Simulation of the epidemiology of *Salmonella* in the pork supply chain

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Abstract
A major food safety issue in pork is Salmonella contamination. A stochastic state-transition simulation model was described to simulate the spread of Salmonella from multiplying through slaughter, with special emphasis for critical control points to prevent or reduce Salmonella contamination. Design of Experiments and metamodelling were used for a sensitivity analysis. The finishing stage and the slaughterhouse appeared to be the most important stages in the supply chain to reduce the prevalence of Salmonella contaminated carcasses.

1. Introduction

Public health and food safety is a major issue in current agri-business. In developed countries, infections with Salmonella species contribute a great deal to food borne diseases and therefore are accountable for considerable societal costs (Anonymous 2001). Salmonellosis is caused by bacteria from the genus Salmonella, and can result in severe gastro-enteritis, enteric fevers and septicaemia. It is estimated that 90% of the human salmonellosis is food borne (Anonymous 2001) and about 15% of the food borne salmonellosis originate from pork (Berends 1998). To reduce the incidence and the societal costs, more insight is needed in the impact of measures to reduce or prevent Salmonella in food products. For an effective control, the entire supply chain must be involved, which include primary producers and slaughterhouses. Currently, there is only limited insight in costs and benefits of Salmonella control, although costs of implementing measures can be very high. Hence, improved insight in the (cost)effectiveness of certain control measures will contribute to decision making. Therefore, a detailed stochastic state-transition model was designed to simulate the introduction and spread of Salmonella in the pork supply chain in order to estimate cost-effectiveness of various kind of control measures against Salmonella.

2. Model description

2.1 Salmonella control in pork production

An animal that is infected with Salmonella can start shedding bacteria, and therefore become infectious within four hours. The seroconversion period (to reach detectable antibody levels after infection) is about two weeks. Upon recovery, an animal can remain in a carrier state (bacteria in intestines or lymph nodes, but no shedding), and may become serological negative again. At the slaughter stage, bacteria from the intestines or lymph nodes can contaminate the carcass and thereby contaminate pork products. The prevalence (i.e. percentage of infected pigs in a population) can be measured by serological or bacteriological tests.
The pork supply chain consists of several stages, quite often located on different farms. Figure 1 shows the different stages in the chain: breeding, multiplying, finishing, transportation, slaughtering (lairage and slaughter), processing, retail, and consumer. All stages have relations with partners that are linked to the main food supply chain, such as feed companies and service suppliers. The model includes the stages called multiplying through slaughter. The multiplying stage and the first transport stage are combined in the model, and will be called the multiplying stage, from now on. The slaughter stage includes the slaughtering of the pigs, and the chilling of the carcasses.

Fig. 1. Schematic structure of the pork supply chain. The bold outlined stages are included in the simulation model.

Table 1 shows specific control measures and routines that can be implemented per stage and per risk profile, to prevent or reduce the introduction and spread of Salmonella. Farms or firms in a stage that take these control measures, are considered to have a low-risk profile. A farm or firm with a high-risk profile does not take these control measures and may follow routines that have a higher risk of introduction or spread of Salmonella.

2.2 The simulation model

The aim of the simulation model is to mimic the dynamics of Salmonella within and between the various stages of the production chain, subject to various conditions and measures to prevent or reduce introduction and spread; the model out-