ANSES Opinion
Request No 2016-SA-0037
Related Request no. 2016-SA-0029

The Director General

Maisons-Alfort, 19 September 2018

OPINION
of the French Agency for Food, Environmental and Occupational Health & Safety

on *Salmonella* control measures in the pig sector: review of knowledge and quantitative risk assessment

ANSES undertakes independent and pluralistic scientific expert assessments.
ANSES primarily ensures environmental, occupational and food safety as well as assessing the potential health risks they may entail.
It also contributes to the protection of the health and welfare of animals, the protection of plant health and the evaluation of the nutritional characteristics of food.

It provides the competent authorities with the necessary information concerning these risks as well as the requisite expertise and technical support for drafting legislative and statutory provisions and implementing risk management strategies (Article L.1313-1 of the French Public Health Code).

Its opinions are published on its website. This opinion is a translation of the original French version. In the event of any discrepancy or ambiguity the French language text dated 19 September 2018 shall prevail.

On 7 March 2016, ANSES received a formal request from the Directorate General for Food (DGAL) and the Directorate General for Competition Policy, Consumer Affairs and Fraud Control (DGCCRF) for an opinion on *Salmonella* control measures in the pig sector.

1. BACKGROUND AND PURPOSE OF THE REQUEST

Annex I to Regulation (EC) No 2160/2003 of the European Parliament and of the Council of 17 November 2003 on the control of *Salmonella* and other specified food-borne zoonotic agents provides for the setting of European targets to reduce the prevalence of *Salmonella* in herds of slaughter pigs and breeding herds of pigs. Prior to the setting of these targets, prevalence surveys were conducted in each Member State; in 2006-2007 for slaughter pigs and in 2008 for breeder pigs. France was ranked 6th in Europe in terms of *Salmonella* spp. prevalence in the pig sector. At the time of writing, the European targets have not yet been set.

Several studies have shown that the practices and techniques used in pig slaughter have a major impact on the prevalence of *Salmonella* spp. on carcasses. In addition, the specific procedures for certain dry-cured meats raise the question of their effectiveness in terms of product safety, in cases where processors use meat potentially contaminated by *Salmonella* spp. In 2012 and 2013, the DGAL revived the discussions held in this field in recent years and brought together all the stakeholders in the sector, in order to present the progress of work and discuss the control strategy. During the various meetings, the Interprofessional Organisation for the Pig Sector (INAPORC) and representatives of the various professional families presented a draft control programme to the DGAL.

In addition, the European Commission asked the European Food Safety Authority (EFSA) to carry out a quantitative risk assessment (QRA) of human salmonellosis associated with the presence of *Salmonella* spp. in slaughter and breeder pigs. Given the variability of data between Member States, the opinion issued by EFSA underlined the importance of using the QRA model populated with national data.

In this context, ANSES received a formal request from the DGAL and the DGCCRF to carry out the following work:

1 – Conduct a review of knowledge on the effectiveness of control measures that can be implemented in the sector and assess their impact on reducing risk to the consumer.

2 – Define priority management points, from farm to fork, to control the risk of salmonellosis for the consumer, based on integrated modelling (i.e. all the stages in the chain) inspired by EFSA's quantitative risk assessment (QRA) model (EFSA 2010b).

2. ORGANISATION OF THE EXPERT APPRAISAL

The expert appraisal was carried out in accordance with French Standard NF X 50-110 "Quality in Expert Appraisals – General Requirements of Competence for Expert Appraisals (May 2003)".

It falls within the sphere of competence of the Expert Committee (CES) on Assessment of the biological risks in foods (BIORISK). ANSES entrusted the expert appraisal to the Working Group on "*Salmonella* control measures in the pig sector". The WG met sixteen times, from June 2016 to June 2018. The methodological and scientific aspects of the work were presented to the CES BIORISK at its meetings of 16 October 2016, 20 April 2017, 10 April 2018, 15 May 2018, 19 June 2018 and 11 July 2018. It was adopted by the CES BIORISK at its meeting on 11 July 2018.

ANSES analyses interests declared by experts before they are appointed and throughout their work in order to prevent risks of conflicts of interest in relation to the points addressed in expert appraisals. The experts' declarations of interests are made public via the ANSES website (www.anses.fr).

The WG's expert appraisal was carried out in three phases. Firstly, in order to respond to the first part of the formal request (state of knowledge), the WG conducted an in-depth critical review of the scientific literature on control measures in the pig sector in France and abroad: at the farm level, during transport and lairage, at the slaughterhouse, during processing, during distribution and at the time of consumption. Control programmes set up by professionals and competent authorities were also identified.

At the same time, in order to answer to the second part of the formal request (definition of priority management points to control the risk), a review of the QRA models available since 2009 was conducted and the EFSA-QRA model was adapted to the French situation. The data to be collected were also identified.

An integrated approach to the French pig sector was adopted, and the model (called SiPFR[1]) was used to monitor changes in the prevalence of *Salmonella* infection and concentration from the farm through to the consumer's plate. The probability of human salmonellosis cases was derived using a dose-response model in SiPFR.

Lastly, the experts evaluated scenarios for the application of control measures, defined on the basis of the knowledge acquired during the in-depth literature review, and analysed priority management points by measuring the relative impact of a scenario compared to the reference scenario on reducing the number of human salmonellosis cases.

[1] SiPFR for *Salmonella* in Pig for France (EFSA 2010b).

3. ANALYSIS AND CONCLUSIONS OF THE CES BIORISK

3.1. In-depth literature review and description of the sector

The work began by describing the different stages in the pig production sector, from rearing through to manufacture of processed pork products.

3.1.1. In-depth review

To carry out this task, the WG drew on the expertise of its members and supplemented its knowledge by conducting hearings with representatives of professionals and authorities, and by visiting a pig slaughterhouse.

The control measures identified in the bibliography and grey literature were listed. For some of these measures, potential obstacles[2] to their implementation in France were identified.

The effectiveness of the control measures at their point of application was assessed through an in-depth literature review, following the methodology of the EFSA guidance document (2010a).

Out of the 1503 articles initially selected, 119 were read in depth. In order to systematically extract and process qualitative and quantitative data, a critical appraisal tool (CAT) was developed following EFSA's recommendations (2015). For each publication, the experts assigned a score based on the relevance of the impact assessment method (choice of analytical method, control/test group, population tested), assumptions, biases and overall quality of the study. This publication analysis method enabled each control measure to be assessed in a transparent and harmonised manner. The weight of evidence, which was also established for each article, enabled the uncertainty associated with the extracted data to be assessed.

Only articles with a satisfactory weight of evidence (combining the relevance of the method for assessing effectiveness with a probably or definitively low level of bias) were considered by the WG for assessing the effectiveness of the actions and their integration in the modelling process.

3.1.2. Hearing with the technical institute and representatives of professionals in the pig sector

To gain a better understanding of the diversity of practices in terms of manufacturing processes and control measures (practices, constraints, feasibility, experience in assessing the effectiveness of control measures at the different links in the chain), the WG interviewed professionals from the pig sector and the technical institute concerned.

These hearings provided an opportunity to discuss the measures currently in place and the history of the actions undertaken by the professionals. Technical and economic data were also provided to ANSES during and after these hearings.

Lastly, the WG reviewed the *Salmonella* control programmes in the pig sector set up by the other EU Member States since 2010.

3.2. Integrated modelling methodology for assessing the impact of control measures on reducing the risk of human salmonellosis

3.2.1. Choice of the QRA model

A critical review of the existing QRA models was conducted by the WG:

- the QRA model of human salmonellosis following the consumption of fresh pork meat in Belgium, derived from the METZOON project (Bollaerts *et al.* 2010).

[2] Obstacle: something that prevents the implementation of a control measure in France. There are five different types (regulatory, technological, organoleptic, economic, societal).

- the model of *Salmonella* infection in pig herds, developed by the National Institute for Agricultural Research (INRA) (Lurette *et al.* 2011, Lurette 2007): SalMoPiB v2.0 – Copyright INRA, 2011-2017 (transmitted to ANSES as part of the WG's work).

- the integrated QRA model developed by the FCC Consortium[3] for EFSA (FCC Consortium, 2010).

The approach adopted by the WG was based on the EFSA model (made available to the WG by the FCC Consortium) and included all the proposed modules. To adapt this model to the French situation, modelling work was carried out using MatLab® and Scilab® softwares.

The general modelling structure used by EFSA (2010b) was adopted for SiPFR, and is shown in Figure 1.

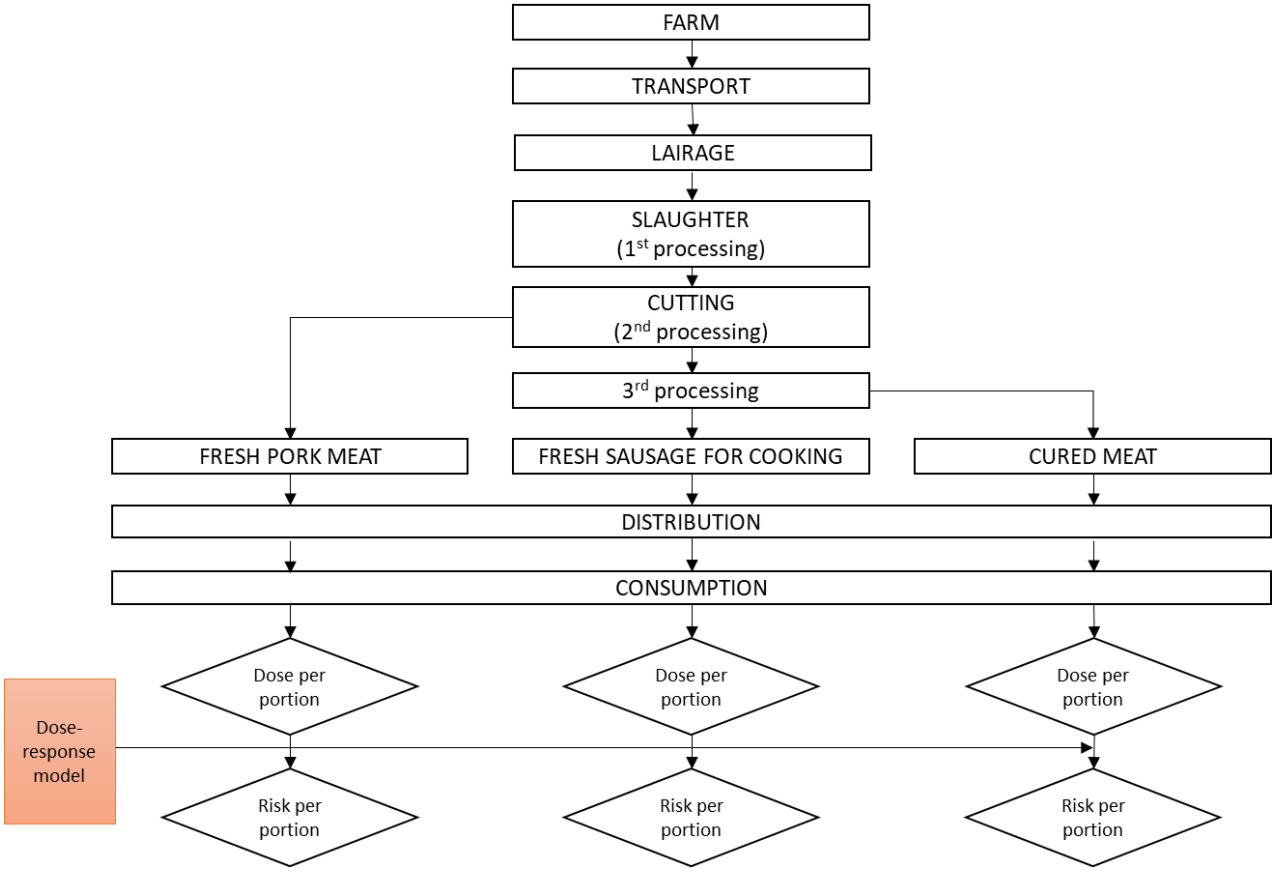

Figure 1. General structure of the model for assessing the risk associated with *Salmonella* spp. contamination in the pig sector

This model was chosen in particular because its parameters can be modified by integrating French data, along with some key elements of the modules, mainly those relating to the structure of the farms, prevalence in animal feed and intervention points.

The literature review and the hearings yielded a large amount of data useful for setting the model's parameters in order to adapt it as closely as possible to the characteristics of the French pig sector.

[3] Consortium mandated by EFSA to carry out a *Salmonella*-related QRA in breeder and slaughter pigs (FCC Consortium 2010).

The model contained 165 parameters (70 for the farm, 39 for transport and lairage, 27 for the slaughterhouse, 5 for distribution and 24 for consumption of the three types of products), which were reviewed and modified by the WG. Some of them, either very specific to the modelling assumptions or not specific to a type of sector or country, were not modified by the WG.

3.2.2.Consumption data

The consumption data used to estimate dietary exposure came from the INCA3 study (Dubuisson *et al.* 2017), the third national consumption survey conducted between February 2014 and September 2015 in metropolitan France, among 2698 children and adolescents aged 17 and under, and 3157 adults aged 18 to 79, representative of metropolitan France (excluding Corsica).

3.3. The *Salmonella* spp. hazard and sources of contamination

Under certain conditions, non-typhoid *Salmonella* is responsible for a primarily foodborne infection in humans: salmonellosis, characterised by clinical gastroenteric manifestations.

Non-typhoid human salmonelloses are zoonotic diseases. Transmission to humans occurs mainly through the consumption of contaminated food that is raw, undercooked or re-contaminated after cooking, and in which the bacterium has had the opportunity to multiply. It is estimated that 95% of infection is transmitted through food. Other transmission routes include direct, inter-human, or through contact with infected animals or a contaminated environment.

Due to the zoonotic nature of *Salmonella* spp. and their frequent involvement in cases of foodborne infectious diseases, this hazard is the focus of major surveillance efforts, both for strains causing human cases and for those isolated in veterinary medicine and in the agri-food sector. The main reservoir of *Salmonella* spp. is the gastrointestinal tract of mammals (pigs and cattle) and birds (domestic poultry).

Salmonella are classified according to their antigenic formula. The diversity of serovars is very high (more than 2600). *S.* Typhimurium is the predominant serovar in the area of food, but the relative importance of serovars varies with time and isolation sources. However, all *Salmonella enterica* subsp. *enterica* serovars should be viewed as potentially pathogenic to humans. The WG therefore chose to treat this hazard independently of the nature of the serovar, assuming that the control measures have the same effect on all *Salmonella* in the pig sector. Nevertheless, it should be noted that most of the publications in the literature review focused specifically on the Typhimurium serovar.

In France, between 2002 and 2017, thirteen foodborne disease outbreaks (FBDOs) associated with pork products were recorded.

The work presented below was carried out for the same three types of food identified as products of interest by EFSA in 2010:

- fresh pork meat, which is not processed after its preparation in a cutting plant and is cooked just before consumption;
- fresh sausage products intended for cooking;
- dry-cured products.

3.4. Control measures selected by the Working Group

The WG identified control measures currently or potentially available to professionals and managers; the results of the analysis of their effectiveness on *Salmonella* contamination are presented below.

3.4.1. *Salmonella* control measures at the farm level

The ecology and ubiquitous nature of *Salmonella* in the environment mean that they can enter a

farm in many different ways. Contamination can come from animals introduced into the farm, mainly gilts for breeder-fattener herds or piglets for fattener herds, from birds, rodents or pets, or from personnel (farmers, veterinarians, and technicians), removable equipment, vehicles circulating around the building, or visitors. Contamination can also come from drinking water or feed.

Although the studies to date have not really favoured one or other of these routes, none can be ruled out as a starting point for contamination.

Amplification of contamination involves colonisation and then excretion of *Salmonella* by animals. The ability to break the contamination cycles of consecutive batches of animals therefore requires excellent control not only of cleaning and disinfection operations, but also of the implementation of biosecurity measures, whose effectiveness should be validated. Under these conditions, depending on the level of biosecurity applied in the farm, certain contamination routes may take precedence: in a closed and adequately protected farm (e g. breeding herds where internal and external[4] biosecurity measures are strengthened), the relative importance of foodborne introduction may become predominant.

Animal feed is one of the ways in which *Salmonella* is introduced into livestock buildings. Feed is distributed to pigs in two forms (dry or wet) depending on the age of the animals. There are very few recent data on the relationship between liquid distribution (soup) and *Salmonella* contamination in animals. However, it would seem that with this type of distribution, large quantities of microbial flora become established, which are generally highly lactic and therefore relatively unfavourable to the development of *Salmonella* (Corrégé and Minvielle 2013).

The WG in charge of the linked formal request 2016-SA-0029 for issues related to *Salmonella* in animal feed (ANSES, 2018) concluded that *Salmonella* spp. contamination of plant raw materials and compound feed remains a rare event (contamination rate of around 1 to 2%). However, this contamination can lead to that of animals and their environment and, consequently, to the presence of *Salmonella* in food intended for humans. Furthermore, "it is not possible to determine from the data currently available how much of the transmission of *Salmonella* spp. between the different links in the food chain may be associated with animal feed". The application of Guides to Good Hygiene Practices (GGHP) in French establishments manufacturing compound feed and in farms is an important measure for controlling *Salmonella* in the pig sector.

Vaccination of pigs can also be an effective control measure, but its effectiveness may be limited just to the serovar targeted by the vaccine, whereas several serovars have been identified in the pig sector (in particular *S.* Typhimurium and its monophasic variant, *S.* Derby). Lastly, it should be emphasized that vaccination is not currently authorised by the French regulations.

At the farm level, three main categories of control measures can be distinguished:
- control measures involving the **physical processing** of the animal feed (soup/dry);
- internal and external **biosecurity** measures[4];
- **vaccination**.

3.4.2. *Salmonella* control measures during transport and lairage at the slaughterhouse

The loading/transport/unloading/lairage stages are sources of stress for pigs. The animals are moved to new environments and may be brought into contact with unfamiliar congeners. In *Salmonella*-carrying animals, this stress activates faecal excretion, resulting in environmental contamination in transport trucks and holding barns. The bacterium spreads through the environment and other animals are contaminated through direct contact with faeces or with the environment contaminated by them. Healthy pigs can become infected after two hours of contact with pigs

[4] Internal biosecurity: measures to reduce the spread of micro-organisms within the farm; external biosecurity: measures taken to prevent the introduction of pathogens.

contaminated by *Salmonella* spp. (Hurd *et al.* 2001).

The literature highlights the importance of **cleaning and disinfection measures** to reduce the prevalence and quantity of *Salmonella* in trucks and in the environment of slaughterhouse lairage areas. It also confirms the need to comply with the protocol involving pre-washing, cleaning with detergent, mechanical abrasion, disinfection and drying.

Despite the lack of specific publications in the review conducted by the WG, the partitioning of the storage area, the changing of clothes and the washing and disinfection of the driver's boots between each transport operation are additional hygiene measures that help limit the spread of *Salmonella*.

Regarding lairage at the slaughterhouse, the evidence points to a reduction in *Salmonella* contamination through the application of:
- a **transport time from the farm to the slaughterhouse that is as short as possible**;
- a **lairage time at the slaughterhouse** that is as short as possible (as a reminder, the regulation requires a minimum lairage period of two hours);
- **management of batches according to their serological status or faecal excretion load at the farm level** (logistic slaughter);
- **measures (cleaning and disinfection operations) to prevent the accumulation of *Salmonella* in lairage areas**.

However, the experts believe that logistic slaughter can only be effective for controlling *Salmonella* under the following conditions:
- when it is preceded by the collection of batches from the farm according to the *Salmonella* status of the animal batches to be slaughtered (collection of negative or seronegative animals at the beginning of the week or day, then of positive or seropositive animals);
- when there is separate management of negative and positive batches from the farm to the slaughterhouse (with trucks, unloading docks, and lairage pens allocated according to the status of the batch), followed by priority slaughter of negative batches;
- and when, as with the other slaughter conditions, cleaning and disinfection of storage areas, loading docks, trucks, unloading docks, lairage and slaughterhouse pens are carried out rigorously and frequently.

3.4.3. *Salmonella* control measures at the slaughterhouse

In the pig sector, at the slaughterhouse and in relation to a hazard as important as *Salmonella*, operators must implement a sanitary control plan (SCP) including good hygiene practices (GHP), procedures based on HACCP principles, traceability and management of non-conformities. They are also required to verify that the defined control measures are effective. Own-check (screening for *Salmonella* spp. on chilled carcasses) carried out according to Regulation (EC) No 2073/2005 may be used for this purpose, with a view to meeting the process hygiene criterion for this pathogen.

The slaughter stage concentrates several operations in a very short period of time (about thirty minutes), most of which are defined by regulations and which can promote either contamination or decontamination. In principle, assuming that regulatory operations are carried out in accordance with GHPs, the possibilities for further action are limited and will consist in adding optional decontamination operations that must be implemented rapidly. These operations must be effective on *Salmonella* spp. and not be subject to any regulatory and/or economic obstacles.

The evidence identified for control measures applicable at the slaughterhouse points to a reduction in the quantity of *Salmonella* through the application of:
- **double singeing,** which can ensure a 0.5 decimal reduction;
- **treatment with potassium lactate or with a solution of citric acid and sodium chlorite** (chemical treatment of carcasses at the slaughterhouse is not currently authorised);
- **washing after evisceration** and before chilling (especially with hot water).

Case of **skinning**: removing the skin from carcasses at the end of the chain seems to be an

interesting *Salmonella* control measure, but its effectiveness has yet to be validated. This technique is not or very rarely used in French pig slaughterhouses.

The experts point out that these measures can only be effective if **cleaning and disinfection operations** along this entire part of the chain (from lairage pens to cold rooms used for chilling and storage) are rigorously carried out and monitored, and in a context where slaughter operations are carried out with strict and optimised application of GHPs.

3.4.4. *Salmonella* control measures during secondary and tertiary processing

The published studies show a reduction in *Salmonella* spp. contamination when using **chemical processes** (use of **nitrites/nitrates** in certain processed products or application of a **lactic acid** solution on meat cuts or finished products). Effectiveness varies from 0.5 to 2 decimal reductions depending on the treatments used. Vacuum or modified-atmosphere packaging can also reduce the multiplication of *Salmonella* in "fresh meat" and "sausage" products.

Various measures to reduce the quantity or prevalence of *Salmonella* spp. in finished products can be applied on raw materials (meat cuts), as well as on products being manufactured and on finished products.

The control measures applied to raw materials (meat cuts) used in the manufacture of processed products help reduce the level of contamination at the start of manufacture. While the use of chemical treatments such as acids or chlorine may be effective, it is not authorised in Europe. The use of nitrites and nitrates is also covered by regulations. **High hydrostatic pressure** treatments may be permitted and are effective in reducing *Salmonella* spp. contamination.

For cured meat products that are dried or dried and fermented (e.g. raw ham, dry sausage), the manufacturing process may be a means of controlling *Salmonella*, but its effectiveness is highly dependent on the acidification and drying conditions and must therefore be validated for each manufacturing process.

3.4.5. *Salmonella* control measures during distribution and by the consumer

No articles on control measures at the distribution stage were selected during the in-depth literature review. However, there are two main levers of action: (i) storage conditions (mainly the cold chain) and (ii) control of contamination of exposed or bulk products (not protected by packaging).

After the distribution stage, the practical measures applied in out-of-home catering need to be distinguished from the more limited ones that can be applied in the home. In out-of-home catering, food is prepared in a professional setting, in principle in compliance with good hygiene and manufacturing practices. The situation is different in the consumer's home where, for example, food may be cooked according to individual tastes and/or in ways that may lead to insufficient cooking (in the case of barbecues, for example). The information given to consumers is therefore essential. It can be very specific when it appears on the product label ("cook the rib for two minutes on each side in a hot frying pan") or more generic (e.g. a "domestic hygiene" fact sheet).

3.5. Assessment of the impact of control measures and programmes on reducing the risk of human salmonellosis

Reminder: the WG chose to use the model developed for EFSA, available in Matlab®. The general modelling structure used by EFSA (2010) was retained, along with all the assumptions and biases identified in the FCC Consortium's report.

3.5.1. Calculation of the reference risk (R_{ref})

The reference risk, noted as R_{ref}, corresponds to the probability of triggering a human salmonellosis (P_{ill}) per serving of one of the three products studied. This probability was calculated without applying any intervention in the model.

3.5.2. Validation of the approach with existing data

The chosen approach was validated by the following two findings:

- The estimated prevalence at the end of each module of the SiPFR model and the seroprevalence before transport of pigs to the slaughterhouse were very close to the values observed in production.
- The number of human salmonellosis cases estimated by the model (43,000 cases) was close to the estimate (62,400 cases) derived from the epidemiological estimate by Van Cauteren *et al.* (2018) combined with the fraction attributable to the pig sector estimated by Pires *et al.* (2014).

3.5.3. Computing the relative risk

The risk under scenario R_{scex} corresponds to the number of cases of human salmonellosis following application of an intervention.

The effectiveness of the intervention scenarios was compared in terms of the percentage reduction in salmonellosis risk per serving of each product (R_{scex}) compared to the reference risk R_{ref}. The risk reduction, after applying the interventions, is given by the following formula:

$$\%\ RedRisk = \left(1 - \left({Rscex}/{Rref}\right)\right) * 100$$

3.5.4. Definition of the tested scenarios

In view of the conclusions reached for each stage in the pig sector and the uncertainty associated with quantifying the impact of the control measures identified in the literature, it was agreed to introduce levels of reduction in the prevalence (in percentage) or concentration (in number of decimal reductions) of *Salmonella* spp. into the model without indicating precisely which control measures would achieve these levels. There is therefore no unequivocal link between these reduction levels and the effectiveness of the available measures, as listed in Section 3.4.

The tested scenarios (Table 1) were as follows:

a. At the "farm" level:

- the PREVREPRO scenario tested the effect of reducing the prevalence of *Salmonella* in the breeding herd from 0.5 to 0.25;
- the SC1 scenario tested the effect of decimal reductions in *Salmonella* concentration, in log CFU/g faeces, at the end of the rearing process (from 0.1 to 2 decimal reductions);
- the ALAN0 scenario tested the impact of zero prevalence of *Salmonella* in animal feed;
- the PIL0.1 scenario tested the impact, in terms of risk reduction, if intra-batch prevalence (in the presence/absence of *Salmonella* in faeces) were reduced to 0.1;
- the AH (wet feed) scenario tested the impact, in terms of risk reduction, of feeding pigs only in wet form.

b. At the "slaughterhouse" level:

- the AL scenario (logistic slaughter) tested the impact, in terms of risk reduction, of the systematic slaughter of highly contaminated batches at the end of the day;
- the SC2 scenario tested the effect of decimal reductions in *Salmonella* concentration, in log

CFU/sampled carcass surface unit, measured after singeing (from 0.1 to 2 decimal reductions);

- the SC3 scenario tested the effect of decimal reductions in *Salmonella* concentration, in log CFU/sampled carcass surface unit, measured at the end of chilling (from 0.1 to 2 decimal reductions);
- the SC4 scenario tested the effect of decimal reductions in *Salmonella* concentration, in CFU/g product (i.e. fresh meat, sausage meat for cooking or dry sausage), before consumption (from 0.1 to 2 decimal reductions).

c. Combinations of measures:

- the SCG scenario tested the impact, in terms of risk reduction, of a 0.5 decimal reduction in *Salmonella* concentration at the end of each module (farm, slaughterhouse and consumer), combined with wet feeding at the farm and systematic logistic slaughter.
- the SCGbis scenario tested the impact, in terms of risk reduction, of a 0.5 decimal reduction in *Salmonella* concentration at the end of each module (farm, slaughterhouse and consumer).

It should be noted that not all modules were tested using an intervention scenario.

Table 1. Description of the intervention scenarios assessed

Identification of the scenario		Module and/or product concerned	Decimal reduction or prevalence
PREVREPRO		Breeding herd	P = 0.25
ALAN0		Zero prevalence in animal feed	P = 0
SC1	SC1-1	Pig/end of rearing	DR = 0.1
	SC1-2	Pig/end of rearing	DR = 0.25
	SC1-3	Pig/end of rearing	DR = 0.5
	SC1-4	Pig/end of rearing	DR = 1
	SC1-5	Pig/end of rearing	DR = 2
PIL0.1		Reduction in intra-lot prevalence to 0.1 (instead of 0.5)	P = 0.1
AH		Farm – wet feed only (100% wet feed)	
AL		Logistic slaughter (slaughter of highly contaminated batches at the end of the day)	
SC2	SC2-1	Carcass after singeing	DR = 0.1
	SC2-2	Carcass after singeing	DR = 0.25
	SC2-3	Carcass after singeing	DR = 0.5
	SC2-4	Carcass after singeing	DR = 1
	SC2-5	Carcass after singeing	DR = 2
SC3	SC3-1	Entire carcass at the end of slaughter (leaving chilling)	DR = 0.1
	SC3-2	Entire carcass at the end of slaughter (leaving chilling)	DR = 0.25
	SC3-3	Entire carcass at the end of slaughter (leaving chilling)	DR = 0.5
	SC3-4	Entire carcass at the end of slaughter (leaving chilling)	DR = 1

Identification of the scenario		Module and/or product concerned	Decimal reduction or prevalence
SC4	SC4-1	Finished product	DR = 0.1
	SC4-2	Finished product	DR = 0.25
	SC4-3	Finished product	DR = 0.5
	SC4-4	Finished product	DR = 1
SCG		0.5 decimal reduction at each module + AH + AL	DR 0.5 + AL + AH
SCGbis		0.5 decimal reduction at each module	DR = 0.5

3.5.5.Results

The observed reduction in relative risk, following implementation of the different scenarios, is shown in Table 2.

Table 2: Effect of the tested scenarios on the relative risk for the products "sausage meat for cooking", "fresh pork meat" and "cured meat"

Scenario		% Risk reduction for sausage meat for cooking	% Risk reduction for fresh pork meat	% Risk reduction for cured meat
PREVREPRO		58	53	65
ALAN0		13	11	13
AH		3	5	16
PIL0.1		75	73	70
SC1	SC1-1	3	3	10
	SC1-2	5	7	13
	SC1-3	6	7	14
	SC1-4	8	8	15
	SC1-5	11	13	17
AL		9	8	13
SC2	SC2-1	0	0	0
	SC2-2	0	6	5
	SC2-3	10	6	16
	SC2-4	12	9	17
	SC2-5	12	10	18
SC3	SC3-1	37	26	30
	SC3-2	40	26	33
	SC3-3	59	65	89
	SC3-4	76	90	99
SC4	SC4-1	4	5	7
	SC4-2	7	10	11
	SC4-3	31	31	13
	SC4-4	47	40	14
SCG		95	97	99
SCGbis		76	89	89

Thus, at the farm level (SC1), applying decimal reductions of 0.1 – 0.25 – 0.5 – 1 or 2 did not lead to major reductions in the relative risk to the consumer. For example, for cured meat products, the foreseeable reductions in relative risk to the consumer ranged from 10% to 17% depending on the decimal reduction applied. Similarly, the introduction of wet feed for pigs at the farm level (AH) or logistic slaughter (AL) did not obtain very high rates of reduction in relative risk to the consumer (e.g. 16% and 13% respectively for cured meat products). Reducing the prevalence of *Salmonella* spp. to zero in pig feed (ALAN0) did not lead to a major reduction in relative risk to the consumer (10 to 13%, depending on the products concerned). On the other hand, the scenario (PREVREPRO) providing for a decrease in the prevalence of *Salmonella* spp. in the breeder pig population from 0.5 to 0.25% resulted in a relative reduction of 53 to 65%, depending on the product.

The reduction in carcass contamination obtained after the slaughterhouse module (SC3) led to a sharp reduction in the relative risk, regardless of the product concerned; for example, for cured meats, the relative risk reduction was 30% when a 0.1 decimal reduction was applied and 99% when a 1 decimal reduction was applied. Both preventive and curative means need to be applied in the slaughterhouse to achieve these objectives, with the former aiming to minimise *Salmonella* transfers onto carcasses and the latter to inactivate any *Salmonella* that were transferred during this or previous modules. The model did not individually test each possible intervention at the slaughterhouse (except for the double singeing stage), given that a succession of operations are involved whose results are not strictly independent of the others. In addition, some potential general interventions, such as "improving the implementation and monitoring of GHPs", seem effective but are difficult to determine objectively. In addition, it is reasonable to assume that the overall effectiveness of the slaughterhouse module is not entirely independent of the efforts made in the previous modules to reduce the pressure of *Salmonella* contamination.

The scenarios combining several interventions therefore proved to be very interesting. Thus, the SCG scenario, combining wet feed, logistic slaughter and a 0.5 decimal reduction in carcass contamination at the end of slaughter operations, resulted in a relative reduction of 95, 97 and 99% respectively for sausage meat, fresh meat and cured meat products. Similarly, the SCGbis scenario, corresponding to a decimal reduction of 0.5 in each module, enabled relative risk reductions of 76, 89 and 88% respectively for sausage meat, fresh meat and cured meat products.

In conclusion, the tested scenarios showed that the proposed interventions have different consequences on risk reduction for consumers, regardless of the product concerned. Some of them, implemented individually, particularly on the "farm" module, had little influence. Others, on the contrary, applied at the slaughterhouse, enabled very significant reductions in the relative risk. Lastly, the most effective scenarios were those combining interventions applied both at the farm and at the slaughterhouse. Thus, 0.5 decimal reductions at each module (farm, transport-lairage and slaughterhouse), applied to all French pig production, would reduce the relative risk of human salmonellosis associated with the consumption of these products by 75 to 90%.

3.5.6. Taking uncertainties into account

⇨ Uncertainties related to available data on the effectiveness of control measures in the sector

The in-depth literature review conducted by the WG, which supplemented that conducted by the FCC Consortium in 2010, revealed a high level of uncertainty associated with the data on the effectiveness of the control measures, including:

- the few recent studies available;
- the non-negligible number of studies considered to have an unsatisfactory weight of evidence (mainly methodological bias);
- the lack of quantification data, in conditions other than experimental;
- the fact that many control measures and their potential effectiveness on *Salmonella* spp. were not assessed (or data for assessing their effectiveness were not available/accessible).

These observations limit the possibility of reaching a quantitative conclusion on the effectiveness associated with the control measures, and thus of identifying the levers for action to be implemented for *Salmonella* control.

Collection of the data used for the expert appraisal relied partly on extracts from publications/articles selected from the Scopus and PubMed databases, as well as on data from the WG expert members (some from the grey literature): it should therefore be noted that there may be some uncertainty associated with the non-exhaustiveness of the data collected on the effectiveness of control measures and on the model parameter values (publication bias).

⇨ Uncertainty related to the data used to model the sector and the behaviour of *Salmonella* spp.

The FCC Consortium report and the EFSA opinion published in 2010 reported a high level of uncertainty about the modelling assumptions used at that time. Through its work on the parameters, the WG has probably reduced some uncertainties regarding the model parameters, but those related to the structure and the general modelling approach remain unchanged (see the identification of uncertainties in the consortium report for details of the points identified).

Lastly, the lack of recent national surveillance data (public and private) at the different stages in the pig sector limits any interpretation and the ability to validate the model outputs, and therefore to truly conclude as to the effectiveness of the intervention scenarios tested.

3.6. Conclusions and recommendations of the CES BIORISK

3.6.1. Conclusions of the collective expert appraisal

3.6.1.1. Review of knowledge on the effectiveness of control measures that can be implemented in the sector and assessment of their impact on reducing risk to the consumer

The WG conducted an in-depth review of the publications available between 2010 and 2016: no significant technological advances in *Salmonella* control in the pig sector were identified.

The pig sector was studied according to the following modules: farm, transport and lairage, slaughterhouse and processing, consumer.

Various measures are now being taken during the stages of rearing, transport, lairage, slaughter and processing of pigs, in particular through the implementation of good hygiene practices.

The farm is the main route of introduction of *Salmonella* into the food chain. There are many vectors of introduction, but it is not possible to rank them. However, in farms with a high level of biosecurity, breeding animals and the feed distributed can be regarded as the main routes for the introduction of *Salmonella*. Thereafter, the rearing period should be regarded as a stage of multiplication and spread of *Salmonella* between animals and in the building.

For the farm component, the following control measures have a favourable impact:

- ✓ In feed:
  - liquid feed (soup) seems to provide some element of protection against *Salmonella* spp. contamination, but this type of feed cannot be distributed at every physiological stage of the animals.
  - the addition of organic acid(s) to the feed.
- ✓ The application of biosecurity measures, by referring to the GGHP in the farm.
- ✓ Vaccination: this measure is not applied in France, as it is not currently authorised. Moreover, its effectiveness would probably be limited just to the serovar targeted by the vaccine, whereas several of them predominate in the pig sector (in particular *S*. Typhimurium and its single-phase variant, *S.* Derby).

Lairage and transport to the slaughterhouse are important stages because they are stressful for the animals, causing faecal excretion, spread of *Salmonella* spp. in the environment and contamination of other animals. The following measures seem to be effective in reducing *Salmonella* spp. contamination in pigs:

- ✓ A transport time from the farm to the slaughterhouse that is as short as possible.
- ✓ The shortest possible lairage time at the slaughterhouse, provided that the two hours of rest required by the regulation are complied with.
- ✓ Logistic slaughter of animals (with batches of animals being slaughtered successively according to their level of contamination) could be advantageous, provided that:
    - it is preceded by a collection of batches from the farm according to the *Salmonella* spp. status of the batches of animals to be slaughtered;
    - there is separate management of negative and positive batches from the farm to the slaughterhouse (trucks and lairage pens allocated according to the status of the batch), followed by priority slaughter of animals recognised as free from *Salmonella* spp.;
    - cleaning and disinfection of storage areas, loading docks, trucks, unloading docks, lairage and slaughterhouses pens are carried out rigorously and frequently.

The **slaughterhouse** is a place that is favourable to the spread of *Salmonella* through tools and equipment, and through inappropriate practices, for example during evisceration accidents.
During this process, however, certain operations have a reducing effect on carcass contamination. In this respect, the following measures seem to be effective in reducing *Salmonella* contamination:

- ✓ Double singeing: 0.5 decimal reduction in *Salmonella* spp. contamination
- ✓ Application of a treatment with potassium lactate or a solution of citric acid and sodium chlorite. However, chemical treatment of carcasses is not currently authorised.
- ✓ Washing of the carcasses before chilling, especially with hot water.

These measures will be all the more effective if:

- cleaning and disinfection operations on the entire module (from lairage pens to cold rooms used for chilling and storage) are rigorously carried out and monitored;
- potentially contaminating operations in the slaughter protocol are carried out in accordance with good hygiene practices to limit this contamination.

For the **secondary and tertiary processing component**, the following measures seem to be effective in reducing the concentration of *Salmonella*:

- ✓ The use of different chemical processes: use of nitrites/nitrates or application of a lactic acid solution, in compliance with the regulations in force.
- ✓ Vacuum or modified-atmosphere packaging slows down the multiplication of *Salmonella*.
- ✓ High hydrostatic pressure treatments on meat cuts or finished products are effective in reducing the *Salmonella* concentration.
- ✓ Ionisation, a process subject to authorisation, could also be effective, but remains subject to societal and regulatory obstacles.

For the distribution component, the experts are not aware of any new publications, but they point out that the following measures are recognised for their effectiveness:

- ✓ Storage conditions (maintaining the cold chain in particular).
- ✓ Avoiding contamination transfers for exposed or bulk products (not protected by packaging).

For the **consumer component,** the only article identified by the WG concerned the positive impact of cooking.

3.6.1.2. Definition of priority management points to control the risk of salmonellosis for the consumer based on integrated modelling (i.e. all the stages in the chain) inspired by EFSA's quantitative risk assessment (QRA) model from 2010

⇨ Model results

The model enabled different scenarios to be tested assuming a reduction in *Salmonella* spp. carriage prevalence or concentration at different stages within the pig production sector.

The tested scenarios showed that the proposed interventions had different consequences on risk reduction for consumers, regardless of the product concerned. Some scenarios, implemented on a single module, had little influence, with a reduction in relative risk of less than 20%. Others, on the contrary, such as those applied at the slaughterhouse, enabled greater reductions. Nevertheless, the most effective scenarios were those combining interventions applied both at the farm and at the slaughterhouse. Thus, a 0.5 decimal reduction at each module (farm, transport-lairage and slaughterhouse), applied to all French pig production, would reduce the relative risk of human salmonellosis associated with the consumption of these products by 75 to 90%.

⇨ Model limitations

The results of the modelling must be considered in light of the uncertainties that accompany them. These are related to the availability and quality of data required for the modelling (including the availability of quantitative excretion/contamination data) and the modelling assumptions. Nevertheless, these results enabled intervention assumptions in the sector to be tested. All these results will have to be confirmed by conducting field studies.

In addition, it should be noted that precise knowledge on the implementation of certain practices is lacking. This means that it is generally difficult to assess whether an intervention is already in place and to what extent it is being applied and, therefore, what its real effect would be if it were applied systematically.

⇨ Final consideration

Among all the control measures identified by the WG, it should be noted that very few are specific to *Salmonella* control. All these measures are based on application of hygiene and good practice principles throughout the food chain and therefore apply to the majority of pathogens. The only measures specific to *Salmonella* identified by the WG were vaccination and logistic slaughter, with the limitations presented above.

3.6.2. Recommendations of the collective expert appraisal

The recommendations below have not been prioritised.

R1 – A national plan for the control of *Salmonella* spp. in the pig sector involving all the actors in the food chain, without exception, should be put in place. Indeed, as shown by the results of the model, to obtain a large reduction in relative risk it seems necessary to combine interventions applied at each stage of the production sector.

R2 – Better knowledge of the sources of human salmonellosis is needed (source attribution study, ANSES, 2017). Indeed, this disease is not only associated with the consumption of products from pigs reared in France. It can also be caused by imported products and by other foods. The results presented in this report should therefore be understood as representing only a part of the human salmonellosis cases.

R3 – Validation and verification of the implementation of GGHPs in the farm and during processing should be strengthened.

R4 – Development of a GGHP for the transport and slaughter of pigs is recommended.

R5 – All the procedures organised and planned in companies with the aim of improving operational hygiene should be encouraged: cleaning and disinfection operations (premises, equipment) are hardly ever formally included in operation protocols. However, this absence should not lead to their importance being underestimated, because these are highly significant operations aimed at obtaining the microbiological cleanliness of surfaces and materials on a routine basis. Validation, monitoring and verification of cleaning and disinfection operations are therefore key points that should not be overlooked.

R6 – A new survey on the situation with regard to *Salmonella* spp. (prevalence, level of contamination) in the pig sector in France should be conducted and followed by regular monitoring.

R7 – The health status of pigs with regard to *Salmonella* spp. should be improved, in breeding animals in particular: reducing carriage and contamination before slaughter contributes to the control of *Salmonella* at the slaughterhouse, as does logistic slaughter (positive batches should be slaughtered at the end of the day).

R8 – The CES BIORISK reiterates the importance of thorough cooking for pork products, particularly sausage products (home cooking and collective catering).

R9 – During the literature review, it was noted that most studies did not contain quantitative prevalence or concentration data. Interventions that were only described in one study were not included. The CES BIORISK therefore makes recommendations for data collection on the following points in particular:

- ✓ In the farm:
  - the effect of animal vaccination seems to warrant a significant research effort;
  - acquiring national data would provide better input for existing models.
- ✓ At the slaughterhouse:
  - at the lairage stage,
  - at the scalding stage:
    - to assess the effectiveness or otherwise of current dipping systems on *Salmonella* contamination of carcasses,
    - to compare scalding practices in a tank or in a "steam chamber",
  - at the singeing stage (double singeing),
  - at the evisceration stage,
  - during washing before chilling.

4. AGENCY CONCLUSIONS AND RECOMMENDATIONS

The French Agency for Food, Environmental and Occupational Health & Safety adopts the conclusions and recommendations of the CES BIORISK.

Since the late 1990s, veterinary public health priorities in terms of salmonellosis control have focused on the poultry sector, with dedicated measures that have proven their effectiveness on certain serovars. The pig sector is increasingly implicated in human foodborne salmonelloses. In this respect, the Agency emphasizes the importance of an integrated approach to managing this hazard in the sector, from primary production – especially that of breeder pigs – through to the consumer, as shown by the results of the modelling carried out for this expert appraisal.

According to ANSES's June 2017 report on source attribution for foodborne diseases, the priority for *Salmonella* is to collect strains from sectors other than poultry (the pig and cattle sectors in particular). Data collection during foodborne disease outbreaks (outbreak surveillance with investigation actions) should remain one of the priorities for the epidemiological documentation of human salmonellosis cases. This action will be sustained and supported by close cooperation between ANSES (the NRL), the French Public Health Agency (SPF) and the NRC (for human strains), making use within the NRL of the complete sequencing of the genome, a key tool for *Salmonella* surveillance.

In order to fine-tune strategies for controlling foodborne salmonellosis, it is necessary to continue epidemiological surveillance and the updating of scientific knowledge helping further refine conclusions on the allocation of *Salmonella* sources. This approach could usefully be extended as part of the work of the surveillance platform for the food chain.

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KEYWORDS

Salmonella, pig, pork, Regulation (EC) No 2160/2003, intervention, quantitative risk assessment, QMRA, control measures.