which might be why their implementation is lacking (Bonardi et al., 2021; Ferri et al., 2023; Salines et al., 2023). This hypothesis is also reinforced by the fact that there are few publications on this topic. This study was conducted to evaluate the current implementation of HEIs for pigs in Europe.

2. Materials and methods

2.1. Questionnaire development and design

A questionnaire on the implementation of HEIs for pigs was designed by members of Working Group 2 from the risk-based meat inspection

and integrated meat safety assurance (RIBMINS) COST Action (CA18105). The questionnaire was created and distributed in English. After positive feedback and validation by two social scientists from the Agriculture Economics Research Institute (AGRERI) ELGO-DIMITRA in Greece, the questionnaire was entered into SurveyHero®, a cloud-based software and questionnaire tool (enuvoGmbH, Zurich, Switzerland). The questionnaire was approved by the Central Ethics Committee of Freie Universität Berlin, Germany (ZEA-Nr. 2022-008). Anonymity was guaranteed to all respondents. The questionnaire included single-choice, multiple-choice (multiple answers possible), and open-ended questions. In total, the questionnaire consisted of 61 questions, divided into two sections: three questions on general information, and 58 questions on HEIs including six higher-level questions that each revealed multiple sub-questions on the answer "yes" being chosen and one open-ended question to enter free text (Supplement S1). The three questions on general information were about the respondent's professional role and the country and size of the abattoir (average estimated pigs slaughtered per week) in which the respondent worked. The main section was composed as follows: five out of the six higher-level questions asked if testing for a specific pathogen was conducted. When "yes" was chosen, three sub-questions appeared which asked for the type of monitoring and surveillance system (MoSS) in place for the pathogen, the stage at which testing was conducted, and the subsequent measures taken following positive findings of the pathogen. Instead of "MoSS", the term "monitoring" was used, since language barriers were expected and some languages do not differentiate between the terms "monitoring" and "surveillance". The second sub-question about the stage at which testing was conducted was a multiple-choice question with "on farm", "slaughterhouse before chilling", "slaughterhouse after chilling", and "other" as possible answers. When one or more of the first three answers were chosen, two more sub-questions on the diagnostic methods and sample materials for each option appeared. The final higher-level question asked about additional monitoring. In addition to the five hazards, respondents were also asked to communicate their suggestions regarding hepatitis E virus monitoring, as this pathogen was not included in the EFSA report.

2.2. Questionnaire distribution and data collection

The distribution of the weblink to the online survey was carried out by the RIBMINS science communication manager who instructed the (at the time) 33 RIBMINS national contact points (NCPs), located in the EU, the European Economic Area (EEA), and European non-EU countries, to recruit suitable respondents. Each NCP could decide independently on the number of respondents they would invite to answer the questionnaire. The communicated aim was to create a representative picture of the participating countries in terms of structural aspects of each individual country. Therefore, each NCP was asked to ensure the participation of respondents from small, medium, and large abattoirs, representing the specific pig abattoir structure in their country. Furthermore, each NCP was asked to ensure the participation of at least one meat inspection officer, including official veterinarians (further referred to as OVs), and at least one FBO/quality assurance manager (further referred to as FBOs). The target group for this questionnaire, apart from the abovementioned, was industry professionals involved in meat safety assurance systems at farm or abattoir level. Since the questionnaire was in English, the NCPs were asked to translate the questionnaire into their language and the answers back into English if language barriers were expected. The period for answering was between 6 November and December 16, 2020.

2.3. Data analysis

The data were analysed using Microsoft Excel® (Version 2211) for descriptive statistics. IBM® SPSS Statistics (Version 29) was used for chi-square tests, calculation of phi coefficient and determination of the correlation between the variables. To ensure anonymity for all respondents, data evaluation was not conducted by individual country but by grouping them into four regions according to EuroVoc (2023). The countries participating in the survey were grouped as follows: Northern Europe included Denmark, Iceland, Norway and Sweden. Central and Eastern Europe (further referred to as Eastern Europe) included Bosnia and Herzegovina, Croatia, Latvia, Poland, Romania, Serbia and Slovakia. Italy and Portugal were categorised in the region Southern Europe. Western Europe contained France, Germany, Ireland and the United Kingdom (UK). To ensure further anonymity, the countries were only divided into EU MSs and non-EU MSs. Countries from the EEA were categorised as non-EU MSs, and the UK was included in EU MSs since the Brexit transition phase was still ongoing and the UK continued to be subject to EU rules at the time the survey was performed. When respondents chose more than one diagnostic method or sample material for one pathogen, the survey design did not allow us to discern whether they had linked the two accurately. As almost every question had the answer option "other", all of these answers were examined, and when compatible, each was classified and counted with one of the existing answer options. In total, 65 respondents replied to the survey, but only the 51 questionnaires that were completely answered were analysed.

3. Results and discussion

3.1. General questions

The 51 respondents worked in 17 European countries, 42 of them in 13 EU MSs. Most respondents worked in Western Europe (45%; 23/51), followed by Eastern Europe (35%; 18/51). Looking at the top three countries across both groups, the most answers were received from Germany, France and Poland. This ranking correlates with the 2020 and 2021 statistics on pigs slaughtered by country in the EU (European Commission, 2022), which reported Germany, France and Poland being in second to fourth place after Spain, indicating that this part of the results reflects a representative picture in terms of structural aspects for the EU. Most of the respondents were OVs (61%; 31/51), while FBOs made up 27% (14/51) of respondents. The six respondents (12%) who fell into the category "other" worked in the meat safety sector either as academics or advisors. In total, 24% (12/51) of the respondents assigned themselves to a small-sized abattoir with $<$ 1000 pigs slaughtered per week, 31% (16/51) of the respondents assigned themselves to a medium-sized abattoir with 1000–10,000 pigs slaughtered per week, and 41% (21/51) to a medium-to large-sized abattoir with 10,001–100,000 pigs slaughtered per week. Two respondents (4%) worked in large-sized abattoirs with $>$ 100,000 pigs slaughtered per week.

3.2. Monitoring and surveillance for Salmonella

In total, 88% (45/51) of the respondents tested for *Salmonella* (Table 1). Among these respondents, most (84%; 38/45) worked in EU MSs. Out of the remaining six respondents (12%; 6/51) who said they did not test for *Salmonella*, 8% (4/51) worked in EU MSs and 4% (2/51) did not. All six respondents were OVs. An explanation for these six OVs stating they did not test for *Salmonella* could be related to the practical arrangements outlined in Article 35 of Regulation (EU) 2019/627 (European Commission, 2019). According to this Article, CAs verify the implementation of *Salmonella* control measures by FBOs through various measures, including official sampling and the collection of information on *Salmonella* testing. OVs, as part of their role, focus on collecting and verifying information on tests conducted by or for the FBOs. Therefore, it is plausible that the six OVs in our study primarily relied on this approach rather than official controls through official sampling, which is more common.

In terms of the MoSSs in place for *Salmonella*, 33% (15/45) of the respondents had an official system and 18% (8/45) a private system (Table 1). An official and private MoSS was stated to be in place by 49%

Table 1
Overview of the respondents' backgrounds monitoring for *Salmonella*, the MoSSs in place, the diagnostic tests, including diagnostic methods and sample materials, and the implemented HEIs.

Respondent	Region	Role	Abattoir size[a]	MoSS	Stage[c]: Farm	Stage[c]: Abattoir before chilling	Stage[c]: Abattoir after chilling	HEI(s)
1	Eastern EU MS	OV	Small	Official	N/A	N/A	M: MB MT: CS, TS	7
2	Eastern EU MS	OV	Medium	Official	N/A	M: MB MT: CS	M: MB MT: CS	6, 7
3	Eastern EU MS	OV	Medium	Official	N/A	N/A	M: MB MT: CS	7
4	Eastern EU MS	OV	Medium	Official	N/A	N/A	M: MB MT: CS	7
5	Eastern non-EU MS	OV	Small	Official	N/A	N/A	M: MB MT: CS	7
6	Northern non-EU MS	OV	Small	Official	N/A	M: MB MT: CS	M: MB MT: CS	6, 7
7	Southern EU MS	OV	Medium	Official	N/A	M: MB, PCR MT: CS, IC	N/A	5, 6
8	Southern EU MS	OV	Large	Official	N/A	M: MB MT: CS	N/A	6
9	Western EU MS	OV	Medium-Large	Official	N/A	M: MB MT: CS	N/A	6
10	Northern non-EU MS	FBO	Small	Official	N/A	M: MB MT: CS	N/A	6
11	Western EU MS	FBO	Medium	Official	N/A	N/A	M: MB MT: CS	7
12	Western EU MS	FBO	Medium-Large	Official	N/A	M: PCR MT: CS, MJ, TS	N/A	n/a
13	Northern EU MS	Other	Medium-Large	Official	M: MB, PCR MT: CaS, MJ	N/A	M: MB, PCR MT: CS	7
14	Northern non-EU MS	Other	Medium	Official	N/A	M: MB, PCR MT: CS, LN	N/A	6
15	Western EU MS	Other	Medium-Large	Official	N/A	M: MB MT: CS	N/A	6
16	Eastern non-EU MS	OV	Small	Private	N/A	M: MB MT: CS	N/A	6
17	Western EU MS	OV	Medium-Large	Private	N/A	N/A	M: MB MT: CS	7
18	Western EU MS	OV	Medium-Large	Private	N/A	N/A	M: MB MT: CS	7
19	Western EU MS	FBO	Medium	Private	N/A	M: MB MT: MJ	N/A	n/a
20	Western EU MS	FBO	Medium-Large	Private	N/A	N/A	M: MB MT: CS	7
21	Western EU MS	FBO	Medium-Large	Private	N/A	M: MB MT: CS	M: MB MT: CS	6, 7
22	Western EU MS	FBO	Medium-Large	Private	N/A	N/A	M: MB MT: CS	7
23	Western EU MS	FBO	Medium-Large	Private	N/A	N/A	M: MB MT: CS	7
24	Eastern EU MS	OV	Medium	Both[b]	N/A	M: MB MT: CS	N/A	6
25	Eastern EU MS	OV	Medium	Both[b]	N/A	M: MB MT: CS	N/A	6
26	Eastern EU MS	OV	Medium	Both[b]	N/A	M: MB MT: CS	N/A	6
27	Eastern EU MS	OV	Medium-Large	Both[b]	N/A	M: MB MT: CS	N/A	6
28	Eastern EU MS	OV	Medium-Large	Both[b]	M: MB MT: Fae	M: MB MT: CS	N/A	1 or 2, 6
29	Eastern non-EU MS	OV	Medium	Both[b]	N/A	M: MB MT: CS	N/A	6
30	Northern EU MS	OV	Mmedium	Both[b]	N/A	M: MB MT: CS, LN	N/A	6
31	Northern non-EU MS	OV	Small	Both[b]	N/A	N/A	M: MB MT: CS, MJ	7
32	Southern EU MS	OV	Medium	Both[b]	N/A	M: MB MT: CS	N/A	6
33	Western EU MS	OV	Medium	Both[b]	N/A	M: MB, SL MT: CS, MJ	N/A	6
34	Western EU MS	OV	Medium-Large	Both[b]	M: MB MT: Fae	M: MB MT: CS	M: MB MT: TS	1 or 2, 6
35	Western EU MS	OV	Medium-Large	Both[b]	N/A	M: MB, PCR, SL MT: CS, IC, MJ	N/A	5, 6
36	Western EU MS	OV	Medium-Large	Both[b]	N/A	M: MB, SL MT: CS, MJ	N/A	6

(*continued on next page*)

Table 1 (*continued*)

Respondent	Region	Role	Abattoir size[a]	MoSS	Stage[c]: Farm	Stage[c]: Abattoir before chilling	Stage[c]: Abattoir after chilling	HEI(s)
37	Western EU MS	OV	Medium-Large	Both[b]	N/A	M: MB, PCR MT: CS	M: MB, PCR MT: CS	6, 7
38	Western EU MS	OV	Medium-Large	Both[b]	N/A	M: MB, PCR, SL MT: CS, IC, MJ	M: MB, PCR MT: CS, TS	5, 6, 7
39	Eastern EU MS	FBO	Medium-Large	Both[b]	M: Audit, MB MT: Fae, Fee	M: MB, PCR MT: CS	N/A	1 or 2, 3, 6
40	Western EU MS	FBO	Medium-Large	Both[b]	N/A	M: MB, PCR MT: CS, MJ	M: MB MT: TS	6
41	Western EU MS	FBO	Medium-Large	Both[b]	M: SL MT: BL	M: MB, SL MT: CS, MJ	M: MB MT: TS	6
42	Western EU MS	FBO	Large	Both[b]	N/A	M: MB MT: CS, TS	M: MB MT: CS, TS	6, 7
43	Eastern EU MS	Other	Small	Both[b]	N/A	M: MB MT: CS	N/A	6
44	Eastern EU MS	Other	Medium	Both[b]	N/A	M: MB, SL MT: CS, TS	N/A	6
45	Western EU MS	Other	Medium-Large	Both[b]	M: SL MT: BL	M: MB, PCR, SL MT: CS, MJ	N/A	6

EU MS = member state of the European Union.
OV = official veterinarian; FBO = food business operator.
[a] based on pigs slaughtered per week MoSS = monitoring and surveillance system.;
[b] official and private MoSS.
[c] stage at which testing was performed; N/A = not available/no answer; M = method(s); MB = microbiology; MT = material(s); CaS = caecum sample; MJ = meat juice; Fae = faeces; Fee = feed; SL = serology; BL = blood CS = carcass swab; IC = ileal content; TS = tissue sample; LN = lymph nodes HEI(s) = harmonised epidemiological indicator(s) as proposed by EFSA; n/a = not applicable.

(22/45) of these respondents. Out of the eight respondents who only had a private system in place, seven (16%; 7/45) worked in Western EU MSs, and more specifically, six of them in the same country (4x FBOs, 2x OVs). The results showed that five FBOs (11%; 5/45) who worked in EU MSs did not comply with the official testing regime for *Salmonella* according to Regulation (EC) No 2073/2005 (European Commission, 2005b). The regulation specifies sampling with an abrasive sponge method for carcasses after dressing but before chilling, and it requires analysis using the reference method EN ISO 6579-1 (International Organization for Standardization, 2017). It is possible that the FBOs misinterpreted the term private monitoring, confusing it with self-monitoring. However, even if this was the case, four out of the five FBOs answered that they perform the microbiological testing of the pig carcasses after chilling only (Table 1). Additionally, two OVs answered that only a private system was in place, and they also did not test according to Regulation (EC) No 2073/2005 (see first paragraph of this section). Furthermore, the results showed that eight respondents (18%; 8/45), six working in EU MSs, had an official MoSS in place that did not comply with the legislated controls.

Regardless of a private or an official system, 32% (12/38) of the respondents who worked in EU MSs and carried out examinations for *Salmonella* did not comply with the PHC (6x FBOs, 5x OVs, 1x "other"). Adding the four OVs who did not test at all, a majority of OVs (56%; 9/16) either did not perform testing for *Salmonella* at all or did not perform it according to EU regulation. It is likely that the OVs fulfilled their obligations within the framework of official controls for *Salmonella* by collecting information on *Salmonella* testing. The testing they reported conducting should be regarded as additional, non-officially mandated examinations, as official sampling should be carried out using the same method and sampling location on the carcasses as the FBOs use (European Commission, 2019). While OVs operated within their monitoring capabilities, the absence of official samplings raises concerns regarding food safety. OVs who have tasks within CAs have not only auditory roles, but also advisory roles. A previous survey among FBOs showed that they considered the influence of official controls beneficial for food safety, partly because they consider the CAs to be an important source of information (Mari et al., 2013). Furthermore, Mari et al. (2013) showed the more frequent the visits of official inspectors, the better the FBOs understood their non-compliance being a hazard to food safety. Another aspect about the disbalance that is concerning to food safety is that since 2017, EFSA has continuously stated in its zoonosis reports that the self-monitoring through FBOs results in significantly fewer positive *Salmonella* findings than does official samplings by CAs (EFSA & ECDC, 2018; 2019; 2021a; 2021b, 2022). Several studies have investigated the impact of the behaviour of FBOs on food safety and their intentional or unintentional non-compliance (Arendt et al., 2015; Manning & Soon, 2019; Moyer et al., 2017; Spink et al., 2019; van Asselt et al., 2012, 2021; van Ruth et al., 2018). Underlying their behaviour, however, is predominantly a lack of understanding the measures required. If FBOs, e.g., do not understand the substance of an audit by a CA or the outcome of it, the probability that subsequent improvements will be accomplished is reduced (Røtterud et al., 2020).

When comparing the results to the proposed *Salmonella* HEIs 1–7 (Figs. 1), 7% (3/45) of the answers matched with HEI 1 or HEI 2, 2% (1/45) matched with HEI 3, 7% (3/45) matched with HEI 5, 69% (31/45) matched with HEI 6, and 40% (18/45) with HEI 7 in all parameters (Table 1). As the questionnaire did not include transport as a food chain stage, there were no results that could be compared with HEI 4.

The monitoring of slaughter hygiene was by far the most commonly mentioned consequence (80%; 36/45) resulting from positive *Salmonella* findings (Fig. 6). Interestingly, out of the ten respondents who did not comply with the PHC, nine chose this consequence. Bonardi et al. (2021) already pointed out that when there is no complementary control programme for *Salmonella* and no risk categorisation at farm level, reducing the carcass contamination depends solely on the hygiene standards of the abattoir and the slaughter process. This, in turn, depends mainly on the FBOs and, again, their willingness to comply.

In total, 49% (22/45) of the respondents considered "feedback to the farm" and 44% (20/45) "categorisation of farms" as important consequences of *Salmonella*-positive findings (Fig. 6). Overall, 80% (16/20) of the respondents were exclusively testing at abattoir level, complying mainly with HEI 6 or HEI 7 (Fig. 1). The information gained from these HEIs is limited to the slaughter process as such, and more precisely, to the process hygiene and its ability to reduce the occurrence of *Salmonella* (EFSA, 2011). Although the respondents were expected to be experts with knowledge about all stages at which testing was performed within the MoSS, it is possible that they answered only for the tests they themselves performed. Also, there could be a lack of understanding of

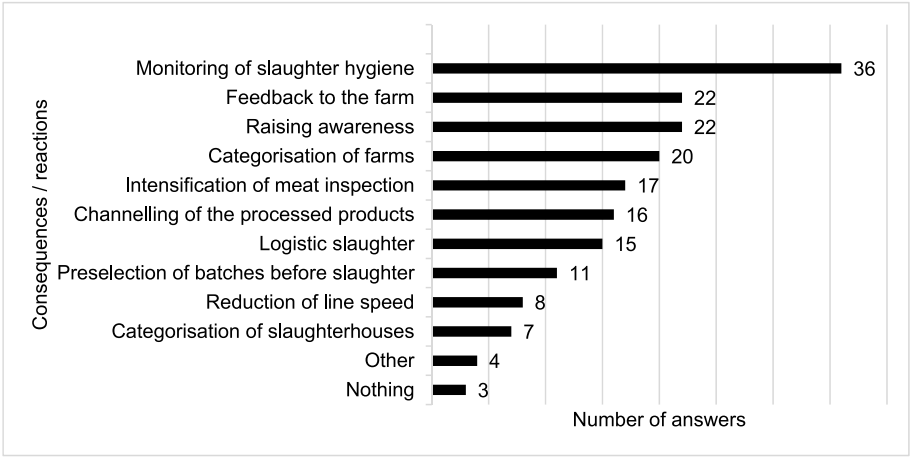

Fig. 6. Consequent measures to MoSSs for *Salmonella* (n = 45; multiple answers possible).

specific procedures and their outcomes, which would also lead to an inability to apply the right consequences, or, due to misinterpretation of the question, the respondents did not categorise the farms, but expressed their wish for this to be a consequence and be practised and implemented in the future.

Furthermore, the data showed that 47% (21/45) of respondents applied a destructive testing method by collecting meat juice or tissue samples, including lymph nodes (Table 1). Five respondents (11%; 5/45) did not link meat juice with serology as the corresponding diagnostic method; three of them were FBOs who worked in the same EU MS where a control programme for *Salmonella* is in place. One respondent mentioned serology as the diagnostic method for tissue samples. The tissue samples could be diaphragm muscles from which meat juice is extracted. The answer was given as a free text response, and it was possible to select meat juice as an answer option in the questionnaire, which is why we classified the answer as a wrong pairing of diagnostic method and sample material. These results show that six respondents (13%; 6/45) did not know how diagnostic tests for *Salmonella* should be performed or which sample materials should be collected.

3.3. Monitoring and surveillance for Yersinia enterocolitica

Five respondents (10%; 5/51) answered that they performed testing for *Y. enterocolitica* on pig carcasses (Table 2).

As shown in Table 2, only one respondent who performed official testing before chilling corresponded with the proposed *Y. enterocolitica* HEI 1, and one respondent who said that official monitoring after chilling was performed conformed to HEI 4. The proposed HEIs for *Y. enterocolitica* solely focus on abattoir level since there was no useful indicator to apply at farm level in 2011 (EFSA, 2011). Still today, the scientific opinion on the serological monitoring at farm level is very ambiguous. Some studies indicate that serological monitoring of blood or meat juice could be utilised to categorise farms according to their risk factor for *Y. enterocolitica* (Felin et al., 2015, 2019; Meemken et al., 2014). Others raise concern about the low specificity of the ELISA tests (Van Damme et al., 2014), due to the non-harmonised standards applied to sampling and testing (Wallander et al., 2015), or about the value of the results for fattening pigs at the time of slaughter (Buncic et al., 2019; Nesbakken et al., 2006). One OV who worked in a Western EU MS also stated that serologic tests could be used at abattoir level but noted that such testing at farm level would be even better.

In total, 60% (3/5) of the respondents who tested for *Y. enterocolitica* regarded "monitoring of slaughter hygiene" as the most important consequence of positive findings (Fig. 7). Adequate slaughter process hygiene is of utmost importance to reduce the prevalence of and the (cross-)contamination with *Y. enterocolitica*. Since the bacterium is predominantly found in the pigs' oral cavity, particularly in the tonsils, and in intestines and faeces (Moreira et al., 2019), splitting the carcass with the head on is one of the most relevant risk factors for contamination (Van Damme et al., 2015; Zdolec et al., 2015). Removing the head before evisceration as proposed in HEI 2 (Fig. 2) is a highly effective measure to reduce the probability of contamination (Vilar et al., 2015). If an abattoir does not perform head removal, or for other reasons cannot ensure the necessary hygienic measures to reduce the

Table 2
Overview of the respondents' backgrounds monitoring for *Yersinia enterocolitica*, the MoSSs in place, the diagnostic tests, including diagnostic methods and sample materials, and the implemented HEIs.

Respondent	Region	Role	Abattoir size[a]	MoSS	Stage[b]: Abattoir before chilling	Stage[b]: Abattoir after chilling	HEI
1	Southern EU MS	OV	Large	Official	M: MB MT: BL, IC, TO	N/A	1
2	Western EU MS	OV	Medium-Large	Official	M: MB MT: N/A	N/A	n/a
3	Eastern non-EU MS	OV	Small	Official	N/A	M: MB MT: CS	4
4	Western EU MS	FBO	Medium-Large	Private	N/A	M: MB MT: TS	n/a
5	Western EU MS	FBO	Large	Private	N/A	M: MB MT: TS	n/a

EU MS = member state of the European Union OV = official veterinarian; FBO = food business operator.
[a] based on pigs slaughtered per week MoSS = monitoring and surveillance system.
[b] stage at which testing was performed; M = method(s); MB = microbiology; MT = material(s); BL = blood; IC = ileal content; TO = tonsils; N/A = not available/no answer CS = carcass swab; TS = tissue sample HEI = harmonised epidemiological indicator as proposed by EFSA; n/a = not applicable.

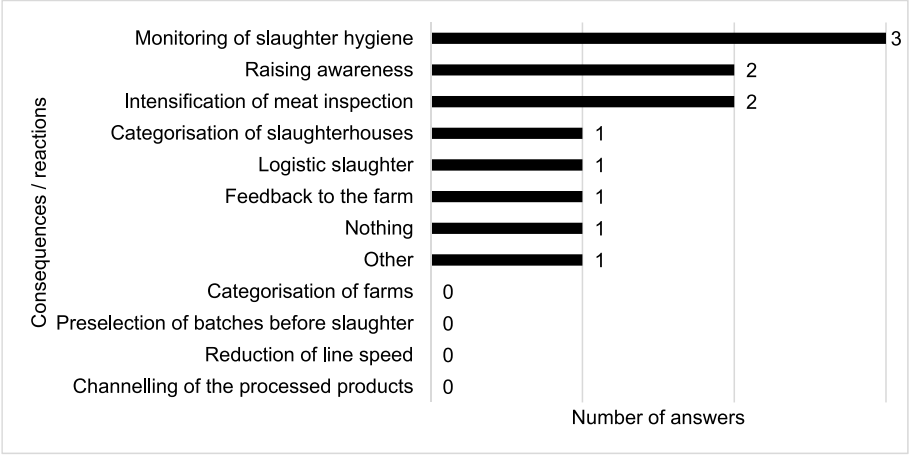

Fig. 7. Consequent measures to MoSSs for *Yersinia enterocolitica* (n = 5; multiple answers possible).

Y. enterocolitica prevalence on carcasses in the routine process, additional risk-reducing measures like decontamination should be considered (Buncic et al., 2019). This is an example on how the interaction of the bidirectional information flow between farm and abattoir, and the accompanying risk categorisation of both, would advance a future risk-based meat safety assurance system (RB-MSAS). Risk categorisation will help to identify *Y. enterocolitica*-low-risk farms from which pigs could be slaughtered using the company-specific standard procedures in low-risk abattoirs with proven good hygiene practice, whereas pigs from high-risk farms would need additional processing following the slaughter process to reduce the risk (Blagojevic & Antic, 2014; Blagojevic et al., 2021; Buncic et al., 2019; Ferri et al., 2023; Nastasijević et al., 2020). This could involve enhancing process hygiene or implementing additional risk-reducing measures, such as chemical decontamination or thermal treatment, to eliminate hazards.

3.4. Monitoring and surveillance for Toxoplasma gondii

Only one respondent (2%; 1/51) stated that testing for *T. gondii* was performed. The respondent was an OV who worked in a Western EU MS in a medium-to large-sized abattoir. The testing of pigs within a private monitoring system by blood analysis corresponds with *Toxoplasma* HEI 2 or HEI 3, depending on the category of pigs and the housing system (Fig. 3). The monitoring at this facility did not result in any operational measures being taken. However, the OV expressed the wish to feed back any result to farms, particularly farms for fattening pigs.

T. gondii is considered an important foodborne parasite that causes human health problems (Bouwknegt et al., 2018) and was classified as medium-risk by EFSA (EFSA Panel on Biological Hazards, 2011). The estimated seroprevalence of *T. gondii* in pigs in Europe is 13% (Foroutan et al., 2019). The correlation of seropositivity with *T. gondii*-contaminated pork (Foroutan et al., 2019; Opsteegh et al., 2016) speaks in favour of implementing MoSSs. Serological testing has been suggested to be the most practical method for monitoring (Basso et al., 2013; Felin et al., 2015; Steinparzer et al., 2015), if it is targeted specifically at smaller or outdoor farms or uncontrolled housing conditions (EFSA, 2011; Felin et al., 2019). Loreck et al. (2020) have shown that serological testing as a multi-serology analysis of meat juice through protein microarray could be the way forward since it provides a cost-efficient way to test for multiple hazards. For both *T. gondii* and *Y. enterocolitica*, high test accuracies were achieved (Loreck et al., 2020). Multi-serology analysis could also improve the monitoring situation for *Y. enterocolitica* and could replace ELISA testing (Subsection 3.3).

Prevention and control strategies that focus on farm level (Aguirre et al., 2019) substantially contribute to preventing *T. gondii* infections (Kuruca et al., 2023; Stelzer et al., 2019). In addition to categorising farms in order to subject carcasses from high-risk farms to decontamination by freezing, heating or curing (Buncic et al., 2019; Felin et al., 2019; Kijlstra & Jongert, 2008), testing for *T. gondii* could also be used to optimise farm management.

3.5. Monitoring and surveillance for Trichinella

Overall, 90% (46/51) of respondents stated that they tested for *Trichinella* (Table 3). Most respondents (96%; 44/46) answered "slaughterhouse before chilling" for the stage at which testing was conducted. Two OVs, who worked in one Eastern EU MS and did not have an official MoSS, stated that they tested after chilling only. Regardless of the stage at which testing was conducted, unless a freezing treatment of the meat is conducted, having only a private MoSS in place is not sufficient to comply with EU regulation, as this country was not listed as being able to apply for derogation (European Commission, 2023). In 96% (44/46) of cases, the digestion method using tissue samples was applied for *Trichinella* testing (Table 3), which corresponds with the suggested HEIs 1 or 2 or 4 (Fig. 4). Only two FBOs (4%) who worked in the same Western EU MS specified meat juice as the sample material. Either the FBOs did not know about the correct test procedure and performed it wrongly, or they confused the sample material, since meat juice is most commonly obtained from diaphragm muscles, which is the correct sample material. A single OV who worked in a Western EU MS additionally stated they perform an audit of farms, which corresponds with HEI 3 (Fig. 4) if the farms are "[…] with officially recognised controlled housing conditions and *Trichinella* free status". As proposed for the *Trichinella* HEIs, for pigs raised under controlled conditions, auditing of the farms is sufficient, while carcass testing is only relevant for pigs from non-officially controlled housing conditions. This was also assessed in a recent study by Gamble (2022), which evaluated the current *Trichinella* control and monitoring. The study highlighted the importance of HEIs for a risk-based approach to pork production systems, and at the same time, it showed that the existence of HEIs is, unfortunately, not widely known, as they were not mentioned or referred to at all in the publication by Gamble (2022).

The two most frequently mentioned consequences in the case of *Trichinella*-positive results were both at farm level: 67% (31/46) of the respondents gave feedback to the farms and 57% (26/46) categorised the farms (Fig. 8), while 40% (17/46) did both.

In total, five respondents (10%; 5/51), all working as FBO in the same Western EU MS, did not test for *Trichinella* (1x medium-sized, 4x medium-to large-sized). While some EU MSs are allowed to apply for derogation from *Trichinella* testing, the country in question was not included on the corresponding list published by the EC (European Commission, 2023). In accordance with Annex II of Regulation (EU)

Table 3
Overview of the respondents' backgrounds monitoring for *Trichinella*, the MoSSs in place, the diagnostic tests, including diagnostic methods and sample materials, and the implemented HEIs.

Respondent	Region	Role	Abattoir size[a]	MoSS	Stage[c]: Farm	Stage[c]: Abattoir before chilling	Stage[c]: Abattoir after chilling	HEI(s)
1	Eastern EU MS	OV	Small	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
2	Eastern EU MS	OV	Small	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
3	Eastern EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
4	Eastern EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
5	Eastern EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
6	Eastern EU MS	OV	Medium-Large	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
7	Eastern EU MS	OV	Medium-Large	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
8	Eastern non-EU MS	OV	Small	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
9	Eastern non-EU MS	OV	Small	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
10	Northern EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
11	Northern non-EU MS	OV	Small	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
12	Northern non-EU MS	OV	Small	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
13	Southern EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
14	Southern EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
15	Southern EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
16	Southern EU MS	OV	Large	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
17	Western EU MS	OV	Small	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
18	Western EU MS	OV	Small	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
19	Western EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
20	Western EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
21	Western EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
22	Western EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
23	Western EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
24	Western EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
25	Western EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
26	Western EU MS	OV	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
27	Western EU MS	OV	Medium	Official	M: Audit	M: Digestion MT: TS	N/A	3, 1 or 2 or 4
28	Eastern EU MS	FBO	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
29	Northern non-EU MS	FBO	Small	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
30	Western EU MS	FBO	Large	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
31	Western EU MS	FBO	Medium-Large	Official	N/A	M: Digestion MT: MJ	N/A	n/a
32	Western EU MS	FBO	Medium	Official	N/A	M: Digestion MT: MJ	N/A	n/a
33	Western EU MS	FBO	Medium-Large	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
34	Western EU MS	FBO	Medium-Large	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
35	Eastern EU MS	Other	Small	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
36	Eastern EU MS	Other	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4

(*continued on next page*)

Table 3 (*continued*)

Respondent	Region	Role	Abattoir size[a]	MoSS	Stage[c]: Farm	Stage[c]: Abattoir before chilling	Stage[c]: Abattoir after chilling	HEI(s)
37	Northern EU MS	Other	Medium-Large	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
38	Northern non-EU MS	Other	Medium	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
39	Western EU MS	Other	Medium-Large	Official	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
40	Eastern EU MS	OV	Medium	Private	N/A	N/A	M: Digestion MT: TS	1 or 2 or 4
41	Eastern EU MS	OV	Medium	Private	N/A	N/A	M: Digestion MT: TS	1 or 2 or 4
42	Eastern non-EU MS	FBO	Small	Private	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
43	Eastern non-EU MS	OV	Medium	Private	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
44	Eastern EU MS	OV	Medium	Both[b]	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
45	Eastern non-EU MS	FBO	Small	Both[b]	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4
46	Western EU MS	Other	Medium-Llarge	Both[b]	N/A	M: Digestion MT: TS	N/A	1 or 2 or 4

EU MS = member state of the European Union OV = official veterinarian; FBO = food business operator.
[a] based on pigs slaughtered per week MoSS = monitoring and surveillance system.;
[b] official and private MoSS.
[c] stage at which testing was performed; N/A = not available/no answer; M = method MT = material; TS = tissue sample; MJ = meat juice HEI(s) = harmonised epidemiological indicator(s) as proposed by EFSA; n/a = not applicable.

Fig. 8. Consequent measures to MoSSs for *Trichinella* (n = 46; multiple answers possible).

2015/1375 (European Commission, 2015), derogation from testing is also allowed if the meat is frozen. Therefore, either the meat underwent a freezing treatment or the FBOs did not comply with EU regulation – be it out of ignorance or from a lack of awareness that the testing in their facilities was indeed performed, but by the CAs and not by themselves. Notably, the four FBOs from the medium-sized abattoir who did not test for *Trichinella* also did not perform any official monitoring for *Salmonella*. Interestingly, the other respondents who worked in the same Western EU MS and did perform testing were all OVs and from a medium-sized abattoir. To help explore and understand the rationality of compliant or non-compliant behaviour, social science provides several tools (Garforth, 2015). Gaining a deeper understanding of the underlying processes and motivations behind these decisions for non-compliance could greatly aid in the development of effective advisory and policy interventions (Garforth, 2015).

3.6. Monitoring and surveillance for Cysticercus cellulosae

During visual meat inspection of pig carcasses, examination for cysticercosis must be performed (European Commission, 2019). In total, 31% (16/51) of the respondents stated that they tested for *C. cellulosae* (Table 4). All of them, except for one OV who worked in an Eastern non-EU MS, had an official MoSS in place. The official systems and the private system did not differ from each other in terms of diagnostics. The only difference was the stage at which testing was conducted: for the official MoSSs, it was before, and for the private MoSS, it was after carcass chilling. Since the meat inspection is performed before carcass chilling, the private MoSS did not correspond with the HEI for *C. cellulosae*. In terms of the diagnostic method, visual meat inspection was stated every time. One OV who worked in a Southern EU MS additionally opened 10% of the hearts from each batch to inspect the muscle.

Considering that the respondents who tested for *C. cellulosae* just performed the regular meat inspection and assuming all other respondents performed it as well, it is interesting to see which countries considered visual meat inspection as a form of active testing for *C. cellulosae*. As shown in Table 4, respondents who stated they tested for *C. cellulosae* were predominantly from Eastern Europe (69%; 11/16). A significant correlation between region and testing was found ($r(49) = 0.473$, $p = <.001$). There are limited data on the *C. cellulosae* prevalence

Table 4
Overview of the respondents' backgrounds monitoring for *Cysticercus cellulosae*, the MoSSs in place, the diagnostic tests, including diagnostic methods and sample materials, and the implemented HEIs.

Respondent	Region	Role	Abattoir size[a]	MoSS	Stage[c]: Abattoir before chilling	Stage[c]: Abattoir after chilling	HEI
1	Eastern EU MS	OV	Small	Official	M: VMI MT: Heart, TS	N/A	n/a
2	Eastern EU MS	OV	Medium	Official	M: VMI MT: TS	N/A	n/a
3	Eastern EU MS	OV	Medium	Official	M: VMI MT: TS	N/A	n/a
4	Eastern EU MS	Other	Medium	Official	M: VMI MT: TS	N/A	n/a
5	Eastern EU MS	OV	Medium	Official	M: VMI MT: TS	N/A	n/a
6	Eastern EU MS	OV	Medium-Large	Official	M: VMI MT: TS	N/A	n/a
7	Eastern EU MS	OV	Medium-Large	Official	M: VMI MT: TS	N/A	n/a
8	Southern EU MS	OV	Medium	Official	M: VMI MT: N/A	N/A	n/a
9	Southern EU MS	OV	Medium	Official	M: VMI MT: TS	N/A	n/a
10	Western EU MS	OV	Small	Official	M: VMI MT: N/A	N/A	n/a
11	Western EU MS	OV	Medium-Large	Official	M: VMI MT: TS	N/A	n/a
12	Western EU MS	OV	Medium-Large	Official	M: VMI MT: N/A	N/A	n/a
13	Eastern non-EU MS	OV	Small	Official	M: VMI MT: N/A	N/A	n/a
14	Eastern EU MS	FBO	Medium-Large	Official	M: VMI MT: TS	N/A	n/a
15	Eastern non-EU MS	OV	Small	Private	N/A	M: VMI MT: TS	n/a
16	Eastern EU MS	OV	Medium	Both[b]	M: VMI MT: Heart	N/A	n/a

EU MS = member state of the European Union OV = official veterinarian; FBO = food business operator.
HEI = harmonised epidemiological indicator as proposed by EFSA; n/a = not applicable.
[a] based on pigs slaughtered per week MoSS = monitoring and surveillance system.;
[b] official and private MoSS.
[c] stage at which testing was performed; M = method; VMI = visual meat inspection; MT = material(s); TS = tissue sample; N/A = not available/no answer.

in Europe in general, and in particular they are lacking for Eastern European countries, where it is presumed that cysticercosis exists (Devleesschauwer et al., 2017; EFSA & ECDC, 2022; Trevisan et al., 2018). For the most part, if countries did report data, species identification was missing or the findings were not confirmed (Devleesschauwer et al., 2017; Laranjo-González et al., 2017; Trevisan et al., 2018). For *C. cellulosae,* only one HEI is suggested (Fig. 5). It proposes the visual meat inspection, as performed in all cases, but additionally, PCR for confirmation is expected. None of the respondents performed the PCR confirmation as suggested (Table 4).

When asked for consequences in the case of *C. cellulosae*-positive findings (Fig. 9), the reaction "raising awareness" was ranked first, with 81% (13/16) of respondents choosing this option. Considering the low data availability on the occurrence of *C. cellulosae* or *T. solium*, the endemicity across Europe and the assertion that *T. solium* "has been eradicated in most countries in Europe" (EFSA, 2011) should be

Fig. 9. Consequent measures to MoSSs for *Cysticercus cellulosae* (n = 16; multiple answers possible).

questioned. Data collection needs to be improved. In terms of consequences for farms, 75% (12/16) of the respondents stated feedback of a positive finding to the farm occurs, and 38% (6/16) of respondents declared that they categorise the farms (Fig. 9); 25% (4/16) did both. For each of the consequences, "intensification of meat inspection" and "channelling of the processed products", 50% (8/16) of the respondents considered these consequences to be appropriate. All six respondents who categorised farms were among the eight respondents who processed the meat. Based on the risk categorisation of farms and the post-mortem findings, decontamination of carcasses using procedures like freezing, heating or salting (Aminjanov et al., 2005) could be used for processing.

3.7. Additional monitoring and surveillance

Altogether, 24% (12/51) of respondents answered affirmatively to the final question, expressing their desire for additional MoSSs to address either previously mentioned pathogens or additional ones. Out of the ten respondents who wanted additional MoSSs for *Salmonella*, seven (70%; 7/10) were in favour of implementing or improving monitoring on farms to allow risk categorisation and, consequently, adapting measures at abattoir level. With regard to additional MoSSs for *Y. enterocolitica,* two respondents (29%; 2/7) wanted the monitoring to be implemented at abattoir level. One respondent wanted to have monitoring of farms and according risk categorisation of farms. Another respondent wanted *Y. enterocolitica* to be added into the regular zoonoses monitoring, with sampling on a random basis. For additional MoSSs for *T. gondii*, three respondents (50%; 3/6) wanted to have serological testing at farm or abattoir level or both, to support risk categorisation of farms. Furthermore, one respondent wished for international (consumer) acceptance of the use of controlled housing conditions. The same respondent (25%; 1/4) expressed this aspiration for *Trichinella* as well. Another respondent (25%; 1/4) wanted to improve monitoring in terms of *Trichinella*-free farms. An OV voiced concern about the conflict between the significance and importance of *Trichinella* for public health and the cost of MoSSs. For additional MoSSs for *C. cellulosae,* two respondents (29%; 2/7) from Eastern Europe answered that they would like to have (additional) on-farm testing. Three respondents (43%; 3/7) from Northern, Southern and Western Europe stated that there were currently no cases of cysticercosis in their countries, but they still presented their opinions regarding additional MoSSs. One of them elaborated that there was a need for increased awareness of *C. cellulosae* since the possibility of infection had increased with the diversification of husbandry systems over recent years. Lastly, as an additional pathogen, wishes to monitor for hepatitis E virus were expressed. Seven respondents endorsed the monitoring of hepatitis E virus, mostly through sampling at farm and/or abattoir levels in blood and/or faeces (57%; 4/7), or through PCR testing of liver tissue (14%; 1/7). Finally, one OV from a Western EU MS indicated their preference for regular sampling on a random basis and examination by a national laboratory for all the pathogens included in the survey.

3.8. Overall discussion

The results from this study show that for *Salmonella* and *Y. enterocolitica* the most frequent actions were focused at abattoir level, while they aimed at farm level for *Trichinella* and *C. cellulosae*. However, regarding *Salmonella*, Finland, Norway and Sweden have demonstrated the possibility of successful farm level interventions that have been in place since 1995. These include heat-treatment of feed and breeding with *Salmonella*-free pigs, starting from the top of the breeding pyramid (Nesbakken et al., 2019). The *Salmonella* HEIs 1–4 as proposed by EFSA (Fig. 1) are implemented in these three Nordic countries. All these precautions contributed to the effective control of *Salmonella*, which led to Regulation (EC) No 1688/2005 (European Commission, 2005a), to prevent the import of contaminated meat and to maintain a low prevalence of *Salmonella*. Another factor essential for the success of measures in these countries is the interaction between both levels, farm and abattoir. In Norway, there is traditional cooperation between farmers, FBOs at abattoirs and CAs (Nesbakken et al., 2019).

A future RB-MSAS is designed specifically to utilise this kind of longitudinal integration along the food chain (Ferri et al., 2023). RB-MSAS is a flexible and dynamic management system informed by risk assessment, and encompasses all actions applied at pre-harvest and harvest phases of the meat chain that contribute to chilled carcass and organ safety (Blagojevic et al., 2021). It is characterised by the following key components: i) food chain information, ii) harmonised epidemiological indicators enabling risk categorisation of farms and abattoirs, iii) risk-based meat inspection, iv) additional diagnostics (e.g., computer-based vision systems, meat juice serology, etc.) and v) additional reactive interventions (chemical decontamination, freezing etc.). Current studies on the RB-MSAS describe the integration of more harmonised and advanced FCI, including HEIs or the information gained from them, as the way forward to continuously improve public health (Blagojevic, 2019; Blagojevic et al., 2021; Bonardi et al., 2021; Buncic et al., 2019; Ferri et al., 2023; Nastasijević et al., 2020). On the path to establishing a RB-MSAS, all parties, their knowledge, needs and requirements should be incorporated in building an effective system (Alban et al., 2020; Blagojevic et al., 2021). The motivation and willingness of FBOs to participate are crucial for its success (Garforth, 2015). However, it will take more training, support and trust on both sides to successfully implement the RB-MSAS (Alban et al., 2020; Garforth, 2015). Considering cost effectiveness, but also for a more appropriate future RB-MSAS, it makes sense to rely on combined systems, e.g., farm categorisation for more than one pathogen, or testing for multiple pathogens, if possible, at the same stage and with the same diagnostic method or sample material (Alban et al., 2020; Loreck et al., 2020). Finally, the monitoring and diagnostic criteria should be harmonised to improve RB-MSAS's applicability and to enable better comparisons of the information this system provides. HEIs are a pivotal component of the RB-MSAS, as they enable the categorisation of farms and abattoirs based on their associated risk levels. Through the utilisation of predefined HEIs, it becomes feasible to determine the risk level of animal batches. However, to achieve the intended purpose of risk categorisation, the implementation of combined HEIs is of paramount importance. Exclusively considering individual HEIs would limit the assessment to a single aspect, e.g., HEI 6 *Salmonella* for pigs, which solely focuses on process hygiene.

In our study, we found that raising awareness, farm categorisation and providing feedback to the farms were the most commonly implemented measures in response to identified risks. However, it is interesting to note that abattoir categorisation was significantly less frequently adopted as a risk mitigation measure, despite it being one of the main reasons for using HEIs as proposed by EFSA (2011). Notably, Salines et al. (2023) discovered that none of the examined European countries has implemented HEIs in abattoir categorisation. Moreover, the methods used for abattoir categorisation often deviate from EFSA's recommendations and lack a clear scientific and risk-based basis (Salines et al., 2023).

Regarding farm categorisation, our findings showed that it primarily involved retrospective categorisation of herds, frequently conducted through serological examinations of meat juice samples. On-farm monitoring, which enables the categorisation of the current herd and facilitates the exchange of information from farm to abattoir, was reported to be rarely performed by the respondents. In order to accurately assess the risk associated with biological hazards, it is crucial to consider their prevalence at critical points in the food chain (EFSA, 2011). One significant area of focus is on-farm, as it can be a pivotal stage where the risk is initially generated (EFSA, 2011). The prevalence of the hazard within the animal population serves as a fundamental epidemiological indicator for evaluating the associated risk (EFSA, 2011). However, the retrospective risk categorisation of farms, predominantly conducted at abattoir level, as commonly observed for *Salmonella* in Germany, for

example, (QS-Salmonellenmonitoring, 2023), reveals certain limitations. A closer examination of the German approach highlights a notable emphasis on category III farms, where mandatory improvement measures must be implemented (Anonymous, 2007). Conversely, category I and II farms are often led to believe that no additional measures are necessary, potentially fostering a laissez-faire attitude (Blaha, 2017). Consequently, such farms are at an increased risk of rapidly descending into category III, perpetuating the prevalence of *Salmonella* instead of reducing it (Blaha, 2017). In order to efficiently manage and reduce the occurrence of food-borne biological hazards, it is crucial to implement a comprehensive system, such as MoSSs, along with appropriate risk-reducing measures at all stages of the food chain, starting at farm level. Moving forward, it is necessary to re-evaluate the suitability of EFSA's HEIs to ensure their effectiveness and to identify if any adjustments are required.

4. Conclusion

In general, 88% of the respondents stated that monitoring for *Salmonella* takes place, as did 10% for *Y. enterocolitica*, 2% for *T. gondii*, 90% for *Trichinella* and 31% for *C. cellulosae*. According to our analysis of respondents' answers, the monitoring and sampling conducted to perform examinations for *Salmonella*, *Trichinella* and *C. cellulosae* are based on statutory diagnostics required within meat inspection. For *Salmonella*, this is testing carcasses before chilling as a PHC according to Regulation (EC) No 2073/2005, which corresponds to *Salmonella* HEI 6. In the case of *Trichinella*, it is testing by the tissue digestion method according to Regulation (EU) 2015/1375, which corresponds to *Trichinella* HEIs 1, 2 or 4. *C. cellulosae* is determined within the regular meat inspection according to Regulation (EU) 2019/627, which almost corresponds to the *C. cellulosae* HEI, but requires the addition of PCR confirmation. Most of the other HEIs are either not implemented at all or are implemented by less than 10% of the respondents, with the exception of *Salmonella* HEI 7 (40%). The results not only show a lack of implementation of HEIs for pigs, but also reveal some concerning irregularities within the obligatory monitoring required by EU regulations. Several respondents show a lack of understanding with regard to diagnostic procedures, particularly for *Salmonella*. These respondents do not match the sample materials to the right diagnostic methods or vice versa. Overall, 32% of the respondents who work in EU MSs test for *Salmonella* but do not comply with the PHC (which is legally required), while another 10% of respondents who work in EU MSs do not test at all.

A major tool of the RB-MSAS is risk categorisation of farms. Although this is often mentioned by respondents as a consequence of positive findings, when asked about on-farm monitoring, respondents state that these are not implemented. We conclude that HEIs for pigs are underutilised throughout Europe. HEIs provide valuable data and they should be integrated into FCI. Successful establishment of a RB-MSAS, including the implementation of HEIs, requires the exchange of information between actors at different production stages in both directions, as well as the integration, training and acknowledgement of the professionals tasked with implementing HEIs within a RB-MSAS.

CRediT authorship contribution statement

Ting-Ting Li: Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Susann Langforth:** Investigation, Writing – review & editing. **Nina Langkabel:** Investigation, Writing – review & editing. **Smaragda Sotiraki:** Conceptualization, Methodology, Writing – review & editing. **Sofia Anastasiadou:** Methodology, Writing – review & editing. **Truls Nesbakken:** Conceptualization, Methodology, Writing – review & editing. **Diana Meemken:** Conceptualization, Methodology, Project administration, Supervision, Writing – review & editing, All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

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

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodcont.2023.109954.

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