Salmonella control within the pyramidal structured network of pigs' movements in France

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Abstract

Due to economical and public health consequences, control of Salmonella spread within pig herds is a major concern for the swine industry. A better understanding of the links between herds as well as between herds and slaughterhouses within a production structure is then needed to assess the effect of possible control measures at this level. In the French pork production chain, herds have specific links between them: some herds being animals suppliers for others. This organization induces a specific complex network in which the contacts between herds are hierarchized, dynamic and directed. We present here a modelling approach to assess the effect of control measure implementation on the Salmonella spread within the pyramidal structure of French pork production chain, coupled with the within-herd dynamics to represent the spread of Salmonella. Firstly, the susceptibility of the pyramidal organization to an external infection is tested. The number of infected herds at the end of the simulation is highly variable according to the initial infected herd (type of herd, level of the pyramid). Secondly, we assess the effect of a control measure implementation on the seroprevalence in groups of slaughter pigs. This measure, which consists in restricting animals' purchases according to the infectious status of herds combined with a reduction of within herd transmission of Salmonella, leads to decrease the number of highly contaminated herds. This modeling approach allows us to investigate the impact of control measures both at the within and the between-herds level.

Introduction

Pork is regarded as an important source for Salmonella infection. Due to economical and public health consequences, control of this pathogen spread is a major concern for the swine industry. To be efficient, control has to be implemented at the production chain level, especially because animal movements between herds are a major route of transmission. A better understanding of the links between herds as well as between herds and slaughterhouses within a production structure is then needed to assess the effect of possible control measures at this level. The pork production chain consists in several pyramidal production structures including (i) different types of herds and (ii) slaughterhouses. Herds have specific links between them: some herds being animals suppliers (of reproductive gilts or piglets) for others. This organization induces a specific complex network in which the contacts between herds are hierarchized, dynamic and directed. The modeling approach can be a useful tool to assess the effect of control measure implementation at several level of this organization.

We present here a modelling approach to assess the effect of control measure implementation on the Salmonella spread within the pyramidal structure of French pork production chain.

Material and method

The pig production structure organisation and data
In this study, the structure of the pig movements' network in France is investigated using the pig movement database collected and maintained by a group of French producers. In the pyramidal organisation of pig herds, each herd is defined according to the level of the pyramid it belongs (i.e. Selection, Multiplication and Production levels). The Selection level is composed of pure breed animals that are selected to supply the following levels. The produced pigs are then cross-bred at the Multiplication level to improve the level of production performances and to satisfy the needs of the pig industry. At the Production level, numerous produced pigs are delivered to the slaughterhouses. The
organization studied is composed by 4 herds in the Selection level, 25 herds in the Multiplication level and 350 herds in the Production level. In the database, four types of herds are included (Figure 1): Breeding herds (16 herds), Farrow-to-finish herds (210 herds), Post-weaning-finishing herds (10 herds) and Finishing herds (143 herds). The Selection and the Multiplication levels are only composed by farrow-to-finish herds. At the production level co-exist the four types of herds.

Recorded pig movement data includes source (herd), destination (herd or slaughterhouse), date of movement and type of animals moved (8kg-weighted, 25 kg-weighted piglets, slaughter pigs, reproductive gilts or culled sows). Data used in the study are collected during 12 months (between 02/05/07 and 30/04/08).

**Figure 1. Model framework: type of herds represented in the model**

Model description

The contact structure can be viewed as a social network of potentially existing links among herds. These links are defined by the purchase of animals. The network model developed is stochastic with a one-week discrete time step. It is based on a complete within-herd dynamics model describing a farrow-to-finish pig herd (Lurette et al., 2009). It includes both the reproduction cycle of sows and the growth of pigs from birth to slaughterhouse delivery. A batch system with a three-week interval between two matings is implemented. The other types of herd correspond to a part of this complete model, as shown on the figure 1.

Recorded data of movements correspond to the chronological succession of movements between two places (from herd to herd). These data are used to elaborate a network. The movement network is generated by calculating a probability of movement pij between herd i and herd j. This probability corresponds to the number of batch movements which occur between the two herds during the studied period divided by the number of weeks during this period.

To model the infection of Salmonella in sows and pigs, three states were distinguished: (i) the susceptible state S (Salmonella-free pigs); (ii) the seronegative shedder carrier state I- (infected pigs shedding Salmonella in the environment); (iii) the seropositive shedder state I+ and (iv) the non shedder carrier state C+ (infected pigs not shedding) (Lurette et al., 2009). We considered an indirect transmission of Salmonella by the environment. The bacteria originated from shedder pigs in the batch or from other batches having previously contaminated the room floor. Input parameter values for Salmonella transmission were estimations from literature (Beloel et al., 2003; Fraval et al., 2003; Kranker et al., 2003) and from expert opinions. At each time step, the evolution of the number of pigs affected by a transition between health states is drawn from a binomial law.

At each age at which a possible sale can occur, the proportion of pigs in each health state is calculated per category of age c for the herd h considered. The proportions are denoted S(h,c), I-(h,c), I+(h,c) and C+(h,c), and represent respectively, the proportion of susceptible pigs, the proportion of seronegative shedding pigs, the proportion of seropositive shedding pigs and the proportion of seropositive carrying pigs in the category c in the herd h.

**Simulation and Results**

Control measure implementation

The pyramid is divided into two sub-networks, a 'clean' one and a 'dirty' one. Purchase of animals differs according to the sub-network the destination herd belongs. For that two factions of equal size consisting in herds which are the most connected are generated with UCINet software version 6. Each herd of the
network is classified according to the seroprevalence of the groups of slaughter. This classification is based on the classification used in the Danish control plan (Nielsen et al., 2004). In the 'clean' sub-network, a herd can be only supplied by herds of equal or lower level of contamination. In the 'dirty' sub-network, all purchases are permitted. Combining with movements' restriction, a measure aiming at reducing the Salmonella transmission is applied in herds belonging to the 'clean' sub-network.

To assess the effect of control measures, the pyramid is initially infected. 200 replications are performed for each scenario during 500 weeks. Outputs obtained are the distribution of the seroprevalence in groups of delivered pigs coming form the 'clean' or the 'dirty' sub-network. The prevalence of seropositive pigs (including animals in I+ and C+ health states) is calculated for each group of delivered pigs at each slaughterhouse delivery (every two weeks) over the whole simulation and for all herds.

**Effect of control measure implementation on the seroprevalence in groups of slaughter pigs and on the classification of herds**

Using a movements' restriction decreases the mean seroprevalence in groups of slaughter pigs from 11.3% (sd = 8.5%) to 8.2% (sd = 13.7). This mean seroprevalence reaches 6.2% (sd=11.3%) when the restriction is combined with a reduction of the infection in herds belonging to the 'clean' sub-network. Under that conditions, the mean seroprevalence in groups of slaughter pigs coming from the 'clean' sub-network decreases from 6.3% (sd = 12.2) to 4.7% (sd = 10). When the restriction of animals' movements is combined with a reduction of the transmission in herds from the 'clean' sub-network, the distribution of herds changes over time (Figure 2). Actually, the mean number of herds in the Level 0 increases from 141 to 169 herds between 2 and 200 weeks, and increases to 179 at 500 weeks. At 200 weeks, the number of herds decreases from 56 to 5 in Level 3 and increases from 102 to 122 in Level 2. At 500 weeks, the measure implementation leads to decrease the number of herds in Level 2 (from 122 to 70 herds) and to increase the number of herds in Level 1 (from 82 to 127 herds).

**Figure 2. Distribution of herds according to their level of contamination based on the Danish plan characterisation at 2 weeks, 200 weeks and 500 weeks of simulation. The measure control applied combined both the restriction of animals' movements and action aiming at reducing the infection in herds belonging to the 'clean' sub-network**

**Discussion**

The representation of both intra and inter-herd level allows us to investigate the impact of control measures applied at these two levels.

Assessing the pyramid susceptibility to the infection introduction allows the identification of at-risk part of the pyramid. It may further benefit biosecurity as surveillance effort can be prioritised where and when it is most needed. Actually, an introduction at the upper levels induces more infected herds than an introduction at the Production level.

As observed in the 'dirty' sub-network, the restriction of pigs' movements alone leads to decrease the seroprevalence in groups of slaughter pigs. When the restriction is combined with the reduction of the infection in the 'clean' sub-network, it leads to reduce the transmission within-herd and then induces a decrease in the number of highly contaminated herds.

Moreover, in a perspective of Salmonella control within the French pig Industry, it could be interesting to take into account the links between several production structures. Actually, these links, defining by the purchase of animals, can lead to introduce infection over the whole pyramid and should be studied more precisely.
Conclusion

To ex-ante assess the effect of Salmonella control at the production organisation level, other steps such as transport and lairage could be represented.

References