



HAL
open science

Controlling hepatitis E virus in the pig production sector: Assessment of the technical and behavioural feasibility of on-farm risk mitigation strategies

Charlotte Teixeira-Costa, Mathieu Andraud, Nicolas Rose, Morgane Salines

► To cite this version:

Charlotte Teixeira-Costa, Mathieu Andraud, Nicolas Rose, Morgane Salines. Controlling hepatitis E virus in the pig production sector: Assessment of the technical and behavioural feasibility of on-farm risk mitigation strategies. Preventive Veterinary Medicine, 2020, 175, pp.104866 -. 10.1016/j.prevetmed.2019.104866 . hal-03488615

HAL Id: hal-03488615

<https://hal.science/hal-03488615>

Submitted on 21 Jul 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

Controlling hepatitis E virus in the pig production sector: assessment of the technical and behavioural feasibility of on-farm risk mitigation strategies

Charlotte Teixeira-Costa¹, Mathieu Andraud¹, Nicolas Rose^{1,*}, Morgane Salines¹

¹ANSES, French Agency for Food, Environmental and Occupational Health & Safety,
Ploufragan-Plouzané-Niort Laboratory, 22440 Ploufragan, France

* corresponding author: nicolas.rose@anses.fr

Abstract: Hepatitis E virus (HEV) is a zoonotic agent with pigs as the main reservoir in industrialised countries. Recent studies conducted on pig farms, in experimental conditions or through modelling approaches, have led to a better understanding of the spread of HEV on pig farms. The findings have also made it possible to define a set of measures to reduce HEV prevalence and the risk of marketing contaminated products. The objective of this study was to assess the feasibility of a set of HEV control strategies on pig farms. Individual semi-structured interviews were conducted with farmers, veterinarians and farming advisors to collect general data, their level of knowledge of HEV, their opinion on the technical feasibility of certain changes in practices, their perception of the respective responsibilities of the different stakeholders, and their feelings about the importance of the issue, following the framework of the Theory of Planned Behaviour. The interviews made it possible to highlight potential barriers and preferred motivators for the implementation of on-farm risk mitigation strategies. Barriers included lack of knowledge, scientific gaps, perceived inability to control

HEV, and low perception of the importance of the issue. Motivators included professional satisfaction, family recognition, and the opportunity to achieve higher quality standards. Three clusters of stakeholders were also identified, with a group of leaders who could help unlock reluctance and disseminate innovations. This type of behavioural approach appeared useful to help risk managers facilitate zoonotic control on pig farms.

Keywords: decision-making process; disease control; foodborne zoonosis; hepatitis E virus; mixed methods; pig production sector; Theory of Planned Behaviour

Highlights

- An interview-based study was done to assess the feasibility of HEV on-farm control.
- Farmers, advisors and veterinarians were all willing to participate in HEV control.
- Lack of knowledge, scientific gaps, and inability to control HEV were barriers.
- Family recognition, opportunity for higher quality standards would be motivators.
- A cluster of potential leaders would help engage stakeholders in such a programme.

1. Introduction

Hepatitis E virus (HEV) is a non-enveloped single-stranded RNA virus that can cause acute or chronic hepatitis (Emerson and Purcell, 2003; Kamar et al., 2011; Choi et al., 2018). In many industrialised countries, a number of locally acquired cases have been linked to the consumption of raw or undercooked pork products, especially those containing liver in high proportions (Moal et al., 2012; Renou et al., 2014; Guillois et al., 2016; Pavio et al., 2017).

Several risk factors for the presence of HEV in the liver of slaughtered pigs have been found at the individual or the farm scale through field studies, experimental trials, or modelling approaches. They are related to the farm size, type of production (e.g. free-range or organic versus conventional farming), batch management system (e.g. one week versus three week between-batch interval), biosecurity measures (e.g. absence of a hygiene lock, no quarantine sector), farming practices (e.g. cross-fostering and mingling practices), farm health status regarding intercurrent pathogens affecting pig immunity (e.g. porcine circovirus type 2 (PCV2), and porcine respiratory and reproductive syndrome virus (PRRSV)) (Li et al., 2009; Jinshan et al., 2010; Hinjoy et al., 2013; Walachowski et al., 2014; Lopez-Lopez et al., 2018; Salines et al., 2019a; Salines et al., 2019b; Salines et al., 2019c). To our knowledge, no systematic HEV control or surveillance programme has been implemented in the European pig production sector to date (Salines et al., 2017a). Potential control measures could be suggested based on these recent findings in order to design a risk mitigation plan limiting on-farm HEV spread and persistence, and thus the presence of HEV in foodstuffs. However, the effective implementation of these upstream measures would rely on stakeholder involvement, primarily farmers, but also their direct professional environment, i.e. farming advisors and veterinarians. Their commitment would depend on a combination of several external and internal factors that are crucial to understand in order to motivate them to change. The literature contains extensive reports on factors that influence farmer decision-making, particularly about animal or public health issues, and these factors are not only based on policies, economics, or rational judgments (Edwards-Jones, 2006; Ritter et al., 2017). First, individual characteristics such as age, sex, education, personality, previous experiences, routines, family influences, etc. can affect a farmer's opinions on animal health and prevention and control strategies, as well as their decision-making (Racicot et al., 2012; Wilson et al., 2015; Frössling and Nöremark, 2016). Farmers also need to have sufficient

knowledge about the disease and management strategies to make effective changes (Benjamin et al., 2010; Ellis-Iversen et al., 2010; Racicot et al., 2012; Ritter et al., 2015). In the specific case of HEV, farmer knowledge has been shown to be quite low, according to the results of our previous survey (Salines et al., 2018). The impact of the disease on animal health and/or on the farm's economic performance can also motivate farmers to take steps towards disease control and prevention (Alarcon et al., 2014). HEV spreads on pig farms without leading to any clinical signs in pigs or causing financial losses, meaning that awareness of the problem among farmers may be low. Another interesting point is that the threshold at which an issue becomes an actual problem depends on a farmer's frame of reference, itself often influenced by the farmer's descriptive and injunctive norms and previous experiences (Jansen et al., 2010; Jansen et al., 2016). It has also been shown that the farmer's evaluation of a problem is not performed according to an absolute scale, but rather in relation to other issues that also require their efforts (Leach et al., 2010a; Bruijnis et al., 2013; Horseman et al., 2014). The overall farming context is therefore an important factor to consider: laws and regulations, market prices, consumer demands, cues and nudges, etc. (Ritter et al., 2017). A farmer's perception of their own responsibility in dealing with the problem has also been identified as a key factor in their motivation, especially for zoonotic pathogens raising concerns about consumer health or consumer perception of the production sector's quality (Sorge et al., 2010; Nielsen, 2011; Toma et al., 2015). Other internal incentives can include professional satisfaction, reputation, family recognition, etc. (Leach et al., 2010b; Bruijnis et al., 2013; Alarcon et al., 2014; Roche et al., 2015). The efficacy and the cost-effectiveness of recommended strategies, as well as their feasibility and practicality, are also known to be strong drivers for farmers to adopt recommended disease prevention and control measures (Gunn et al., 2008; Valeeva et al., 2011; Garforth et al., 2013; Alarcon et al., 2014; Toma et al., 2015). Regarding the farmer's professional environment, several studies have shown that

veterinarians and farming advisors play a significant role in spreading information and motivating farmers to adopt best management practices (Alarcon et al., 2014; Laanen et al., 2014; Marier et al., 2016; Mahon et al., 2017; Poizat et al., 2017). However, their own mindset and opinions, for example on the effectiveness of control and prevention measures, and self-efficacy, in other words their belief in their ability to perform a behaviour and obtain a desired outcome (Bandura, 1977), have only been partially explored so far (Ritter et al., 2017; Hidano et al., 2018).

In this context, and with the goal of providing risk managers with tangible and pragmatic information for decision-making, the aim of our study was to evaluate the technical and behavioural feasibility of on-farm HEV control measures from the perspective of pig farmers, advisors and veterinarians through semi-directed interviews.

2. Materials and methods

2.1. Survey design

2.1.1. Survey methodology

The three categories of stakeholders (farmers, veterinarians and farming advisors) were interviewed using semi-structured questionnaires designed with a similar framework. Farming advisors are considered as technicians helping farmers in all farming aspects but health (farming practices, genetics, feed, etc.). First, several questions were asked to gather general data and, for farmers, a mind map was used as a tool to collect farm characteristics. Then, the

conversation was directed to address three key points. The first two were the level of knowledge of the interviewees regarding HEV, and their practices and possible changes. For the second aspect, the interviewees were first asked to describe the structure and the management of their farm or of their clients' farms, then if it would be possible to change some of their practices and why/why not. Several possible changes in practices were assessed: type of housing facilities for gestating sows, cross-fostering practices at farrowing, mingling practices at weaning, management of intercurrent pathogens (PRRSV, PCV2), HEV screening of the herd and of slaughtered pigs, and potential HEV vaccination in the event a vaccine was available. The third key point was their attitude towards HEV in the pig production sector: their opinion in terms of control measures, their willingness to pay for them, and their opinions on the responsibility of the stakeholders in addressing the problem. The interview was concluded with general questions about the individual's characteristics (e.g. age, sex, education, personality, previous experiences, etc.). Throughout the interview, open-ended questions alternated with several types of closed-ended questions (binary questions, graduated questions on a Likert scale, multiple-choice questions), according to a logical and consistent process. Eight questions were part of the framework of the Theory of Planned Behaviour, which states that the intention to adopt a behaviour depends on perceived behavioural control, norms and attitudes (Ajzen, 1991) (Figure 1). Moreover, brief information on HEV was also provided to enable interviewees to answer the questions in an informed way.

2.1.2. Sample selection

With the objective of leading deep interviews with a variety of actors, the desired sample size was estimated to 15 farmers, 10 farming advisors and 10 veterinarians. Stakeholders were

sampled as follows: (i) First, producer organisations and veterinarians were asked to provide a list of farmers representing different types of farms (e.g. multiplication farms, nucleus, farrow-to-finish farms, etc.), and following several types of quality charts. All sampled farmers were located in the Western part of France, the main area of pig production in the country. (ii) Then, farming advisors were selected from the main producer groups in Western France. (iii) Finally, veterinarians specialising in pig health and who practiced as liberal practitioners or employees of different companies were sampled. In all, 59 farmers, 12 farming advisors and 26 veterinarians were included in the contact list.

2.1.3. On-site interviews

Interviews were held from April to June 2019. They were grouped, as far as possible, by geographical area. The appointments were made by email or by telephone. The interviews were preferably held face to face, but some were carried out by telephone for practical reasons. The questionnaire was not sent to the participants prior to the interview and all professionals were investigated in the same way. With the participant's agreement, the conversations were recorded while notes were taken. All the interviews were conducted by the same interviewer, which allowed answers to be compared and avoided information bias.

2.2. Data analysis

The interviews were transcribed in order to carry out a qualitative analysis of the interviewees' comments and to include verbatim in the results. The quantitative data from the interviews were recorded in an Access database. In addition, the distribution of the responses

to graduated questions was represented by boxplots. Since we chose to apply the Theory of Planned Behaviour, the effect of seven explanatory variables on the outcome variable 'behavioural intention' (question: “Would you be willing to participate in an HEV control programme?”) was analysed by Spearman correlation tests (univariate analysis) and a principal component analysis (PCA, multivariate analysis), followed by hierarchical clustering (HC). The seven explanatory variables were divided into three groups: (1) variables representing attitudes towards the behaviour (“Would controlling HEV be satisfactory?”, “Do you feel directly concerned by this issue?”, “Do you think that better managing pig health would mitigate the risks for human health?”), (2) variables describing the effect of subjective norms (“Would your relatives want you to participate in an HEV control programme?”, “Is hepatitis E an important issue for human health?”, “Is hepatitis E an important issue for the pig production sector?”), and (3) variables related to perceived behavioural control (“Do you feel able to control HEV?”). The statistical analyses were carried out using R software (R 3.5.1).

3. Results

3.1. Features of the study sample

A total of 11 veterinarians, 10 farming advisors and nine farmers agreed to participate in the study (Table 1). Of the 30 interviews, five were conducted by telephone. The majority of the interviewees were men, with a wide age range, and all were specialised in pig production only. The respondents were mainly located in North-Western France, except three

veterinarians working in the North and South-West regions of the country. The interviews lasted on average one hour, with a maximum of 2h24.

Table 1. Interviewee and interview characteristics

	Farmers	Farming advisors	Veterinarians
Number of interviews	9	10	11
(of which telephone interviews)	(1)	(0)	(4)
Average age [range]	47 [29-57]	41 [26-55]	47 [36-56]
Sex ratio (men:women)	8:1	8:2	10:1
Average duration (min) [range]	62 [45-90]	60 [45-75]	81 [45-144]

The farmer sample included two multiplication farms, four production farrow-to-finish farms, two farrowing farms and one post-weaning farrowing farm. These farms were managed according to a 4-, 5-, 7- or 10- batch management system. The number of sows ranged from 85 to 600 (mean: 283), and the number of fattening pigs ranged from 560 to 5,000 (mean: 2,350).

When asked about several potentially worrying aspects of pig farming, farmers gave particular importance to human resources, explaining that they experienced difficulties in recruiting skilled employees, which was confirmed by veterinarians (Figure 2). Farming advisors and veterinarians attributed high scores to animal health and external health threats.

Regarding the interviewees' knowledge of HEV, high within- and between-group diversity was observed. All surveyed veterinarians, half of the interviewed farming advisors and one farmer had previously heard of HEV, but their knowledge about the virus was variable.

The feasibility of several practices' modifications was then investigated (corresponding to the second key point of the questionnaire).

3.2. Would it be feasible to...

3.2.1. ... house gestating sows in smaller groups?

Three of the nine surveyed farmers housed their gestating sows in large pens (more than 15 sows per pen) and stated that changing this housing system to a more segregated one would be impossible. In fact, it would require significant structural changes that would be too costly. A veterinarian also explained: *“There are many of them, and in particular on the largest farms, where the size of the groups is much larger and reviewing the management of these farms by moving from large groups to small groups is probably totally unthinkable given the constraints of the buildings”*. Moreover, some farmers explained that they recently changed this structure to meet welfare requirements. Veterinarians and farming advisors had various opinions regarding welfare criteria for gestating sows: for some of them, housing sows in smaller groups would help reduce competition thanks to a more quickly established hierarchy, and would improve food and health monitoring. For others, large pens would reduce locomotor disorders and decrease competition thanks to increased escape possibilities.

3.2.2. ... have safer mingling practices?

All the veterinarians and farming advisors interviewed stated that they already recommend that farmers reduce cross-fostering and mingling of weaned piglets for the beneficial effect of

these practices on other diseases. They therefore believed that reducing these practices to lower the risk of HEV would be feasible in the medium to long term. However, they explained that limiting cross-fostering could sometimes be difficult given the genetic evolution towards increasingly prolific sows: *“Five to six years ago, we were weaning between 11.5 and 12 piglets; today, I see farms with 15 or more weaned pigs. At some point, with this level of prolificacy, they have to homogenate the litter sizes”*, said one veterinarian. Farmers, for their part, claimed that they already limit these practices, even though a 10% cross-fostering threshold would be difficult to meet because of the need to maintain the technical and economic performances of the farm. Regarding mingling practices of weaned pigs, the farmers interviewed housed on average 28 [14-34] pigs per nursery pen; four of them housed more than 30 pigs per pen. When these farmers were asked whether it would be possible for them to make smaller nursery pens, half agreed that it would be possible.

3.2.3. ... improve management of intercurrent pathogens?

It has been demonstrated that co-infection with PRRSV and/or PCV2 increases the risk of HEV. Only one veterinarian believed that this knowledge would encourage farmers to take action to better manage these pathogens: *“Farmers feel responsible. They want to feed people safely, so it’s an argument that could be presented to them, it would only increase their motivation”*, explained this veterinarian. Half of the farming advisors also thought that this could be an additional argument to convince farmers to take action against PRRSV and/or PCV2. One of them said: *“Yes, it could be another reason to convince them to take action if they have not already done so, but it is up to us to communicate on this too”*. The other veterinarians and farming advisors did not consider it necessary to specifically increase the management efforts already undertaken for intercurrent pathogens for the sole reason of HEV

control. According to them, controlling HEV would not be sufficient incentive to motivate farmers: if farmers take measures to better manage PRRSV/PCV2, it would be for their direct technical and economic consequences, not for their impact on HEV dynamics.

3.2.4. ... screen for HEV on the farms and in slaughtered pigs?

If there were a readily available routine test, six out of 11 veterinarians and seven out of 10 farming advisors would be interested in using it. Five of the interested veterinarians and all advisors would encourage farmers to test their animals. However, opinions differed regarding the type of farms that should be tested as a priority. One of the veterinarians explained that *“the most sensitive part will be the part that is directly related to human consumption, so that’s the fattened pigs, meaning we should test farrow-to-finish farms or finishing farms or post-weaning finishing farms, as long as they sell finished pigs”*. Nevertheless, the majority of the veterinarians stressed the importance of starting at the top of the pyramid, i.e. of testing nucleus farms and multipliers: *“I would start by cleaning up the top of the pyramid, you see, nucleus, multipliers, if we want to try to limit the introduction of shedders, [...] because it is true that they are the most at-risk of disseminating HEV”*. Seven out of nine farmers would be interested in testing their farm for HEV in order to know their status. Nevertheless, all of them said they would like this test to be free of charge. The two farmers who did not wish to know the status of their farm mentioned the fear of diagnosing a new disorder in their animals that they cannot treat: *“By searching, we always end up finding”*, one of them added.

Most of the interviewees did not support screening of animals entering a farm for various reasons: (i) the objectives of such screening were still unclear for them, as one advisor stated: *“if the farm is positive, this may not change much, and since this involves healthy carriage, all farms are equally likely to be positive”*, (ii) the cost may be charged to farmers instead of

slaughterhouses, and (iii) these screenings could only be considered as a collective approach, otherwise some farmers would not be able to sell their positive animals.

Seven out of 11 veterinarians and eight out of 10 farming advisors would recommend screening livers at slaughter: *“In my opinion, an important control point would be to screen for the presence of the virus in livers that are intended for human consumption”*, said one veterinarian. Four out of nine farmers also mentioned that it would probably be beneficial to test the livers and sort them before processing, which would limit the constraints for farmers. The other farmers considered that they are not directly concerned by this question since it is related to the downstream part of the chain; they even explained that they do not know what the livers are used for.

3.2.5. ... vaccinate pigs against HEV?

If a vaccine against HEV were available for pigs, four out of 11 veterinarians and eight out of 10 farming advisors believed that farmers might be willing to vaccinate their animals because it is a human health issue: *“the utility is for the pork sector and for public health, so [...] they would be willing to vaccinate if they were told to vaccinate”*, explained a veterinarian.

Developing a multivalent vaccine would also facilitate vaccination, as well as financial support for the vaccine. According to these respondents, vaccination should also be part of a *“collective approach”*, with for example the development of a sub-sector providing HEV-free livers for liver-based products, and better payment for the farmers involved in this kind of production. On the contrary, the others considered vaccination unthinkable, particularly because of the asymptomatic nature of the infection in pigs: *“Honestly, I think [farmers] would only do so if it became mandatory, if it were part of a public health or other approach”*, said one farming advisor. Nevertheless, four out of nine farmers said they would

be willing to vaccinate despite the fact that there are no symptoms in pigs, because this is a human health issue. For the other five, vaccination against HEV would not be feasible given the cost of vaccines, the additional workload involved, and the absence of symptoms of infection in pigs.

3.2.6. ... create a specific chain dedicated to the production of liver-based products?

Unanimously, the veterinarians were in favour of organising such a sub-sector, provided that farmers derive added value from it: *“It could probably be another type of outlet [...], it is true that today the marketing of livers is nil or almost nil [...], it would certainly be an economic plus”*, said a veterinarian. The opinion of advisors was similar, only one seemed reluctant about this idea because, according to him, it would not be of benefit to the farmer: *“it would be more the responsibility of the slaughterhouse to sort the livers and to certify them as HEV-free”*. All veterinarians and farmers stressed that it would be necessary to better pay farmers who would move towards this free status, otherwise they would not be interested. All the interviewed farmers were interested in this HEV-free qualification for various reasons: high interest in taking part in HEV control, new outlet, market diversification, and professional development. All but one confirmed, however, that better remuneration would be necessary. One farming advisor explained that producing HEV-free pigs would be a relevant marketing differentiation factor for the French market, as opposed to other large producers. However, five farmers out of nine feared competitive distortion in the case of new standards or regulatory constraints forcing them to adopt more expensive farming practices.

3.3. Assessment of factors affecting interviewee willingness to participate in an HEV control programme

3.3.1. Descriptive results (Figure 3)

Overall, the interviewees stated their willingness to participate in an HEV control programme, provided they would not act alone, as stated by a veterinarian: “*Yes, as part of a collective control plan*”. The willingness to participate was higher for veterinarians (average score: 5.8/7) than for the other groups (farmer score: 4.6/7; advisor score: 4.5/7). High within-group variability was found regarding the stakeholders’ ability to participate in an HEV control plan, with average scores of 4.3, 3.8 and 3.9 for farmers, advisors and veterinarians, respectively. The main reason why the interviewees would not feel able to control HEV was the lack of detailed and confirmed data and of tangible evidence of the efficacy of the suggested control measures. When veterinarians and advisors were asked if, in their opinion, farmers would be able to control HEV, their answers were highly heterogeneous. Some of the interviewees believed that farmers would not be able to do this because they are unaware of the existence of this disease, and have other more important concerns. Others, on the other hand, believed that farmers would be able to do so if clear explanations were provided. Overall, the question related to the influence of the opinion relatives may have obtained high scores, with average scores of 5, 4 and 4 for farmers, advisors and veterinarians, respectively. Farmers and veterinarians said they feel directly concerned by this issue (average scores: 5 and 5.6, respectively), more than advisors (average score: 3.6). With average scores of 6 in all categories, the benefits of better managing pig health to reduce risks for human health appeared to be of high interest for all interviewees. Regarding the importance of the issue for human health and for the pig production sector, answers were highly variable and, on average,

around the middle score. This was essentially related to the rather low number of human hepatitis E cases. Farmers attributed higher scores to these two questions than the other interviewee categories.

Although some veterinarians thought that it is important not to “*turn a blind eye*” but to “*remain attentive*” because “*it is a matter of consumer health, [one] cannot ignore it*”, others pointed to the risk of being overly cautious and of stigmatizing pig farms in an already sensitive social, economic and political context: “*I mean, we’re in a context where we’re already pointing fingers at the animal sectors, so waving a small hepatitis E flag would create worry without [hepatitis E] really being potentially serious for humans*”. This risk of a media crisis was addressed by the interviewees from two opposite points of view: for some of them, the fear of a media crisis would be a positive incentive argument, which could push farmers to take an interest in the issue, while for others it would affect the entire sector negatively and lead to a crisis in consumer confidence. Among the barriers highlighted by the interviewees, the cost of implementing control measures (depending on the individual characteristics of each farm) was the major one: “*The economic aspect remains the only obstacle that often prevents us from being positive and 100% committed to control plans*”, said one of the farmers surveyed. Financial incentives could be considered, according to some of the surveyed individuals. However, interviewees found it difficult to answer all the questions related to the willingness to pay into a control programme. As a result, no conclusions could be drawn because of the high level of missing data. Unanimously, veterinarians considered themselves to be the main contact points to provide advice and information on this topic during farm visits. They mentioned the annual health check-ups, meetings, documents and social networks as good opportunities to talk about this issue. All farmers and advisors also selected the veterinarian as their main contact person.

3.3.2. Statistical analysis

The univariate analysis showed a positive association between the willingness of veterinarians to participate in an HEV control programme and the influence of their relatives' opinion (Spearman correlation coefficient = 0.75, p -value < 0.05) (Table 2). The same tendency was observed for farming advisors (CC = 0.60, p -value < 0.10). There was also a tendency for an association between the veterinarians' intention to control HEV and the value they give to improving pig health in order to reduce the risks for human health (CC = 0.60, p -value < 0.10).

Table 2. Correlation between interviewee willingness to participate in an HEV control programme and seven explanatory variables within the framework of the Theory of Planned Behaviour

CC: Spearman correlation coefficient

	Farmers		Farming advisors		Veterinarians	
	CC	p -value	CC	p -value	CC	p -value
Do you feel able to control HEV?	- 0.15	$p > 0.10$	0.33	$p > 0.10$	0.45	$p > 0.10$
Would your relatives want you to participate in an HEV control programme?	0.56	$p > 0.10$	0.60	$p < 0.10$	0.75	$p < 0.05$
Do you feel directly concerned by the HEV issue?	0.08	$p > 0.10$	0.44	$p > 0.10$	0.28	$p > 0.10$
Would controlling HEV be satisfactory?	- 0.25	$p > 0.10$	0.61	$p > 0.10$	0.28	$p > 0.10$

Do you think that better managing pig health would mitigate the risks for human health?	0.53	$p > 0.10$	0.67	$p > 0.10$	0.60	$p < 0.10$
Is hepatitis E an important issue for human health?	- 0.19	$p > 0.10$	0.24	$p > 0.10$	0.08	$p > 0.10$
Is hepatitis E an important issue for the pig production sector?	0.02	$p > 0.10$	0.42	$p > 0.10$	0.13	$p > 0.10$

The multivariate analysis (PCA followed by HC) made it possible to identify three clusters (Figure 4). The first axis was mainly represented by var4 (“Do you feel directly concerned by the HEV issue?”); the second axis was mainly represented by var6 (“Do you think that better managing pig health would mitigate the risks for human health?”) and var7 (“Is hepatitis E an important issue for human health?”). Var6 and var7 appeared orthogonal, thus independent.

The smallest cluster (cluster 1) contains one farmer, one farming advisor and three veterinarians. With high scores given to the eight questions, these interviewees were highly motivated by taking part in an HEV control programme and felt directly concerned by the issue (Figure 5). The second one gathers three farmers, six advisors and two veterinarians. They had the lowest scores to all but one question, especially to those regarding their ability to control HEV and the importance of the issue for human health and the pig production sector. However, they found particularly interesting the fact that better pig health management would help reduce risks for human health. The last one (cluster 3) hosts five farmers, three advisors and six veterinarians who had middle-range scores to most questions, and a low score concerning their ability to participate in an HEV control programme.

4. Discussion and conclusion

The primary interest of our study lies in the in-depth exploration of the potential barriers and challenges that would arise from the implementation of an HEV control programme, and in the suggestion of levers favouring stakeholder involvement in HEV management strategies. Assuming that pig farmers would be the main actors involved in the implementation of a future on-farm HEV control plan, our study was designed as a three-level survey targeting both farmers and their direct collaborators, i.e. farming advisors and veterinarians. This approach made it possible to cross-reference the views of three categories of stakeholders, working together on several technical and health issues of pig production. In this study, we decided to focus on up-stream stakeholders only, but downstream surveys would be needed to investigate the possibility of control plans at the slaughterhouse and/or processing plant levels. The sample size was deliberately small to allow for a more detailed discussion of the topics covered, hence increasing the validity of the investigation compared to short interviews which would have been necessary to achieve a larger sample size (Crouch and McKenzie, 2006; Alarcon et al., 2014). A high percentage of veterinarians (15/26) and of farmers (50/59) refused to participate in the study or did not answer to our request. Veterinarians mainly cited lack of time as a reason for their refusal. In addition to the lack of time, farmers were also reluctant to open their doors to strangers. The surveyed sample cannot be considered representative because of the non-random selection procedure. Importantly, diverse interviewee profiles were deliberately selected, for instance to ensure that different farm types and the three major French producer organisations were represented in the study. The interviewees were not nationally distributed but mainly located in North-Western France, which is the main pig production area in the country (Agreste, 2013; Salines et al., 2017b). It

is therefore worth mentioning that the sample composition is not adequate to extrapolate findings to the general French pig farmer, advisor and veterinarian populations. The respondents agreed voluntarily to participate in the study, thus suggesting that they are more involved in animal and public health issues. It is very likely that a true random sample of interviewees would have yielded few or no people with intent to be part of an HEV control programme, and it would thereby not have been able to inform our study about extrinsic and intrinsic barriers.

The interview template was designed in such a way that the interviewees were first asked to give their opinion on technical questions, which were considered simple, comfortable and non-personal, before being led to broader considerations needing personal thinking. By doing so, the interviews were conducted in a fluid manner and the questions were overall well understood. Including information points during the interview also appeared relevant. Clearly, this made it possible for the interviewees to give their opinion in an informed way and to ask for clarifications if needed. Moreover, it helped to raise their awareness of the issue and, by starting with these small-scale awareness-raising operations, we could hope that information and knowledge could be disseminated through spill-over effects. The Theory of Planned Behaviour was used as a framework for the purpose of describing the decision-making process involved in the control of HEV by farmers, advisors and veterinarians (Ajzen, 1991). This model presents several limitations, in particular the fact that it assumes that peoples' behaviour fits with a rational and systematic decision-making process, which might not always be the case in real situations. Nevertheless, this concept has already been used in several other studies dealing with risk management in animal production sectors (Gunn et al., 2008; Ellis-Iversen et al., 2010; Alarcon et al., 2014), and has enabled researchers to identify barriers to and/or drivers for disease control. In the present case, our study was designed to

identify and accurately understand behavioural determinants through the stakeholders' own perceptions. Finally, combining qualitative and quantitative analysis by alternating open- and closed-ended questions allowed for a more comprehensive assessment of the stakeholders' opinions and behaviour.

The results of this study enable us to draw a number of important conclusions concerning barriers to and drivers of the potential implementation of an HEV control programme by pig farming stakeholders. One of the major outcomes of our survey is that most participants did not appear reluctant to help tackle the HEV issue, with high scores concerning their willingness to participate in an HEV control plan (86% of answers being above the mean score). This intent to adopt HEV control measures was found to be affected by both extrinsic **(1)** and intrinsic **(2)** factors.

(1) First of all, like in the large-scale survey we conducted previously (Salines et al., 2018), the present study highlighted the lack of knowledge of HEV in all stakeholder categories. As veterinarians were identified as the main referent by the other stakeholders, they could act as a knowledge transfer channel. Other studies have shown that this lack of knowledge was one of the reasons affecting people's decision-making process, e.g. explaining why farmers did not implement biosecurity measures and certain control programmes, or adopt new technologies on their farms (Gunn et al., 2008; Benjamin et al., 2010; Ellis-Iversen et al., 2010; Alarcon et al., 2014; Ritter et al., 2015). However, although these studies demonstrated the lack of awareness of producers on current scientific research, the case of HEV appeared more complex to interpret. Even though all participants admitted their lack of knowledge about HEV, they also stressed the numerous gaps in scientific knowledge that prevent them from considering disease control in concrete terms. They would like the effectiveness of the

presented control strategies to be confirmed with more solid data, for instance on-farm tested measures. Moreover, the absence of any clinical signs or performance losses due to HEV infection in pigs was recognised as a factor that would hinder the interviewees in implementing on-farm risk mitigation strategies, as shown in other studies (Alarcon et al., 2014). Regarding the technical aspects, they were found to be closely related to the individual situation of farmers. For some of them, the required changes to their farming practices would be marginal and would not require much effort from them. For others, whose farm facilities appeared to be risky regarding HEV infection, major investments would be needed and farmers seemed reluctant to make them, as confirmed by veterinarians and advisors. Similarly, stakeholders considered it relevant to be aware of a farm's HEV status and of the HEV status in produced livers, but the participants were not in favour of systematically testing all live traded animals. This type of highly restrictive measure was considered far-fetched and impractical. Moreover, human resources were mentioned by the interviewees as a critical point in the pig farming business, meaning that farmers would have trouble affording additional labour (e.g. for an extra vaccination) or recruiting new employees. As shown in other publications, farmer evaluations of a problem are generally performed in relation to other hot topics or areas of focus that could overshadow other problems (Leach et al., 2010a; Bruijnjs et al., 2013; Horseman et al., 2014); this is currently the case for example with the external threat linked to the African swine fever virus. Economics was also one of the major themes identified consistently throughout the template, alternatively in a negative or positive manner. Interestingly, against the backdrop of global competition between markets and trading systems, farmers also expressed concern that new standards or regulations would be imposed on them, thereby distorting competition in comparison with foreign markets. For others, losing consumer confidence in the product, e.g. due to a media scare, would have far-reaching consequences. They also wished to overcome potential obstacles by turning

challenges into opportunities: to their mind, being involved in an HEV control programme would be a positive differentiating factor on the market, like other labels, which would help them and the whole production sector to move towards higher quality standards that could be financially valuable. Financial incentives could then be effective to stimulate producer enrollment in such programmes. As expressed by the survey's participants, reducing external pressure would also be achievable through a collective approach. It would mitigate the sense of isolation often felt by farmers, as described in Alarcon et al. (2014), and provide them with collective support. Being part of an organised and well-considered strategy would also help reduce potential mistrust and skepticism of stakeholders, as well as the financial and technical burden. Most of the interviewees were in favour of establishing specific HEV-free farms for the production of liver-based products. This kind of collective but targeted approach would make it possible to secure the sector, without impacting too large a number of producers. The interviewees would also need organisational and institutional support that would facilitate recommended changes. They mentioned other organised systems that are in place for the control of zoonotic pathogens, such as *Salmonella* and *Trichinella*. Interviewing actors from the downstream part of the production chain would be highly relevant to discuss this risk mitigation strategy. Segmenting slaughter and process chains to guarantee liver traceability would probably be the major obstacle to this kind of specific HEV-free production chain.

(2) The interviews also made it possible to highlight several intrinsic barriers to or, on the contrary, motivators for HEV control. In the multivariate analysis, the most discriminant variables were those related to the feeling of being directly concerned by the issue, to the influence of better pig health management on the reduction of the risk to human health, and to the importance of the issue for human health. This analysis generated three clusters of individuals. (i) One cluster gathers interviewees who did not feel able to control HEV, did not

attach particular importance to their relatives' opinions, and did not consider HEV an important issue, either for human health or for the pig production sector. This highlights the fact that, despite the probably high number of HEV infections in industrialised countries (Van Cauteren et al., 2017), the low number of actually reported cases leads to an underestimation of the importance of the disease. However, participants were highly interested in the fact that better managing pig farms would help mitigate the risk of HEV for human health. This cluster hosts mainly farming advisors and farmers. They can be considered the most reluctant group of people who would probably be the last to embrace the change. *(ii)* Another cluster contains individuals who gave middle-range scores to almost all questions, but who felt particularly unable to control HEV. This group gathers mainly veterinarians and farmers. One could say that these people would be neither reluctant to nor proactive in fighting HEV. They would probably adopt a wait-and-see approach and would be willing to participate in HEV control once the efficacy of the mentioned strategies had been proven. *(iii)* Finally, the smallest cluster contains individuals with high scores to all questions, and high motivation and self-efficacy for an HEV control plan. In particular, helping tackle the HEV issue would give them professional satisfaction and family recognition. This cluster gathers mostly veterinarians. It could be considered a group of leaders, who would take initiatives and drive change. This clustering process allowed us to identify where in the pathway to pathogen control a person – or a group of persons – is situated. Although information and awareness campaigns would be useful for all stakeholders, it could be said that involvement efforts should be focused on people in the pre-contemplation, contemplation or preparation stages of the transtheoretical model of change (Prochaska and Di Clemente, 1982; Bamberg, 2013), corresponding to the two last clusters described. Clearly, a control programme for this type of non-regulated pathogen would need to be set up incrementally, using the theories of increasing adoption rates (Vanloqueren and Baret, 2009). Leaders, for instance pairs of highly engaged

veterinarians and farmers, would help unlock reluctance, and disseminate innovations and better agricultural practices to the followers (Rogers, 2003). They should be supported in their involvement, for instance if they become committed to a niche market delivering HEV-free livers for liver-based products. Interfaces between leaders and other producers should also be encouraged, in order for these local innovations to be compatible with the dominating model (Geels and Schot, 2007; Bidaud, 2013).

In conclusion, collecting and analysing opinions from stakeholders before proposing HEV control strategies is of major importance to guarantee the successful implementation of such a plan. Our interview-based research proved to be relevant for capturing the high variation of opinions and perceptions amongst farmers, advisors and veterinarians, but also for identifying shared ideas and defining three stakeholder clusters. Our results highlighted potential hurdles (lack of knowledge, scientific gaps, perceived inability to control HEV, low perception of the importance of the issue) and preferred motivators (professional satisfaction, family recognition, opportunity to achieve higher quality standards). The importance of these intrinsic and extrinsic circumstances emphasises the need for socio-ecological behavioral models, which acknowledge and incorporate the influences of external and internal factors on a person's decision-making process. From a practical point of view, these outcomes are also likely to help risk managers facilitate the implementation of an HEV control programme by steering efforts to remove specific barriers, and thereby creating favorable conditions for zoonotic control on pig farms.

Author contributions

NR, MA and MS initiated and coordinated the project. CT and MS designed the questionnaires. CT contacted the study participants, conducted the interviews, and recorded and analysed the data. CT and MS drafted the manuscript. All the co-authors revised the manuscript and approved the final submitted version.

Funding and acknowledgments

This work was supported by the French Ministry of Agriculture and Food, and by the French Interprofessional Pork Council (INAPORC). The authors are very grateful to all the pig farmers, advisors and veterinarians who participated in the study.

Competing interests

The authors declare that they have no competing interests.

Figures

Figure 1: Framework of the Theory of Planned Behaviour (Ajzen, 1991)

Figure 2. Distribution of interviewee scores attributed to potentially worrying aspects of pig farming

Figure 3. Distribution of interviewee answers to eight questions included in the framework of the Theory of Planned Behaviour

Figure 4. Interviewee characteristics regarding behavioural determinants, as represented by a principal component analysis followed by hierarchical clustering

The first graph represents the contribution of each variable to the two dimensions. The second graph represents the contribution of each individual to the two dimensions. The third graph represents the results of hierarchical clustering with three clusters being evidenced.

Var1: Would you be willing to participate in an HEV control programme? Var2: Do you feel able to control HEV? Var3: Would your relatives want you to participate in an HEV control programme? Var4: Do you feel directly concerned by the HEV issue? Var5: Would controlling HEV be satisfactory? Var6: Do you think that better managing pig health would mitigate the risks for human health? Var7: Is hepatitis E an important issue for human health? Var8: Is hepatitis E an important issue for the pig production sector?

Figure 5. Distribution of interviewee answers to eight questions included in the framework of the Theory of Planned Behaviour depending on the cluster they belong to

References

- Agreste, 2013. Les élevages de porcs en France métropolitaine en 2010. 11 500 élevages porcins détiennent la quasi-totalité du cheptel national. Agreste Primeur 300, 8.
- Ajzen, I., 1991. The theory of planned behavior. *Organizational behavior and human decision processes* 50, 179-211.
- Alarcon, P., Wieland, B., Mateus, A.L.P., Dewberry, C., 2014. Pig farmers' perceptions, attitudes, influences and management of information in the decision-making process for disease control. *Preventive veterinary medicine* 116, 223-242.
- Bamberg, S., 2013. Processes of change. In: Steg, L., Van den Berg, A., De Groot, J. (Eds.), *Environmental psychology. An introduction*. BPS Blackwell, Oxford, 268-279.

- Bandura, A., 1977. Self-efficacy: toward a unifying theory of behavioral change. *Psychological review* 84, 191-215.
- Benjamin, L.A., Fosgate, G.T., Ward, M.P., Roussel, A.J., Feagin, R.A., Schwartz, A.L., 2010. Attitudes towards biosecurity practices relevant to Johne's disease control on beef cattle farms. *Preventive veterinary medicine* 94, 222-230.
- Bidaud, F., 2013. Transitions vers la double performance : quelques approches sociologiques de la diffusion des pratiques agroécologiques. *Centre d'Etudes et de Prospective du Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt* 63, 1-8.
- Bruijnis, M., Hogeveen, H., Garforth, C., Stassen, E., 2013. Dairy farmers' attitudes and intentions towards improving dairy cow foot health. *Livestock Science* 155, 103-113.
- Choi, M., Hofmann, J., Kohler, A., Wang, B., Bock, C.T., Schott, E., Reinke, P., Nickel, P., 2018. Prevalence and Clinical Correlates of Chronic Hepatitis E Infection in German Renal Transplant Recipients With Elevated Liver Enzymes. *Transplantation direct* 4, e341.
- Crouch, M., McKenzie, H., 2006. The logic of small samples in interview-based qualitative research. *Social Science Information* 45, 483-499.
- Edwards-Jones, G., 2006. Modelling farmer decision-making: concepts, progress and challenges. *Animal Science* 82, 783-790.
- Ellis-Iversen, J., Cook, A.J.C., Watson, E., Nielen, M., Larkin, L., Wooldridge, M., Hogeveen, H., 2010. Perceptions, circumstances and motivators that influence implementation of zoonotic control programs on cattle farms. *Preventive veterinary medicine* 93, 276-285.
- Emerson, S.U., Purcell, R.H., 2003. Hepatitis E virus. *Reviews in medical virology* 13, 145-154.
- Frössling, J., Nöremark, M., 2016. Differing perceptions – Swedish farmers' views of infectious disease control. *Veterinary Medicine and Science* 2, 54-68.
- Garforth, C.J., Bailey, A.P., Tranter, R.B., 2013. Farmers' attitudes to disease risk management in England: A comparative analysis of sheep and pig farmers. *Preventive veterinary medicine* 110, 456-466.

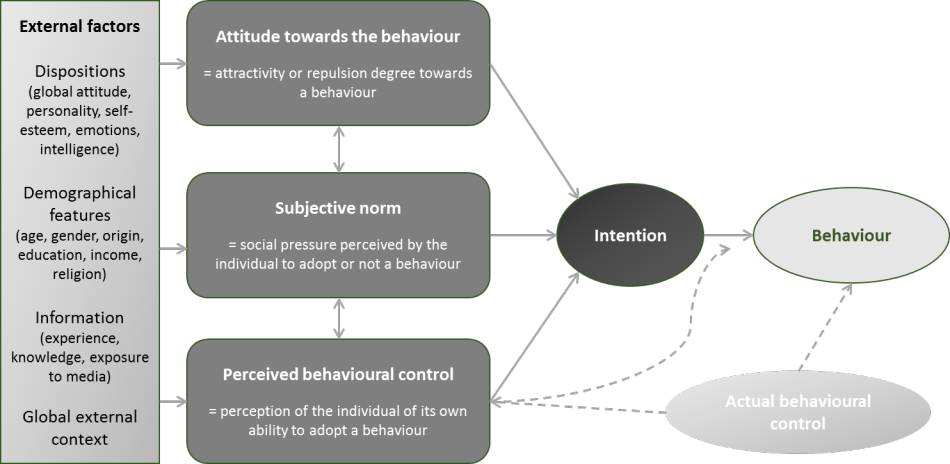
- Geels, F.W., Schot, J., 2007. Typology of socio-technical transition pathways. *Research Policy*, 399-417.
- Guillois, Y., Abravanel, F., Miura, T., Pavio, N., Vaillant, V., Lhomme, S., Le Guyader, F.S., Rose, N., Le Saux, J.C., King, L.A., Izopet, J., Couturier, E., 2016. High Proportion of Asymptomatic Infections in an Outbreak of Hepatitis E Associated With a Spit-Roasted Piglet, France, 2013. *Clinical infectious diseases : an official publication of the Infectious Diseases Society of America* 62, 351-357.
- Gunn, G.J., Heffernan, C., Hall, M., McLeod, A., Hovi, M., 2008. Measuring and comparing constraints to improved biosecurity amongst GB farmers, veterinarians and the auxiliary industries. *Preventive veterinary medicine* 84, 310-323.
- Hidano, A., Enticott, G., Christley, R.M., Gates, M.C., 2018. Modeling Dynamic Human Behavioral Changes in Animal Disease Models: Challenges and Opportunities for Addressing Bias. *Frontiers in veterinary science* 5, 137.
- Hinjoy, S., Nelson, K.E., Gibbons, R.V., Jarman, R.G., Chinnawirotpisan, P., Fernandez, S., Tablerk, P., Labrique, A.B., Patchanee, P., 2013. A cross-sectional study of hepatitis E virus infection in pigs in different-sized farms in northern Thailand. *Foodborne pathogens and disease* 10, 698-704.
- Horseman, S., Roe, E., Huxley, J., Bell, N., Mason, C., Whay, H., 2014. The use of in-depth interviews to understand the process of treating lame dairy cows from the farmers' perspective. *Animal Welfare* 23, 157-165.
- Jansen, J., van Schaik, G., Renes, R.J., Lam, T.J.G.M., 2010. The effect of a national mastitis control program on the attitudes, knowledge, and behavior of farmers in the Netherlands. *Journal of Dairy Science* 93, 5737-5747.
- Jansen, J., Wessels, R.J., Lam, T., 2016. Understanding the mastitis mindset: applying social psychology in practice. In, *Proc. National Mastitis Council 55th Annual Meeting, Glendale, AZ*, 5-15.

- Jinshan, Jirintai, Manglai, D., Takahashi, M., Nagashima, S., Okamoto, H., 2010. Molecular and serological survey of hepatitis E virus infection among domestic pigs in Inner Mongolia, China. *Archives of virology* 155, 1217-1226.
- Kamar, N., Garrouste, C., Haagsma, E.B., Garrigue, V., Pischke, S., Chauvet, C., Dumortier, J., Cannesson, A., Cassuto-Viguiet, E., Thervet, E., Conti, F., Lebray, P., Dalton, H.R., Santella, R., Kanaan, N., Essig, M., Mousson, C., Radenne, S., Roque-Afonso, A.M., Izopet, J., Rostaing, L., 2011. Factors associated with chronic hepatitis in patients with hepatitis E virus infection who have received solid organ transplants. *Gastroenterology* 140, 1481-1489.
- Laanen, M., Maes, D., Hendriksen, C., Gelaude, P., De Vlieghe, S., Rosseel, Y., Dewulf, J., 2014. Pig, cattle and poultry farmers with a known interest in research have comparable perspectives on disease prevention and on-farm biosecurity. *Preventive veterinary medicine* 115, 1-9.
- Leach, K.A., Whay, H.R., Maggs, C.M., Barker, Z.E., Paul, E.S., Bell, A.K., Main, D.C.J., 2010a. Working towards a reduction in cattle lameness: 1. Understanding barriers to lameness control on dairy farms. *Research in veterinary science* 89, 311-317.
- Leach, K.A., Whay, H.R., Maggs, C.M., Barker, Z.E., Paul, E.S., Bell, A.K., Main, D.C.J., 2010b. Working towards a reduction in cattle lameness: 2. Understanding dairy farmers' motivations. *Research in veterinary science* 89, 318-323.
- Li, W., She, R., Wei, H., Zhao, J., Wang, Y., Sun, Q., Zhang, Y., Wang, D., Li, R., 2009. Prevalence of hepatitis E virus in swine under different breeding environment and abattoir in Beijing, China. *Veterinary microbiology* 133, 75-83.
- Lopez-Lopez, P., Rivalde, M.L.A., Frias, M., Garcia-Bocanegra, I., Brieva, T., Caballero-Gomez, J., Camacho, A., Fernandez-Molera, V., Machuca, I., Gomez-Villamandos, J.C., Rivero, A., Rivero-Juarez, A., 2018. Risk factors associated with hepatitis E virus in pigs from different production systems. *Veterinary microbiology* 224, 88-92.

- Mahon, M.M., Sheehan, M.C., Kelleher, P.F., Johnson, A.J., Doyle, S.M., 2017. An assessment of Irish farmers' knowledge of the risk of spread of infection from animals to humans and their transmission prevention practices. *Epidemiology and infection* 145, 2424-2435.
- Marier, E., Piers Smith, R., Ellis-Iversen, J., Watson, E., Armstrong, D., Hogeveen, H., Cook, A.J.C., 2016. Changes in perceptions and motivators that influence the implementation of on-farm Salmonella control measures by pig farmers in England. *Preventive veterinary medicine* 133, 22-30.
- Moal, V., Gerolami, R., Colson, P., 2012. First human case of co-infection with two different subtypes of hepatitis E virus. *Intervirology* 55, 484-487.
- Nielsen, S.S., 2011. Dairy farmers' reasons for participation in the Danish control programme on bovine paratuberculosis. *Preventive veterinary medicine* 98, 279-283.
- Pavio, N., Doceul, V., Bagdassarian, E., Johne, R., 2017. Recent knowledge on hepatitis E virus in Suidae reservoirs and transmission routes to human. *Veterinary research* 48, 78.
- Poizat, A., Bonnet-Beaugrand, F., Rault, A., Fourichon, C., Bareille, N., 2017. Antibiotic use by farmers to control mastitis as influenced by health advice and dairy farming systems. *Preventive veterinary medicine* 146, 61-72.
- Prochaska, J.O., Di Clemente, C.C., 1982. Transtheoretical therapy toward a more integrative model of change. *Psychotherapy: Theory, Research and Practice* 19(3), 276-287.
- Racicot, M., Venne, D., Durivage, A., Vaillancourt, J.-P., 2012. Evaluation of the relationship between personality traits, experience, education and biosecurity compliance on poultry farms in Québec, Canada. *Preventive veterinary medicine* 103, 201-207.
- Renou, C., Roque-Afonso, A.M., Pavio, N., 2014. Foodborne transmission of hepatitis E virus from raw pork liver sausage, France. *Emerging infectious diseases* 20, 1945-1947.
- Ritter, C., Jansen, J., Roche, S., Kelton, D.F., Adams, C.L., Orsel, K., Erskine, R.J., Benedictus, G., Lam, T.J.G.M., Barkema, H.W., 2017. Invited review: Determinants of farmers' adoption of

- management-based strategies for infectious disease prevention and control. *Journal of Dairy Science* 100, 3329-3347.
- Ritter, C., Kwong, G.P.S., Wolf, R., Pickel, C., Slomp, M., Flaig, J., Mason, S., Adams, C.L., Kelton, D.F., Jansen, J., De Buck, J., Barkema, H.W., 2015. Factors associated with participation of Alberta dairy farmers in a voluntary, management-based Johne's disease control program. *Journal of Dairy Science* 98, 7831-7845.
- Roche, S.M., Jones-Bitton, A., Meehan, M., Von Massow, M., Kelton, D.F., 2015. Evaluating the effect of Focus Farms on Ontario dairy producers' knowledge, attitudes, and behavior toward control of Johne's disease. *Journal of Dairy Science* 98, 5222-5240.
- Rogers, E., 2003. *Diffusion of innovations*. Free Press, 5e ed.
- Salines, M., Andraud, M., Pellerin, M., Bernard, C., Grasland, B., Pavio, N., Rose, N., 2019a. Impact of porcine circovirus type 2 (PCV2) on hepatitis E virus (HEV) infection and transmission under experimental conditions. *Veterinary microbiology* 234, 1-7.
- Salines, M., Andraud, M., Rose, N., 2017a. From the epidemiology of hepatitis E virus (HEV) within the swine reservoir to public health risk mitigation strategies: a comprehensive review. *Veterinary research* 48, 31.
- Salines, M., Andraud, M., Rose, N., 2017b. Pig movements in France: Designing network models fitting the transmission route of pathogens. *PLoS One* 12, e0185858.
- Salines, M., Andraud, M., Terrade, F., Rose, N., 2018. Are French pig farmers and veterinarians knowledgeable about emerging foodborne pathogens? The case of hepatitis E virus. *Preventive veterinary medicine* 156, 1-7.
- Salines, M., Dumarest, M., Andraud, M., Mahé, S., Barnaud, E., Cineux, M., Eveno, E., Eono, F., Dorenlor, V., Grasland, B., Bourry, O., Pavio, N., Rose, N., 2019b. Natural viral co-infections in pig herds affect hepatitis E virus (HEV) infection dynamics and increase the risk of contaminated livers at slaughter. *Transboundary and emerging diseases*, 66, 1930-1945.

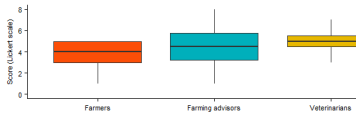
- Salines, M., Rose, N., Andraud, M., 2019c. Tackling hepatitis E virus spread and persistence on farrow-to-finish pig farms: insights from a stochastic individual-based multi-pathogen model. *Epidemics* (in press, <https://doi.org/10.1016/j.epidem.2019.100369>).
- Sorge, U., Kelton, D., Lissemore, K., Godkin, A., Hendrick, S., Wells, S., 2010. Attitudes of Canadian dairy farmers toward a voluntary Johne's disease control program. *Journal of Dairy Science* 93, 1491-1499.
- Toma, L., Low, J.C., Vosough Ahmadi, B., Matthews, L., Stott, A.W., 2015. An analysis of cattle farmers' perceptions of drivers and barriers to on-farm control of *Escherichia coli* O157. *Epidemiology and infection* 143, 2355-2366.
- Valeeva, N.I., van Asseldonk, M.A.P.M., Backus, G.B.C., 2011. Perceived risk and strategy efficacy as motivators of risk management strategy adoption to prevent animal diseases in pig farming. *Preventive veterinary medicine* 102, 284-295.
- Van Cauteren, D., Le Strat, Y., Sommen, C., Bruyand, M., Tourdjman, M., Da Silva, N.J., Couturier, E., Fournet, N., de Valk, H., Desenclos, J.C., 2017. Estimated Annual Numbers of Foodborne Pathogen-Associated Illnesses, Hospitalizations, and Deaths, France, 2008-2013. *Emerging infectious diseases* 23, 1486-1492.
- Vanloqueren, G., Baret, P., 2009. How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. *Research Policy*, 971-983.
- Walachowski, S., Dorenlor, V., Lefevre, J., Lunazzi, A., Eono, F., Merbah, T., Eveno, E., Pavio, N., Rose, N., 2014. Risk factors associated with the presence of hepatitis E virus in livers and seroprevalence in slaughter-age pigs: a retrospective study of 90 swine farms in France. *Epidemiology and infection* 142, 1934-1944.
- Wilson, L., Rhodes, A.P., Dodunski, G., 2015. Parasite management extension – challenging traditional practice through adoption of a systems approach. *New Zealand Veterinary Journal* 63, 292-300.



Animal health



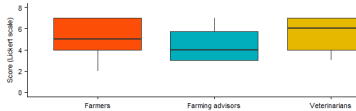
Animal welfare



External health threats



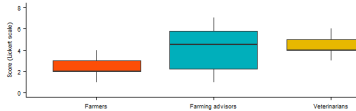
Economic context



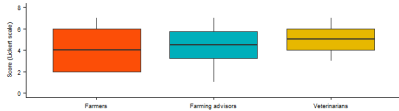
Human resources



Technical aspects



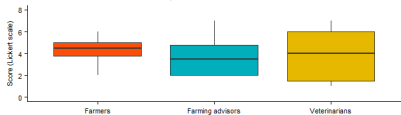
Regulatory constraints



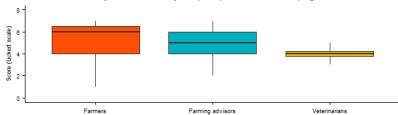
Would you be willing to participate in an HEV control programme?



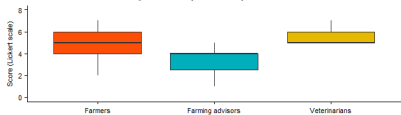
Do you feel able to control HEV?



Would your relatives want you to participate in an HEV control programme?



Do you feel directly concerned by the HEV issue?



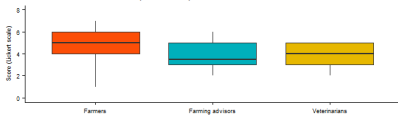
Would controlling HEV be satisfactory?



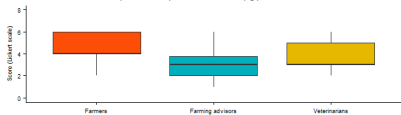
How do you perceive that better managing pig health would mitigate the risks for human health?

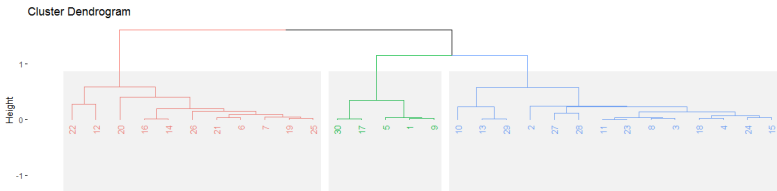
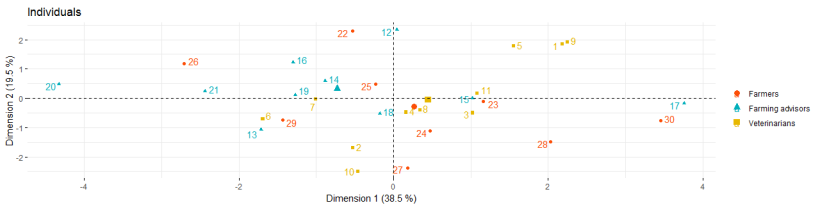
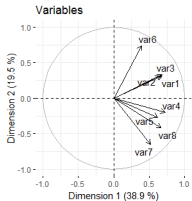


Is hepatitis E an important issue for human health?

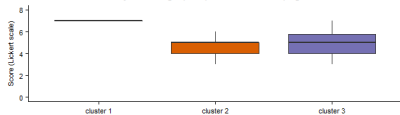


Is hepatitis E an important issue for the pig production sector?

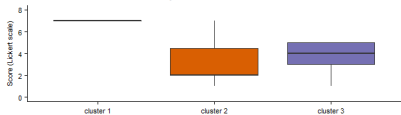




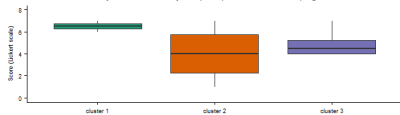
Would you be willing to participate in an HEV control programme?



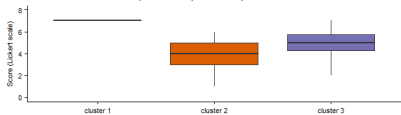
Do you feel able to control HEV?



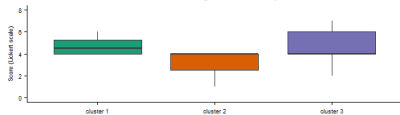
Would your relatives want you to participate in an HEV control programme?



Do you feel directly concerned by the HEV issue?



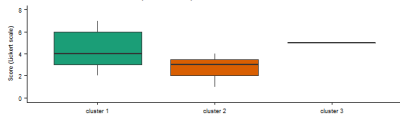
Would controlling HEV be satisfactory?



How do you perceive that better managing pig health would mitigate the risks for human health?



Is hepatitis E an important issue for human health?



Is hepatitis E an important issue for the pig production sector?

