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Estimation of costs for control of *Salmonella* in high-risk feed materials and compound feed

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Introduction: Feed is a potential and major source for introducing *Salmonella* into the animal-derived food chain. This is given special attention in the European Union (EU) efforts to minimize human food-borne *Salmonella* infections from animal-derived food. The objective of this study was to estimate the total extra cost for preventing *Salmonella* contamination of feed above those measures required to produce commercial feed according to EU regulation (EC) No 183/2005. The study was carried out in Sweden, a country where *Salmonella* infections in food-producing animals from feed have largely been eliminated.
Methods: On the initiative and leadership of the competent authority, the different steps of feed production associated with control of *Salmonella* contamination were identified. Representatives for the major feed producers operating in the Swedish market then independently estimated the annual mean costs during the years 2009 and 2010. The feed producers had no known incentives to underestimate the costs.
Results and discussion: The total cost for achieving a *Salmonella*-safe compound feed, when such a control is established, was estimated at 1.8–2.3 € per tonne of feed. Of that cost, 25% relates to the prevention of *Salmonella* contaminated high-risk vegetable feed materials (mainly soybean meal and rapeseed meal) from entering feed mills, and 75% for measures within the feed mills. Based on the feed formulations applied, those costs in relation to the farmers' 2012 price for compound feed were almost equal for broilers and dairy cows (0.7%). Due to less use of protein concentrate to fatten pigs, the costs were lower (0.6%). These limited costs suggest that previous recommendations to enforce a *Salmonella*-negative policy for animal feed are realistic and economically feasible to prevent a dissemination of the pathogen to animal herds, their environment, and potentially to human food products.

Keywords: *Salmonella*; *feed*; *control*; *economic cost*; *feed mill*; *crushing plant*; *food safety*; *preharvest control*; *Sweden*

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In the European Union (EU), efforts are in place to minimize human food-borne *Salmonella* infections from animal-derived food. Special attention is given to animal feed (1) in line with EU regulation (EC) No 178/2002 (known as the 'Food Law'), which considers animal feed as the first link of the animal-derived food chain. A quantitative risk assessment concluded that in both breeder and slaughter pigs, infected incoming pigs and *Salmonella*-contaminated feed are the two major sources of *Salmonella* (2). A similar situation also applies for poultry (3). The importance of feed is further emphasized in that *Salmonella*-safe feed is required to maintain breeding animals free from *Salmonella*. In the same way that *Salmonella*-contaminated food is the main route for transmission of *Salmonella* infections in humans, ingestion of *Salmonella*-contaminated feed is a key route of transmission in animals (4). A striking example emphasizing the potential of contaminated animal feed to act as a source of *Salmonella* infections in humans occurred when *Salmonella* Agona emerged as a public health problem in several countries due to the widespread use of contaminated fish meal that was imported as feed material. In the period 1968–1972, a rapid increase of human infections with *S.* Agona occurred in the United States as well as in Europe (5). Since then, *S.* Agona is among the most prevalent serotypes in humans. It is estimated that the serotype up to 2001 caused >1 million human illnesses in the United States alone since it was introduced in animal feed in 1968 (5).

An integrated approach needed to prevent *Salmonella* contamination of feed is reviewed (6). Jones (7) has separated the control measures into three major strategies: 1) prevention of contamination, 2) reduction of multiplication,

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and 3) procedures to kill the pathogen. In spite of all the challenges involved, it is possible to successfully produce *Salmonella*-safe feed, even for young broilers (8), under commercial and industrial conditions as demonstrated, for example, in the Nordic countries (Denmark, Finland, Norway, and Sweden). The young broiler is very sensitive to peroral exposure to *Salmonella* and can become infected from ingestion of just a few *Salmonella* bacteria (9). In Sweden, with a long tradition of control of *Salmonella* in feed, the incidence of *Salmonella* in broiler production, based on an approach where each flock is tested before slaughter, is found to be very low (8). The average annual (1996–2010) incidence of *Salmonella*-infected flocks (annual production 75 million chickens; average flock size, 20,000 chickens) was 0.2% based on testing prior to slaughter. Only 0.03% of carcasses were found to be *Salmonella*-contaminated when tested after slaughter (10). Also, in other food-producing animal species, the annual incidence of *Salmonella* is relatively low (11). During the same period (1996–2010), *Salmonella* was isolated from only 0.13% of lymph nodes of fattening pigs indicating a low prevalence of *Salmonella* contamination of feed. In addition to the control of *Salmonella* in feed, this relatively positive situation is also the result of actions taken at the farm when *Salmonella* is detected in animals (12). However, the control of feed is considered to be essential.

In contrast to available data on how to prevent and control *Salmonella* contamination of feed, there is a considerable gap of published data on the actual cost of those actions (13). It is currently also important to fill out that gap when considering that the costs, although unspecified, are sometimes used as an argument against implementing a control (14). The objective of this study is therefore to estimate the total extra cost for preventing and controlling *Salmonella* contamination of some high-risk feed materials (mainly soybean meal and rapeseed meal) and compound feed to food-producing animals and also the cost in relation to the price of feed. The study was carried out in Sweden because, as described above, the strategies applied for the prevention of *Salmonella* contamination in the feed industry result in a *Salmonella*-safe feed. These estimations should be of general value since the feed production generally includes the same technical approach in most countries and the price for feed materials and compound feed follows the global prices on feed commodities.

Methods

General approach

In Sweden, different measures are taken with regard to the manufacture of commercial feed in order to realize the ambition of producing *Salmonella*-safe feed. These measures normally result in extra costs above the cost for those measures required to produce commercial feed according to requirements for feed hygiene as described in EU regulation (EC) No 183/2005. However, that regulation does not include any specific requirements concerning reducing the contamination of *Salmonella*. This assessment estimates the extra costs, in addition to the requirements under this EU regulation, for the prevention and control of *Salmonella* contamination in animal feed. Special attention is given to the production of high-risk feed materials (as defined below) during the production process in crushing plants, when used in feed mills, for the manufacture of compound feed.[1] The total cost of compound feed production, as well as costs in relation to the price of the feed in question, is also estimated.

It was not possible to specify the extra costs for feed intended to be used for different food-producing animal species. Therefore, the estimations cover the feed production for all food-producing terrestrial animals in Sweden, predominantly cattle, swine, and poultry, and to a lesser extent sheep. Feed for other species such as pet animals and farmed fish is not considered.

Legislative demands and strategies for the control

The minimum requirements in Sweden for the prevention and control of *Salmonella* in animal feed are provided for in national legislation (12). Some feed materials are classified (S1 to S3) according to risk for *Salmonella* contamination. The highest risk class (S1) only includes feed materials of animal origin, which are currently used only to a very limited extent in animal feed (e.g. animal-derived fat, fish meal, some milk and egg products). Risk class S2 includes meals and expellers (cakes) from the oil crushing industry (e.g. babassu, coconut expeller, palm kernel expeller, rapeseed, and soybean meals) and maize gluten feed and meal. When handling such feed materials, crushing plants and feed mills are required to have a *Salmonella* control program in place. In this program, identified critical control points have to be tested for contamination based on a minimum number of samples at specified intervals according to HACCP principles. Swedish retailers/operators of feed mills are not allowed to use feed materials classified as S2 from other countries until a *Salmonella* control with a negative result has been carried out on every single lot received. Risk class S3 includes feed materials with a lower probability for *Salmonella* contamination. These also need to be tested, but the material can be used before the test result is available. Currently, feed materials classified as S3 only include rice. For other feed materials of vegetable origin, such as cereals, there are no detailed obligations regarding *Salmonella* laid down in national legislation.

[1]In this paper 'feed mill' is applied to plants producing compound feed.

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When feed for animals other than poultry is produced, a minimum of two environmental samples should be tested each week from the top of the storage bin for compound feed (1) and from the intake pit/bottom of elevator for feed materials (2). Special attention is given to the production of compound feed to poultry. For such production, the following five control points are specified as a minimum requirement: 1) intake pit/bottom of elevator for feed materials; 2) pneumatic aspiration (excavations) from feed materials or central aspiration; 3) top of pellet cooler; 4) dust from room for pellet cooler; and 5) storage bin for produced compound feed. Consequently, a minimum of five samples should be taken every week with regard to the production of poultry feed.

The HACCP program, including hygienic procedures for cleaning, has to be adapted to each feed operation and has to be checked by the Competent Authority, the Swedish Board of Agriculture. In addition, all feed for poultry should be heat treated, to a minimum at 75°C. Operators of feed mills have regularly identified feed materials as one of the control points in particular for oil seed meals from abroad. Testing for the absence of *Salmonella* (irrespective of serovar) is often conducted by operators of feed mills even for feed materials where testing is not mandatory before they are allowed to enter the plant or used for feed production. Consignments found to be *Salmonella* contaminated are decontaminated, followed by re-testing with a negative result before use (15). Decontamination is regularly done by treatment with organic acids (15).

The surveillance of consignments of risk feed materials is based on a sampling procedure that takes account of the potential for an uneven distribution of *Salmonella* and is designed to detect contamination in 5% of the batch with 95% probability (16). This means that from consignments of 101–10,000 tonnes, a minimum of eight samples must be analyzed, each consisting of 10 pooled incremental samples of 2.5 g. Where possible, sampling on a moving stream principle is applied. Feed material produced domestically is normally not specifically tested for *Salmonella* in the feed mill but the control is instead based on the control program for the producing plant, as described above.

All samples are tested by standard bacteriological procedures (17) and in particular according to the NMKL-71 method (18). Consignments of feed materials from abroad are now often initially tested by a PCR technique, which in cases of a positive result are verified with the bacteriological methods (19). The analyses are always done at accredited laboratories. The mandatory samples from the feed production must be sent to the National Veterinary Institute for analysis (15).

The national legislation also specifies measures to be taken by crushing plants and feed mills when *Salmonella*, irrespective of serovar, is isolated from:

1. Feed materials
2. Production lines for non-heat-treated feed
3. Production lines (before heat treatment/unclean part) for heat-treated feed
4. Production lines (after heat treatment/clean part) for heat-treated non-poultry feed
5. Production lines (after heat treatment/clean part) for heat-treated poultry feed

These measures seek to identify and eliminate contamination of *Salmonella* and are always undertaken when *Salmonella* is isolated, irrespective of the serovar involved. Slightly more stringent measures are in place for poultry feed. In contrast to feed for other animal species, the delivery of compound feed to poultry producers has to be stopped directly when *Salmonella* is detected on the clean side of the production line. Note, however, that the operators of feed mills, irrespective of the animal species intended, now generally apply such procedures.

Estimation of cost

The study was done on the initiative and under the leadership of the Swedish Board of Agriculture. Initially, the different steps of feed production associated with prevention and control of *Salmonella* contamination were identified as a joint effort with the industry. The annual mean costs during 2009 and 2010 were then estimated, by representatives of the three major feed producers for the Swedish market.[2] One was a producer of crushed feed material from rapeseed at one plant with an annual crushing capacity of 300,000 tonnes of rapeseed for the production of 180,000 tonnes of rapeseed meal and the other two were major producers of compound feed, with an estimated 90% share of the Swedish feed market. Their production was located at approximately 15 feed mills with a total annual production capacity of 1.6–1.8 million tonnes of compound feed.

Based on the legislative demands and associated control strategies and possible additional measures as described above, the cost for preventing and controlling *Salmonella* contamination were identified for 1) high-risk feed material which is split up into domestic production and imported ready-to-use feed material, where each is further split up into four subareas as specified in Tables 1 and 2, 2) compound feed which all concern domestic production in feed mills. This cost was split up into seven groups as specified in Table 2, and finally 3) the total cost for those two groups of feed were related to the commodity price as specified in Table 4.

The three participating producers were competing on the market and therefore insisted on carrying out the

[2]AAK (http://www.aak.com), Lantmännen (http://www.lantmannenlantbruk.se/) and Svenska Foder (http://www.svenskafoder.se/).

Table 1. Estimated cost for achieving *Salmonella*-safe rape seed meal in a Swedish crushing plant during 2009/10

Production of *Salmonella*-safe rapeseed meal	Estimated cost/tonne (€)
Sampling and analysis	1.1
GMP program (*Salmonella*)	0.4
Cleaning	0.1
Insurance fee to cover costs including loss of production and associated measures for decontamination when production stopped due to *Salmonella* contamination	0.4
Total	2.0

analyses individually and not as a joint effort. Their estimations of the total cost for the different identified areas are therefore not further split up but include cost of labor, laboratory analyses, equipment, voluntary industry–based additional controls, for example, heat treatment on non-poultry feed, extra sampling and biosecurity or other related costs as relevant for the estimators who are key persons for the area and who are familiar with similar estimations. The cost was distributed across the total amount of feed produced. The data were analyzed and summarized by the Swedish Board of Agriculture. When necessary, clarification was sought. Diverging estimations of cost were presented as a range.

The costs were originally given in Swedish (SEK) but here recalculated to euro (€) at an estimated mean currency exchange rate during recent years of 1€ = 9 SEK. Where necessary, conversion to/from US currency for prices on feed commodities was conducted at 1$ = 7.20 SEK.

Results

High-risk feed material

Manufacture of crushed feed material in Sweden

Only one commercial plant crushes oil seeds classified as S2 (see above) in relation to risk for *Salmonella* contamination (20). This plant produces rapeseed meal (nr 2.07 in Regulation (EC) No 242/2010) using both domestic and non-domestic sources. In line with legal requirements, the establishment has a declared ambition to deliver only *Salmonella*-safe feed materials to customers/feed mills. This means that product is not delivered until it has tested negative for *Salmonella* contamination (18). The feed safety GMP program of the plant is certified by VFK (The Association for Safe Feed Materials, http://www.vfk.se). The specific costs for delivering *Salmonella*-safe feed materials is presented in Table 1 and in total estimated at 2€ per tonne.

Salmonella

As a clarification of the legislative demands described above, it should be noted that the demand for testing for *Salmonella* of rapeseed (Risk class S 2) originating in other countries is not applied for the crushing plant, as rapeseed is regarded as a raw material for further processing into a final expeller/meal. However, if *Salmonella* is detected in produced rapeseed meal, the product is to be decontaminated by heat-treatment or by organic acid and tested free from *Salmonella* contamination before delivery, as described before.

High-risk feed materials originating from other countries for use in compound feed

The choice of good suppliers: Although it is normally not possible to buy feed materials with any kind of

Table 2. Estimated cost for achieving *Salmonella*-safe high-risk feed material in Sweden during 2009/10

High-risk feed material (mostly soy and rapeseed meal)	Estimated cost per tonne
Domestic production:	
• Rapeseed (from Sweden or elsewhere) crushed in Sweden into feed materials and tested free from *Salmonella* (Table 1)	2.0 €
Produced abroad fulfilling Swedish legislation:	
• from non-Swedish crusher (soy) and tested free from *Salmonella*	3.3 €
Produced abroad independent of Swedish legislation:	
• reception control for *Salmonella*, i.e., testing and storage under quarantine conditions	0.4–0.9 €
• decontamination of *Salmonella* contaminated consignments (acid treatment followed by testing free from *Salmonella*)	1.2–1.6 €[a]
• Total cost	2.1 € (1.6–2.5)
Special treatment:	
• heat treatment of a feed materials (soy and rapeseed meal) delivered directly to farms	11.1–22.2 €

[a]When estimating the mean proportion (7%) of consignments of non-Swedish S2 feed materials, mostly soy and rapeseed meal, being *Salmonella* contaminated. The cost for acid treatment of individual consignments estimated at 16.7–22.2 € per tonne of feed material.

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'*Salmonella* guarantee', experience has shown that the *Salmonella* status of feed materials placed on the market by producers in other countries varies (15). Efforts are therefore made to choose suppliers of high-risk feed materials with statistically good records with regard to *Salmonella* contamination to avoid those extra costs associated with *Salmonella* contamination as described below. So far, the only known example of a foreign producer with good statistical records for absence of *Salmonella* contamination is a Norwegian crusher of soybean, which is known to have a good self-auditing hygiene program that is completely transparent to Swedish customers and authorities (1). Commodities leaving that plant have been tested free from *Salmonella* contamination before delivery, making additional testing on reception unnecessary as otherwise required at the Swedish feed mills. The extra cost due to *Salmonella* control for soybean meal from that plant in relation to soymeal from other producers is by Swedish operators of feed mills estimated at 3.3€ per tonne.

When any intended supplier of feed materials has faced problems with *Salmonella* in their establishment or *Salmonella* has been detected in their products, Swedish feed mills have sometimes been forced to temporarily choose another supplier, which is associated with different kinds of extra costs estimated at approximately 3.3€ per tonne. However, due to the low annual incidence of such events, the extra cost here is considered negligible.

Control of Salmonella

Sampling and analysis: These costs include mandatory sampling and testing of all consignments from other countries of S1, S2, and S3 feed materials for the absence of *Salmonella* contamination and the holding of consignments in quarantine pending the results. Category S1 and S2 feed materials are not to be used in compound feed production until a negative result for *Salmonella* is available.

Sampling and testing may also be applied on a voluntary basis for domestically produced feed materials, although a legal demand for such a procedure is not in place because, in contrast to the situation for non-Swedish feed production, the domestic production can be controlled by the competent Swedish authorities. However, every consignment of feed materials found positive for *Salmonella*, whether risk categorized or not, has to be handled according to provisions laid down in national legislation. The possession of consignments under quarantine means extra costs for storage facilities. The total cost for this control on receipt is estimated at 0.4–0.9 € per tonne.

Acid treatment when Salmonella *has been detected:* When a consignment is found to be Salmonella contaminated – when tested as described before under 'Sampling and analysis' – it must either be sent back to the consignor or undergo a decontamination process. In practice, returning to the consignor is seldom an option. The dominant way of de-contamination is by use of organic acid (15, 21).

After decontamination, further sampling and testing is conducted to verify that the de-contamination has been successful. Then the feed material can be used in the production of compound feed but only in heat-treated compound feed. The storage place for the contaminated feed materials subsequently requires cleaning and disinfecting. Costs for de-contaminating feed materials include capital for investment in equipment, extra storage space, and variable costs including costs for organic acid, labor, sampling, and testing. The total extra costs for the decontamination of a *Salmonella*-contaminated consignment, which have to be paid by the Swedish consignee, usually the feed mill, are estimated at around 16.7–22.2 € per tonne of treated feed material. When estimating the mean proportion (7%) of consignments of non-Swedish S2 feed materials, mostly soy and rapeseed meal, being *Salmonella* contaminated, the mean extra cost for control of *Salmonella* in these feed materials is estimated at 1.1–1.7 € per tonne.

General heat treatment of a feed material: Acid treatment is only performed when Salmonella has been confirmed in a consignment. However, on a voluntary basis, prophylactic heat treatment is often performed when some feed materials, usually soy and rapeseed meal, are delivered directly to farmers. The cost for this heat treatment is estimated at 11–22 € per tonne of treated feed material.

Compound feed

Technical standard of feed mills

For decades, feed mills in Sweden have been continuously improved by taking on board new technologies for the production of feed that is *Salmonella*-safe. They are constructed in a way that separation can be made between an unclean and a clean section where the borderline is the heat treatment step. The development of more effective long-duration conditioners and pellet presses has resulted in ongoing replacement of equipment. Such modern, long-duration conditioners allow for heat treatment of the feed for a longer period of time. Additionally, the construction of coolers which are used to lower the temperature and the humidity in the pelleted material, has been improved. Over-pressure is used to prevent microorganisms from being introduced into the cooler where hot and humid feed is handled.

The annual capital costs for the technical improvements were estimated at 0.1–0.2 € per tonne.

Heat treatment

According to national legislation, feed for poultry has to be heat treated. The operator has to ensure that the temperature has reached 75°C in the feed before it may be passed over to the cooler. In practice, most commercial

compound feed for food-producing animals is heat treated, usually during a pelleting process.

Pelleting the feed could result in nutritional and other advantages but is also an effective way, with effective conditioners, of preventing the spread of *Salmonella* through feed. This procedure is considered an extra cost, noting prolonged residence in the conditioner and the use of high amounts of steam. The extra total costs for having an effective de-contamination effect in the conditioner and in the pellet press are estimated at 0.8–1.1 € per tonne of feed.

HACCP-associated sampling

According to national legislation, environmental sampling for control of *Salmonella* contamination (HACCP) has to be conducted on a weekly basis as described above. Very often the operator takes more samples than laid down as a minimum requirement in the national legislation. In some cases, a large quantity of samples is taken at one specific time in the year in order to get a good overview of the hygienic situation in the establishment.

The extra costs for all the HACCP-associated sampling are estimated to be around 0.2–0.3 € per tonne of feed.

Measures when *Salmonella* has been detected in a feed mill

When *Salmonella* has been detected in a feed mill, further monitoring by sampling is carried out in order to gain an understanding of the extent of the contamination. The contaminated area or object is cleaned and disinfected and the effect verified by repeated sampling. Depending on the situation, production and deliveries may be affected.

The competent authority has to be notified when *Salmonella* has been identified in the clean section of the production line. When *Salmonella* has been detected in the unclean section and the follow-up sampling indicates only local contamination, a local cleaning/disinfection on the spot is required. In such cases, the competent authority, when notified, gives guidance to the operator. The overall goal is to keep the unclean section of the establishment free from *Salmonella* contamination even though it is known that *Salmonella* is occasionally found in that section. However, permanent *Salmonella* contamination is not allowed to be established in any part of the plant.

When *Salmonella* is detected in the clean section, production is normally stopped in the production line involved to prevent the spread of *Salmonella* within and from the plant. Dispatch of feed from the establishment is, in practice, immediately stopped. Under guidance of the competent authority a thorough environmental sampling scheme is then followed. Samples that have to be taken and kept on a routine basis when feed is delivered to customers (dispatch samples) are retrospectively checked for *Salmonella* for a certain period (specific to every situation). Measures are undertaken to eliminate the contamination. Thorough cleaning and disinfection is always carried out and the concerned production line is not re-started until follow-up environmental sampling has confirmed that the decontamination efforts have been successful. Considerable extra costs could result if feed from other feed mills has to be provided and delivered to the customer/animal holdings of the plant during the halt in production.

In some situations, in particular when difficulties in eliminating *Salmonella* contamination occurs, the costs during this critical period may be considerable when, for example, repetitive cleaning operations are required. Based on previous incidences when *Salmonella* is detected within a feed mill, the associated extra costs are estimated at 0.1 € per tonne.

Measures when *Salmonella* has been detected in the farm of a customer

Measures in the feed mill: According to national legislation, a feed operator has to take action when *Salmonella* has been detected in the herd of a customer. This includes monitoring by sampling of the production line from which the feed to the customer was delivered. Dispatch samples from feed delivered to the customer are normally checked as well. The costs for the measures described in this point are estimated as: <0.1 € per tonne of feed. However, if *Salmonella* is detected in the plant, the associated costs are as described above.

Measures when delivering feed to herds under quarantine: When *Salmonella* is isolated in food producing animals the actual herd is put under restrictions aimed at preventing the spread of the infection. Measures are taken to eliminate the infection from the herd (11). The delivery of feed to such farms has to follow certain procedures including cleaning and disinfecting certain parts of the vehicle to prevent the spread of infection to other herds and to the feed mill. The extra costs for these procedures are estimated as: <0.1 SEK per tonne of feed.

Total extra costs due to combating salmonella in feed

The total extra costs for the Swedish feed industry to fulfill the ambition that *Salmonella* should not be transmitted by feed have been summarized as follows and partly also presented in Tables 2 and 3. As can be seen, the costs for the following procedures are specifically estimated as described above.

Cost for achieving *Salmonella* test negative high-risk feed materials (mostly rape – or soymeal)

The high protein-rich feed materials of vegetable origin used in Sweden, mainly soy and rapeseed meal, are either crushed in Sweden or originate in other countries. As presented in Table 2, the specific cost for producing such a

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Table 3. Estimated cost for the production of *Salmonella*-safe compound feed to food producing animals in Sweden during 2009/10

Compound feed	Estimated cost per tonne of produced feed
1. Without specific costs for high-risk feed materials (Table 2)	
• Technical standard of feed mills	0.1–0.2 €
• Heat treatment	0.8–1.1 €[a]
• HACCP associated sampling	0.2–0.3 €
• Measures when *Salmonella* is detected in a feed mill	0.1€
• Measures when *Salmonella* is detected in the herd of a customer:	
– in the feed mill	<0.06€[b]
– when delivering feed to herds under quarantine	<0.06€[b]
Total	1.55€ (1.3–1.8)
2. Including specific costs for high-risk feed material (Table 2)	
• Estimated mean cost with 10–30% inclusion of protein (Table 2)[c]	0.25–0.75 €
Total cost for compound feed	1.8–2.3 €

[a]Mean cost when estimating that 98% of the compound feed is heat treated.
[b]For calculation, the cost is estimated at 0.06 € per tonne.
[c]Mean estimated cost for high-risk feed material/protein of Table 2 estimated at 2.5 € per tonne.

feed material that is tested for *Salmonella* contamination so that it can be used in compound feed is:

2.0€ per tonne for domestically crushed rapeseed produced according to Swedish legislation for feed production.
3.3€ per tonne for soymeal from a non-Swedish crushing plant operating in accordance with standards laid down in Swedish legislation for feed production.
2.1€ per tonne for protein sources (mainly soy and rapeseed meal) from non-Swedish crushing plants selected for having a relatively good hygiene standard in relation to *Salmonella* contamination but produced without connection to the demands in Swedish legislation for feed production.

Cost for production of a *Salmonella*-safe compound feed

The estimated cost for the production of *Salmonella-safe* compound feed excluding the corresponding cost for the high protein-rich feed materials as described above is presented in Table 3. It can be seen that the cost is approximately 1.55€ (1.3–1.8 €) per tonne. Estimation is also made of the total cost for producing *Salmonella-safe* compound feed. Because different formulae for the inclusion in compound feed of high protein-rich feed materials are applied, it was assumed that the three types of proteins (Table 2) were equally mixed into compound feed to a concentration of 10–30%. It was also assumed that the mean cost for achieving those products test negative for *Salmonella* was 2.5 € per tonne. Based on those assumptions, the total cost for producing a *Salmonella*-safe compound feed is 1.8–2.3 € per tonne.

Cost for control of *Salmonella* is in relation to the commodity price

The cost for control of *Salmonella* as described above has also been related to the estimated mean market price for the different feed products during the years (2009/10), as well as during 2012, a year when the global feed prices were generally higher than average prices during previous years. The result is presented in Table 4. It can be seen that at the feed price level of 2010, the mean estimated cost for the control of the high-risk feed materials was approximately 1.0% (0.7–1.2%) of the commodity prices. At the price level of 2012, the cost decreased to 0.7% (0.5–0.8%). For the calculation of the corresponding data for compound feed, based on the assumptions specified in Table 4, the relative cost for the control of *Salmonella* at a 20% inclusion of soy or rape meal was approximately 0.8% at the price level of 2010 and 0.6% at the higher price level of 2012. This is the final price paid by the farmer.

By the use of the data presented above and the feed formulations applied to the major animal species in Sweden, the cost at the 2012 price level for receiving *Salmonella*-safe compound feed can be calculated. For broilers, with the inclusion of 23% soy meal in the feed, that cost is 0.0021 €/kg, or <1% (0.7%) of the price (0.33 €/kg) of commercially produced feed. The corresponding estimated cost for fattening pigs using 14% rapeseed is slightly lower: 0.0018 €/kg or 0.6% of the feed price (0.30 €/kg). For a dairy cow using approximately 25% feed concentrate (of equal parts of rape and soy meal), that cost is similar to broilers: 0.0018 €/kg or 0.7% of the feed price (0.32 €/kg). For broilers this means a total cost of approximately 0.008€ per bird when slaughtered at 2 kg and consuming 3.6 kg of feed. By the use of these data, the production cost for the farmer for different

Table 4. Estimated cost for control of *Salmonella* in feed materials and compound feed in relation to price of feed

Feed material	Cost per tonne to achieve a *Salmonella-safe* product[a]	The cost for a *Salmonella*-safe product in relation (%) to mean market price per tonne during 2009–10	The cost for a *Salmonella*-safe product in relation (%) to mean market price per tonne during 2012
Rapeseed crushed in Sweden according to Swedish legislation	2.0€	1.2% of 166€[b]	0.8% of 266€[b]
Soymeal produced abroad fulfilling Swedish legislation	3.3€	1.1% of 308€[c]	0.8% of 428€[c]
Soy meal produced abroad independent of Swedish legislation and tested free from *Salmonella* contamination upon arrival and decontaminated if needed in accordance with Swedish legislation	2.1€ (1.6–2.5 €)	0.7% (0.5–0.8%) of 308€[c]	0.5% (0.4–0.6%) of 428€[c]
Compound feed	1.8–2.3 €	0.8% (0.7–0.9%) of 244€[d]	0.6% (0.5–0.7%) of 322€[d]

[a]Data from Tables 2 and 3. The same exchange rate was used for all the years (2009–10 and 2012): 1 € = 9.0 SEK and 1$ = 7.20 SEK.
[b]International market price for rapeseed meal in Hamburg included 16 € for transport to Sweden.
[c]International market price Rotterdam (350 and 500 $, respectively) including 35$ for transport to Sweden.
[d]Based on industry information and at a 20% inclusion of soy or rapeseed meal.

food-producing animal species or production systems can be calculated, depending on the proportionate use of compound feed or decontaminated high-risk feed materials (mostly rape and soy meal).

Discussion

This paper presents the cost for all the steps included in the Swedish strategy to control *Salmonella* contamination of feed. Some subset of costs could be estimated in detail but for others only a rough estimation was possible. The study is interesting because similar data are not readily available and the results are largely based on rather solid data from the feed industry with no known incitement to underestimate the cost. This is especially so because there is no national or other economic compensation for the control of *Salmonella* in feed which instead is paid by the producers and included in their feed prices. The estimated costs were interestingly relatively similar between different producers. The results are also valuable because long-term documented data in particular from the poultry and swine industry (8) indicates that the control is effective and largely has eliminated feed as one of the major sources of *Salmonella* infections in food-producing animals. The total cost was estimated at 1.8–2.3 € per tonne of compound feed which based on the 2010 price level for feed material is approximately 0.8% of the farmer's cost for the compound feed. At the higher global feed prices during 2012, the relative cost decreased to 0.6%. Based on the feed formulations applied to different animal species, the above relative cost for achieving *Salmonella-safe* compound feed was almost equal for broilers and dairy cows (0.7% at 2012 feed prices) and due to less use of protein-rich feed lower (0.6%) for fattening pigs.

Control is based on two major steps. The first step aims at preventing *Salmonella*-contaminated feed material from entering feed mills. Those feed materials found to be of highest risk, in particular non-Swedish feed materials of vegetable origin, mainly soy and rapeseed meal, have to be tested and found negative for *Salmonella* contamination, before being allowed to enter the feed mill and used as ingredients in compound feed (15). The second step is based on continuous control within the feed mill according to HACCP principles. Out of the total cost per tonne of compound feed, the estimated mean cost for the first step accounted for 25% (0.5 €; 0.2–0.7 €, depending on the protein concentration) compared to 75% (1.5 €) for the second step (i.e. the control within the feed mill).

The costs (2 € per tonne) for producing a *Salmonella*-safe high-risk protein-rich feed material (rapeseed meal) is specified for one Swedish crushing plant and that is the only known data of its kind found in either the scientific or gray literature. It is not known to what extent cost is specifically added to the final price of rapeseed meal, which also includes other properties with an added value. Another non-Swedish crushing plant is known to produce *Salmonella*-safe soybean meal but the specific cost for the elimination of *Salmonella* contamination is not known. Instead, it is estimated that an extra price of 3.3 € per tonne is paid. This product also has other properties of added value so it is not known to what extent the extra cost for a *Salmonella*-safe source refers only to the cost for elimination of the *Salmonella* contamination. This latter plant can only

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supply part of the demand from the Swedish feed mills and both crushing plants are the only ones known so far to provide high-risk protein-rich feed material with any kind of guarantee for the absence of *Salmonella*. This means that currently at EU level, it is not possible to pay an extra fee for sourcing of *Salmonella-safe* feed materials as seems to be assumed in a recent cost–benefit study (13). Due to the lack of crushing plants that can provide *Salmonella*-safe feed materials, the feed mills are instead obliged to buy feed materials with an unknown *Salmonella* status with a high-risk for *Salmonella* contamination. There is therefore a need to have such products tested and if necessary decontaminated at an estimated cost of 2.1€ per tonne. Earlier up to 30% of consignments of feed materials from crushing plants with an unknown *Salmonella* status were found *Salmonella* contaminated upon arrival to Sweden, but the situation has improved, usually to an annual incidence of $<10\%$ during recent years (15). Very few data are available on the possible human health impact of that source of contamination, which also should vary with the preventive measures applied in the whole feed chain. In one study from Denmark, it was estimated that 2.1% of domestically acquired human *Salmonella* infections during 1999–2003 could be attributed to feed-borne serotypes acquired through the consumption of Danish pork and beef and the dominating source of *Salmonella* was contaminated imported soy bean products (14). However, apart from less intensive sampling of the feed material than in the current study, major human pathogenic serovars (*S. Typhimurium, S. Enteritidis*) with a special ability to establish themselves in food animal populations were not included in the estimation.

The crushing plants, for example, in the continental EU Member States, have often four to five times the production capacity of the Swedish crushing plant described in this paper (1). This means that the relative cost for *Salmonella* control per volume feed (apart from decontamination of *Salmonella* contaminated consignments) would be significantly lower than at the Swedish plant. However, this is not the case for control at feed mills because the mean size of the Swedish feed mills is large compared to most EU countries (22).

The cost described above relates only to all the legislation on control of *Salmonella* in compound feed and associated voluntary measures. However, in Sweden other legislation contributes to minimizing the risk for contamination of feed at the farm, and when *Salmonella* infections occur in animals, the feed is generally controlled including possible spread by compound feed from feed mills. This contributes to ensuring that feed producers remain alert as does the fact that they are paying for the cost of the control as described above. Of fundamental importance for the efficiency of the control measures is that the monitoring of feed materials as well as the sampling within the HACCP program are combined with methods to eliminate those *Salmonella* contaminations that occur.

Soy is the most frequently used protein-rich feed material by the EU livestock industry and a significant risk for *Salmonella* contamination of the food chain. Approximately 97% of soy is imported from third countries and mostly crushed before it reaches the EU (22). Also, other oilseed meals produced within and outside EU have a high-risk for being *Salmonella* contaminated. Therefore, a most effective way to strengthen the ongoing effort to minimize the prevalence of *Salmonella* in EU farms would be to implement stringent measures for elimination of *Salmonella* contamination already in the crushing plants. The current study has shown that this can be done at a cost of around 2 € per tonne of feed material. Another important area of focus for control of *Salmonella* relates to the production of compounded feed at the feed mills, which can be done at a cost of 1.5 € per tonne. The total cost for the production of *Salmonella-safe* feed was estimated at 0.5–0.7% of the farmer's price for compound feed during 2012. This can be considered as a fairly low price when considering that the cost has sometimes been used as an argument against implementing more stringent measures for preventing *Salmonella* contamination of feed.

It should also be emphasized that the estimated cost for achieving a *Salmonella*-safe compound feed does not include the capital costs previously laid down for the technical improvement of feed mills, including the management skill of their staff which in Sweden have been ongoing for decades. However, it is not known to what extent some of those costs are included in those measures required to produce commercial feed according to EU regulation (EC) No 183/2005.

This study indicates that a *Salmonella*-negative standard for animal feed as recommended by the FDA in 1991 and by Crump et al. (5) and as successfully implemented since decades in Sweden due to its relatively limited cost can be considered as a realistic approach. From a one health perspective, it is thus important that efforts are done to prevent *Salmonella*-contaminated animal feed material and animal feed and thus also possibly associated antibiotic resistance genes to move between and within countries and from resulting in a widespread dissemination of the pathogen to animal herds and their environment with potential for a subsequent contamination of a range of human food products (6).

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