Literature Reviews

rccp Revista Colombiana de Ciencias Pecuarias

Salmonella spp. in the pork supply chain: a risk approach¤

Salmonella spp. en la cadena de producción porcícola: un enfoque de riesgo

Salmonella spp. na cadeia de produção de carne de porco: uma abordagem de risco

Diego M Rodríguez, MV, MSc; Martha C Suárez*, MV, MSc.

Grupo Genética Molecular de Patógenos GEMPA, Facultad de Medicina Veterinaria y de Zootecnia, Universidad Nacional de Colombia, Sede Bogotá.

(Received: November 19, 2012; accepted: December 11, 2013)

Summary

The genus *Salmonella* contains approximately 2,579 serovars, most of which are zoonotic and transmitted by foods of animal origin, such as fresh pork and further processed by-products. Non-typhoid salmonellosis in humans manifests as gastroenteritis, septicemia, or can be asymptomatic during the carrier state. *Salmonella* spp. has a considerable impact in the pork industry due to economic losses resulting from diagnosis, treatment, reduced production, and because this pathogen constitutes a non-tariff barrier to food trade and a serious public health problem. The microorganism is usually introduced to farms through incoming breeding stock or pig feed and is subsequently spread by sick animals or asymptomatic carriers. Infection and/or dissemination of the microorganism may increase particularly during pre-slaughtering due to contaminated trucks, long periods of time spent in transit, stress during handling and fasting, or high animal density or time spent in corrals. Contamination during slaughtering is commonly associated with carcass de-hairing and polishing, evisceration and rectum separation, or from *Salmonella* present in skin, oral cavity, feces or lymphatic nodes. Pork contamination may also occur through contact with equipment or tools, handling, storage, or improper preservation during slaughter, post-slaughter, marketing, sale, or consumption. For this reason, *Salmonella* control, with a focus on the supply chain and risk assessment is fundamental for guaranteeing quality and food safety of pork products in Colombia, thereby contributing to public health and improving competitiveness. Studies directed at establishing baselines for the disease and the microorganism in each of the stages of the supply chain should be conducted, including identification of differential risks and establishing measures for monitoring, prevention and control.

Key words: *cross-contamination, farm, pigs, pork, slaughter.*

Resumen

El género *Salmonella* agrupa alrededor de 2.579 serovariedades, en su mayoría zoonóticas, transmitidas por alimentos de origen animal, como la carne de cerdo y sus derivados. La salmonelosis no tifoidea en humanos

¤ To cite this article: Rodríguez DM, Suárez MC. *Salmonella* spp. in the pork supply chain: a risk approach. Rev Colomb Cienc Pecu 2014; 27:65-75

* Corresponding author: Martha C Suárez. Laboratorio de Microbiología, Facultad de Medicina Veterinaria y de Zootecnia, Universidad Nacional de Colombia. Carrera 30 N° 45-03 edificio 503 Bogotá, D.C. Email: mcsuarezal@unal.edu.co

puede manifestarse como gastroenteritis, septicemia o estado portador asintomático. La presencia de *Salmonella* spp. es de gran impacto para la industria porcícola, por las pérdidas económicas por diagnóstico, tratamiento y disminución de la producción, y por constituir una barrera no arancelaria para la comercialización de alimentos y un grave problema de salud pública. El microorganismo se introduce en las granjas a través del alimento, el pie de cría o los cerdos para levante, y se disemina a través de enfermos o portadores asintomáticos. En el prebeneficio la contaminación de camiones, el tiempo de transporte, el estrés por manipulación, el ayuno, la alta densidad animal, y la permanencia en corrales pueden incrementar la infección y/o diseminación del microorganismo. Durante el beneficio la contaminación se asocia al depilado, pulido de los animales, a la evisceración y corte de recto o a la presencia del microorganismo en piel, cavidad bucal, heces o ganglios linfáticos. La contaminación de la carne también puede ocurrir por contacto con equipos o utensilios, por manipulación, almacenamiento o conservación inapropiada de los productos en etapas del beneficio, posbeneficio, comercialización, venta o consumo. Por tal razón el control de *Salmonella* bajo un enfoque de cadena productiva y evaluación de riesgo es un aspecto fundamental para garantizar la calidad y la inocuidad de los alimentos de origen porcino en Colombia, contribuyendo a la salud pública y a mejorar la competitividad de la cadena. Se deben realizar estudios orientados a establecer las líneas base de la enfermedad y del microorganismo en cada una de las etapas, identificando el riesgo diferencial y estableciendo medidas de monitoreo, prevención y control.

Palabras clave: *carne, cerdo, contaminación cruzada, faenado, granja.*

Resumo

O gênero *Salmonella* agrupa ao redor de 2579 sorovariedades, a maioria delas zoonóticas, transmitidas por alimentos de origem animal, como a carne suína e seus derivados. Em humanos, a salmonelose não tifoide pode se manifestar como gastroenterite, septicemia ou pode ser assintomática. A presença de *Salmonella spp*. é de grande impacto na indústria produtora de carne suína pelas perdas econômicas por diagnóstico, tratamento e diminuição da produção. Esta doença constitui também uma barreira não alfandegária para a comercialização de alimentos, sendo também um grave problema de saúde pública. O microrganismo é introduzido nas granjas pelas matrizes e reprodutores, animais na fase de crescimento ou a través do alimento. Tanto os animais doentes quanto os portadores assintomáticos podem ser fontes de contaminação. Na fase prévia ao abate podem ser citados alguns fatores que podem favorecer a infecção e disseminação do microrganismo: contaminação dos caminhões somado ao tempo de transporte em veículos com alta densidade animal, jejum e estresse. Durante o processamento da carcaça, a contaminação está associada à depilação e polimento dos animais, assim como evisceração, presença de microrganismos na pele, cavidade oral, ampola retal, fezes ou linfonodos. A contaminação da carne pode acontecer pelo contato com equipamentos ou implementos, manuseio, armazenamento e conservação inadequada dos produtos nas etapas do abate e após do abate, comercialização, venda ou consumo. Diante do anteriormente exposto, na Colômbia é de fundamental importância direcionar o controle da *Salmonella* considerando um enfoque abrangente da cadeia produtiva, incluindo a avaliação do risco. Este enfoque permitirá garantir a qualidade e inocuidade dos alimentos de origem suíno, redundado em benefícios para a saúde pública e o aprimoramento da competitividade da cadeia. Devem ser realizados estudos orientados ao estabelecimento dos indicadores da presença e impacto da doença em cada uma das etapas produtivas, identificando o risco diferencial, para sentar as bases de medidas de monitoramento, prevenção e controle.

Palavras chave: *abate, carne suína, contaminação cruzada, granjas.*

Introduction

Foodborne disease can be caused by a wide variety of biological, chemical and physical hazards (CDC, 2007). The main cause of foodborne diseases of bacterial origin is *Salmonella* spp., *E. coli* O157:H7, *Campylobacter* spp., among others (Swartz, 2002; CDC, 2005).

Prevention and control of pathogens that cause foodborne diseases should take place in each stage of the supply chain; that is, all actors should guarantee food safety according to the concept of "*stable-to-table"* or "*farm-to-fork*", preventing or controlling infection and/or contamination to protect the health of the consumer.

Non-typhoid serovars of *Salmonella* spp. decrease pig production yield and increase production costs. Contaminated finished products (carcass, fresh pork and further processed by-products) are considered a public health risk and are restricted for international trade (non-tariff barrier), affecting the industry competitiveness. The negative impact of Salmonellosis in humans is related to diagnostic, treatment, cost of cases and outbreaks, and reduced productivity due to absence from work.

Salmonella control has a high impact in Colombia's pork industry, which has shown growth within the national economy (DANE, 2003). Productivity of this sector has significantly improved in the last fifteen years (DNP, 2007; MADR, 2005; FAOSTAT, 2010). Although Colombia's per capita pork consumption is low compared with the world's average (16 Kg), it increased from 2.9 Kg in 2002 to 5.9 Kg in 2012. The total slaughter for that year was 2,939,181 pigs, which is 6.6% higher than the previous year (Asoporcicultores, 2009 – 2013).

This review discusses *Salmonella* focusing on the supply chain. Colombian law regulated the supply chain in this country in 2003. It was stated that the primary production sector should set up monitoring, prevention and control programs. The harvest (slaughter) and postharvest (deboning and meat products) should implement specific control measures regarding quality concepts and food safety. In pre-slaughter, pigs may become infected during the lairage and the carcass may become contaminated in different stages of the slaughter process. Unsuitable manipulation and cross contamination are the main sources of contamination risk during deboning.

Salmonella general characteristics

The genus *Salmonella* spp. comprises gram-negative coccobacilli of the *Enterobacteriaceae* family, which are flagellated, non-spore forming, and facultative anaerobes. The pathogen can be found in the gastrointestinal tract of homeothermic and poikilothermic animals. This microorganism grows at temperatures between 6 °C and 45 °C and can survive freezing and drying, and persists even for years in organic substrates. They are inactivated by heat, direct sunlight, and disinfectants such as phenols, chlorates and iodines (Schwartz, 1999; Grimont *et al*., 2000).

The genus *Salmonella* includes two species: *S. enterica* (pathogenic) and *S. bongori,* (considered non-pathogenic). The first of these species comprises six subspecies designated by Roman numerals or numbers where I. is *Salmonella enterica* subspecies *enterica*, II. *S. enterica* subsp. *salamae*, IIIa. *S. enterica* subsp. *arizonae*, IIIb. *S. enterica* subsp. *diarizonae*, IV. *S. enterica* subsp. *houtenae* and VI. *S. enterica* subsp. *indica*. For nomenclature purposes, serovars may be designated only by genus and serovar. For example, *Salmonella enterica* subspecies *enterica* serovar Typhimurium may be designated as *Salmonella* Typhimurium (Brenner *et al*., 2000; Heyndrickx *et al*., 2005).

The WHO Collaborating Center for Reference and Research on *Salmonella*'s last report generated by the Pasteur Institute in 2007 includes 2,579 *Salmonella* spp. serovars in a broad range of hosts (Grimont and Weill, 2007). Certain serovars are better adapted to a single host, as in the case of typhoidal *S.* Typhi and *S.* Paratyphi in humans, and non-typhoidals, such as *S.* Dublin in cattle, *S.* Enteritidis in poultry, and *S.* Choleraesuis in swine. These serovars may be opportunistic in other species. In this regard, pigs may be infected by a broad range of non-typhoid serovars, constituting a source of contamination for pork (Schwartz, 1999).

Salmonellosis in humans

Non-typhoid salmonellosis in humans may manifest as gastroenteritis, bacteremia or a carrier state. The main signs are nausea, vomit, and light to moderate diarrhea. Among the non-typhoid serovars involved are *S.* Enteritidis, *S.* Typhimurium, *S.* Newport, *S.* Hadar, *S.* Derby, *S.* Heidelberg, *S.* Agona, *S.* Infantis and, on rare occasions, *S.* Choleraesuis (Gebreyes *et al*., 2004; Boyle *et al*., 2007; Foley *et al*., 2008; Schwartz, 1999). Mortality is lower than 1%, and usually occurs in children younger than five years old, older adults or immuno-compromised people (CDC, 2006). For *Salmonella* Choleraesuis, mortality may exceed 20% (CFSPH, 2005), although there is little association with contamination of carcasses and pork products (Schwartz, 1999).

Greig and Ravel (2009) estimated a worldwide association of 41.3% of foodborne disease with pork products consumption. Association between 5% and 25% of human salmonellosis cases with pork consumption has been reported in Europe and the United States (Borch *et al*., 1996; Berends *et al*., 1998; Lo Fo Wong *et al*., 2002; Hald *et al*., 2003; Wegener *et al*., 2003; CDC, 2005). One study showed that an average of 80.3 million cases occur globally each year, with 155,000 deaths, and incidence is 1,140 cases per 100,000 people (Majowicz *et al*., 2010).

Studies performed in recent years have estimated salmonellosis rates (per 100,000 people) of up to 23 in European countries, 17.7 to 28.1 in the United States (Swartz, 2002), 12.7 in Asia, 17.2 in Brazil (Helms *et al*., 2005) and almost 200 in Mexico (Gutiérrez-Cogco, Montiel-Vázquez *et al*., 2000). In general, it is thought that 22% of patients with salmonellosis are hospitalized and per each reported case there may be 38 unreported cases (Mead *et al*., 1999).

In the United States, the annual economic impact of the disease is estimated to be US $365 million in direct medical costs (CDC, 2011) and in US $3.3 billion in illness costs (Batz *et al*., 2011).

Salmonellosis in pigs

In pigs, the disease generates economic losses represented by morbidity and mortality, increase in the time needed to reach slaughter weight (90 Kg to 95 Kg), non-uniform batches, diagnostic expenditures and medications. In addition, the microorganism may persist in the farm environment due to continuous transmission between animals of all age groups (Schwartz, 1999). Regarding international trade, the presence of the microorganism represents a non-tariff barrier that restricts proper marketing and/or negotiation of pork products (Davies, 1997).

Salmonellosis is caused by numerous serovars, including Choleraesuis, Typhimurium, Derby, Saint Paul, Infantis, Heidelberg and Agona (Schwartz, 1999). The first serovar has been related primarily to septicemia in pigs (Gray *et al*., 1996; Chiu *et al*., 2004), while *S*. Typhimurium can cause enteritis, although it may also manifest in septicemia (Fedorka-Cray *et al*., 2000; Rostagno *et al*., 2003).

Salmonella spp. in farms

Most infected animals are asymptomatic carriers of various serovars (Giovannacci *et al*., 2001; Lo Fo Wong *et al*., 2002), meaning that the microorganisms may be transmitted constantly, thus making its control difficult and representing a potential source of indirect contamination of pork and pork products (Schwartz, 1999).

Between 30% and 60% of farms in the United States may be infected with at least one *Salmonella* serovar (Schwartz, 1999). In Canada, 83.3% of farms were reported positive, with 13.2% of pigs infected (Rajic *et al*., 2007).

Epidemiology focuses on microorganism introduction into the farm and transmission within the farm (Lo Fo Wong *et al*., 2002). The most important sources of infection are breeding stock and other pigs entering from other farms, followed by feed (Fedorka-Cray *et al*., 1997; Sauli *et al*., 2005; Österberg *et al*., 2010), water (Davies *et al*., 2004; Jensen *et al*., 2006), and other animals such as bovines, rodents, birds, insects, and pets (Fedorka-Cray *et al*., 2000; Hurd *et al*., 2002, Langvad *et al*., 2006; Fosse *et al*., 2009). The most important source of infection is the asymptomatic carrier pig (Schwartz, 1999), with fecal-oral route being the main form of transmission (Schwartz, 1999; Fedorka-Cray *et al*., 2000). *S*. Typhimurium has been isolated in feces up to 5 weeks after nose-nose contact with infected pigs (Proux *et al*., 2001).

Infection occurs rather quickly; *Salmonella* Typhimurium at a concentration of 1.5 x 10^3 UFC in feces can invade the gastrointestinal tract and the lymphatic nodes associated with the intestine (GALT: gut-associated lymphoid tissue) of exposed pigs in as little as 2 hours (Boughton *et al*., 2007). Three hours after experimental nasal inoculation, *S*. Typhimurium was detected in the cecum, and it was detected in mesenteric lymph nodes and tonsils after 6 hours (Fedorka-Cray *et al*., 1995).

The main source of contamination in slaughterhouses is pigs from infected farms. However, the microorganism's ability to quickly infect animals allows for infection during transport and/or lairage.

Salmonella spp. can persist in the intestinal mucosa, mesenteric lymphatic nodes or tonsils (Berends *et al*., 1998; Vieira-Pinto *et al*., 2005, Methner *et al*., 2011). In studies of groups of pigs, researchers isolated *S.* Typhimurium daily from feces during the 10 days post-infection and frequently during the following 4 to 5 months. At 5 to 7 months, approximately 90% of pigs were positive for the microorganism in mesenteric lymph nodes, tonsils, cecum or feces (Dickson *et al*., 2002; Jensen *et al*., 2006). *S.* Newport was isolated from mesenteric lymph nodes for up to 28 weeks and *S.* Choleraesuis for at least 12 weeks (Gray *et al*., 1995). In moist feces, this microorganism survives for 3 months, and in dry feces between 6 and 13 months (Schwartz, 1999; Dickson *et al*., 2002). *S.* Typhimurium and *S.* Dublin were isolated after almost a year in a moist and warm environment (CFSPH, 2005).

Pigs can acquire the carrier state with 10^4 CFU of *S.* Typhimurium (Dickson *et al*., 2002), and with 10^8 CFU, pigs may develop persistent infection lasting 12 weeks (Fedorka-Cray *et al*., 1995). Ingestion of more than 10^3 CFU of *Salmonella* per gram of feces may cause acute infection in pigs (Loynachan and Harris, 2005). Pigs can excrete 10^6 *S.* Choleraesuis/g of feces or 10^7 in the case of *S*. Typhimurium (Wood and Rose, 1992; Schwartz, 1999).

Salmonella spp. in pre-slaughter

Transportation time, stress due to handling, fasting, high animal density, environmental contamination, social regrouping, and time spent in pre-slaughter pens (lairage) can increase infection and/or dissemination of the microorganism among pig batches (Lo Fo Wong *et al*., 2002, Bolton *et al*., 2013, Kich *et al*., 2011, Hernández *et al*., 2013).

Contamination of trucks and pens during and after pig transport increases the probability of infection (Hurd *et al*., 2002; Mannion *et al*., 2008 and 2011; Swanenburg *et al*., 2001, Lo Fo Wong *et al*., 2002, Oliveira *et al*., 2005). The longer the pigs remain in lairage, the greater the risk of infection. Accordingly, one strategy could be to reduce lairage time. However, it is necessary for the pigs to rest for at least 2 hours to avoid affecting the organoleptic quality of pork.

More than twenty years ago, it was shown that infection prevalence could increase by 50% for every 24 hours spent in the pen (Morgan *et al*., 1987). In recent studies, prevalence increased 3 to 10 times for slaughtering plant samples in comparison to those taken at the farm. Also, additional serovars were recovered from plant samples, suggesting the existence of infection sources external to the farm (Berends *et al*., 1996; Hurd *et al*., 2001; Hurd *et al*., 2002) whereby these findings have been linked to the lairage (Boyen *et al*., 2008). Beloeil *et al*. (2004) reported that risk was four times greater when the microorganism was isolated from the cecum of pigs that remained for more than 6 hours in the pens compared to those that remained less than 6 hours.

Contamination with *S. enterica* has been found in lairage and drinking water offered to pigs (Rostagno *et al*., 2003; Hurd *et al*., 2002; Arguello *et al*., 2012). In one study, among the sampled pens, there was at least one positive sample; all pig groups tested positive for *S. enterica* in ileocecal lymph nodes and cecal contents. From 586 pigs, truck, and pen isolations, 36 different *Salmonella* spp. serovars were isolated. From 353 isolations in pigs (109 of ileocecal lymph nodes and 244 of cecal nodes), 27% corresponded to the same serovars isolated in the trucks, and 19% were related to those from pens (Rostagno *et al*., 2003).

With regard to stress, when animals are transported in trucks for 2 to 4 hours, increased levels of circulating cortisol or beta-endorphins and neutrophils are found (McGlone *et al*., 1993; Geverink *et al*., 1998). Stress may influence the outcome of many bacterial infections. Exposure to various stressors increases fecal shedding of these pathogens. Theoretically, the relationship between animal welfare and food safety is an effect that should not be overlooked (Verbrugghe *et al*., 2012).

Salmonella spp. at slaughter

Pigs can carry the microorganism in their skin, oral cavity, feces or lymph nodes (Lo Fo Wong *et al*., 2002), meaning that cross-contamination of carcasses occurs mainly through bacteria redistribution originating from positive pigs during the various slaughter stages (Berends *et al*., 1997; Botteldoorn *et al*., 2004; Busser *et al*., 2011).

In the initial stage of the process, during scalding, water can enter the lungs and contaminate the oral cavity and the pharynx; later, during the removal of the lungs, this liquid can contaminate the carcass. The dehairing equipment can continuously become contaminated with feces due to the movement of the pigs by the equipment. After flaming and during polishing, knives may favor distribution of microorganisms that were not eliminated by flaming. Additionally, knives may become contaminated if left undisinfected between carcasses. Contact of gastric contents with abdominal and thoracic cavities should be avoided during evisceration. The highest risk of contamination occurs upon separating the rectum and removing the viscera which may be perforated, their contents being able to contaminate the carcass, utensils and/or gloves of the workers (Borch *et al*., 1996; Fedorka-Cray *et al*., 2000; van Hoek *et al*., 2012).

With regard to carcass contamination, 5 to 15% occur during polishing, 55 to 90% during removal of viscera and 5 to 35% during other processes, such as rectum separation, ventral opening of the carcass, and meat inspection (Hald *et al*., 2003; Botteldoorn *et al*., 2004).

During the slaughter process, *Salmonella* spp prevalence was 6.3% (Zerby *et al*., 1998), 10.5% (Bouvet *et al*., 2003), 12.9% (Vieira-Pinto *et al*., 2005), 30% (Berends *et al*., 1997), and even as much as 37% (Botteldoorn *et al*., 2003) in carcass samples, and 24% (Bouvet *et al*., 2003) and as much as 53% (Botteldoorn *et al*., 2003) in environmental samples. These values may have resulted from increased infected animals during extended lairage. It is thought that as much as 30% positivity for *Salmonella* spp. may be due to cross-contamination during slaughter (Berends *et al*., 1997) and meat cutting (Lo Fo Wong *et al*., 2002). A prevalence of 18.8% has been found in mesenteric lymph nodes and in ileum, 13.9% (Vieira-Pinto *et al*., 2005).

Pigs from farms with higher positivity in fecal samples become the most contaminated carcass in the slaughterhouse (Foley *et al*., 2008). Thus, an initial strategy that can be implemented in plants is slaughtering first the animals from sero-negative farms to reduce the cross-contamination risk (Swanenburg *et al*., 2001). It is also possible to improve carcass decontamination processes by using products based on organic acids (Buncic, 2011).

The safety of pigs entering the slaughter process will determine the presence of the organism in subsequent stages. However, carcass contamination during harvest can originate from facilities, equipment, tools, staff, or even from other carcasses.

Salmonella spp. in post-slaughter

The most influential factors in meat cross-contamination with human pathogens are handling, storage, and product preservation when sufficient precautions and correct hygiene (e.g. washing and disinfecting hands, clothes and utensils) have not been taken. It should be assumed that carcasses do not conclude the process with absolute food safety in the slaughterhouse; so one or more carcasses may have a higher load of pathogenic bacteria with respect to the others and thus increase the probability of cross-contamination occurring (Berends *et al*., 1997; Gomez *et al*., 2012).

A study of Belgian cutting plants, which process 48% of the pig production in the country, found presence of *Salmonella* in 0% to 50% of meat samples in a single plant (Delhalle *et al*., 2009). In Ireland, prevalence reached up to 2.6%, with *S*. Typhimurium being the most common serovar (Prendergast *et al*., 2009), and in a study from New Zealand, the prevalence was 3.6% (Wong *et al*., 2009).

Salmonella can remain in the submaxillary lymph nodes or tonsils of living animals; therefore, when the head is separated from the carcass, microorganisms can come into direct contact with utensils or gloves, which subsequently represent a contamination risk

(Borch *et al*., 1996; Scherer *et. al*., 2008; Vieira-Pinto *et al*., 2005). European studies reported that microorganism prevalence in these tissues was 9.3% to 12.9% in nodes and 9.9% to 19.6% in tonsils (Swanenburg *et al*., 2001; Vieira-Pinto *et al*., 2005).

Ready-to-eat pork products commonly contain low price cuts such as meat of the arms and neck, and back fat. Such materials undergo considerable handling during transport and cutting, increasing the risk of cross-contamination. In spite of the fact that cutting plants and plants that elaborate ready-to-eat pork products depend to a certain degree on the microbial quality of the raw material, they also have responsibility for assuring the quality of their end-products.

The thermal process should eliminate the presence of *Salmonella* spp. during preparation of ready-to-eat products; so, theoretically, such products would be free of the pathogen. In spite of this process, evidence of *S*. Typhimurium prevalence has been reported in sausages in Ireland (Boughton *et al*., 2004).

The proportion of wholesale market for pork in Colombia; that is, hypermarkets and supermarkets, is smaller than that of small pork distributors. Some wholesalers have their own cutting plants and distribute the meat directly to the sale points. Some large distributors supply smaller ones, and they cut or sell pieces to small butchers. In addition, not all slaughtered animals at a plant are destined for consumption in the same city or region, meaning that the product may be transported long distances, increasing the risk of contamination due to improper handling and preservation.

There is always a risk of contamination during food handling. Cross-contamination can occur when using contaminated kitchen implements in foods that do not require cooking before consumption, for example, when the meat is cut on a board with a knife and the knife is later used to cut vegetables that will be consumed as salad. In addition, proper cooking time and temperature should be used. The supply chain ends when the product is consumed.

Salmonella and international trade

The presence of non-typhoid *Salmonella* spp. serovars in food affects its safety and thus its international trade. The WTO (World Trade Organization) considers food safety a fundamental subject integrated into commerce to protect consumers in any part of the world where the product may be marketed. The FAO (Food and Agriculture Organization) and the WHO (World Health Organization) establish directives through the *Codex Alimentarius* to guarantee the marketing of safe foods. Likewise, the WTO recognizes OIE (currently World Organization for Animal Health) guidelines as the international reference.

The SPS agreement (Sanitary and Phytosanitary Measures) of the WTO establishes the guiding principles to protect the health and life of people and animals and to preserve plants for international trade. The CONPES 3458 framework of 2007 established the political guidelines on animal health and food safety for the pork supply chain in Colombia.

Although studies toward establishing a baseline for this microorganism have been conducted, health status regarding *Salmonella* spp. is still not known in Colombia. Therefore, future studies and projects should investigate non-typhoid *Salmonella* prevalence in each stage of the supply chain. In addition, further molecular and genomic studies are needed for epidemiological purposes to determine the current serovars present in the country and the clonal relationships among stages.

A productive approach would include inspection, surveillance, and control by official agencies in each stage of the chain, and voluntary programs should be established for monitoring, controlling, and implementing quality and safety systems (Good Practices, HACCP, ISO Standards) to ensure production of safe food under the concept of "stable to table". This way, consumer health would be protected, generating confidence in the product and improving market competitiveness.

In 2007 the Ministry of Health and Social Protection of Colombia issued Decree 1500 (normalized by resolution 4282 of the same year), which regulates inspection, monitoring and control of fresh pork and further processed by-products. Article 51 describes the performance standard for *Salmonella* spp.

As a part of the policy framework mentioned in the CONPES document, the College of Veterinary Medicine and Animal Science of the Universidad Nacional de Colombia completed in 2011 the project entitled "Isolation and molecular characterization of *Salmonella* strains, antimicrobial susceptibility and microbiological risk assessment of contamination in carcass, cuts and pork products, strategies for prevention and control in slaughterhouse and processing plants". This project was funded by the Colombian Ministry of Agriculture and Rural Development to establish the presence of the organism in pre-slaughter, slaughter and post-slaughter stages in Colombia. The results are currently in publication process.

Perspectives

Control of *Salmonella* with a focus on the supply chain and risk assessment is fundamental for guaranteeing the quality and food safety of pork products in Colombia, which, in turn, contributes to public health and increases competitiveness of the chain. This goal is attainable; it has already been achieved in Denmark, which began a *Salmonella* control program in 1993 with an emphasis on primary production. Initial investment for that year was $15.5 million and managed to reduce the incidence of human salmonellosis from 24 to fewer than 5 cases per 100,000 people in 2001. If the program had not been implemented, the estimated losses due to contamination would have been $41 million per year (Wegener *et al*., 2003).

Studies should be conducted to establish baselines for *Salmonella* contamination in each stage of the pork supply chain in Colombia, identifying the differential risks and establishing measures to monitor prevention and reduction in the relevant processes. Controlling the microorganism will require the coordinated actions of each actor in every stage of the supply chain. It also requires implementing quality and food safety systems, official and voluntary adoption, and also the integrated participation of industry with the official and academic sectors.

Salmonella results obtained in the pork supply chain could be related to isolates from human cases in our country, which would allow more targeted and specific strategies.

Achieving these goals should allow improving scientific, technical and operational capacity of official laboratories. It would also help improving diagnostic and university laboratories to develop research projects by implementing reference techniques.

Validation and transfer of research results will enable authorities to focus on national programs aimed at discussing food safety issues on international trade and public health.

Prevention and control of *Salmonella* in foods of animal origin requires participation and interaction of all actors in the production chain: the official, the production, and academic sectors. This will contribute to improved competitiveness of the chain and encourage the opening of new markets under the Sanitary and Phytosanitary Measures framework agreement.

References

Arguello H, Carvajal A, Collazos JA, García-Feliz C, Rubio P. Prevalence and serovars of *Salmonella enterica* on pig carcasses, slaughtered pigs and the environment of four Spanish slaughterhouses. Food Res Int 2012; 45:905-912.

Asoporcicultores. Asociación Colombiana de Porcicultores, Área económica, Costos y estudios varios. Informes, 2009, 2010 y 2011. [Access date: January, 2014] URL: http://www.porcicol.org.co/economica/estudios.php.

Batz MB, Hoffmann S, Glenn Morris J Jr. Ranking the Risks: The 10 Pathogen-Food combinations with the greatest burden on public health. University of Florida, Emerging Pathogens Institute; 2011.

Beloeil PA, Chauvin C, Proux K, Madec F, Fravalo P, Alioum A. Impact of the *Salmonella* status of market-age pigs and the pre-slaughter process on *Salmonella* caecal contamination at slaughter. Vet Res 2004; 35:513-530.

Berends BR, Urlings HAP, Snijders JMA, Van Knapen F. Identification and quantification of risk factors in animal management and transport regarding *Salmonella* spp. in pigs. Int J Food Microbiol 1996; 30:37-53.

Berends BR, Van Knapen F, Snijders JMA, Mossel DAA. Identification and quantification of risk factors regarding *Salmonella* spp. on pork carcasses. Int J Food Microbiol 1997; 36:199-206.

Berends BR, Van Knapen F, Mossel DAA, Burt SA, Snijders JMA. Impact on human health of *Salmonella* spp. on pork in The Netherlands and the anticipated effects of some currently proposed control strategies. Int J Food Microbiol 1998; 44:219-229.

Bolton DJ, Ivory C, McDowell D. A study of *Salmonella* in pigs from birth to carcass: Serotypes, genotypes, antibiotic resistance and virulence profiles. Int J Food Microbiol 2013; 160:298-303.

Borch E, Nesbakken T, Christensen H. Hazard identification in swine slaughter with respect to foodborne bacteria. Int J Food Microbiol 1996; 30:9-25.

Botteldoorn N, Heyndrickx M, Rijpens N, Grijspeerdt K, Herman L. *Salmonella* on pig carcasses: positive pigs and cross contamination in the slaughterhouse. J Appl Microbiol 2003; 95:891-903.

Botteldoorn N, Herman L, Rijpens N, Heyndrickx M. Phenotypic and molecular typing of *Salmonella* strains reveals different contamination sources in two commercial pig slaughterhouses. Appl Environ Microbiol 2004; 70:5305.

Boughton C, Leonard FC, Egan J, Kelly G, O'Mahony P, Markey BK, Griffin M. Prevalence and number of *Salmonella* in Irish retail pork sausages. J Food Prot 2004; 67:1834-1839.

Boughton C, Egan J, Kelly G, Markey B, Leonard N. Rapid infection of pigs following exposure to environments contaminated with different levels of *Salmonella* Typhimurium. Foodborne Pathog Dis 2007; 4:33-40.

Bouvet J, Bavai C, Rossel R, Le Roux A, Montet MP, Mazuy C, Vernosy-Rozand C. Evolution of pig carcass and slaughterhouse environment contamination by *Salmonella*. Revue Méd Vét 2003; 154:775-779.

Boyen F, Haesebrouck F, Maes D, Van Immerseel F, Ducatelle R, Pasmans F. Non-typhoidal *Salmonella* infections in pigs: A closer look at epidemiology, pathogenesis and control. Vet Microbiol 2008; 130:1-19.

Boyle EC, Bishop JL, Grassl GA, Finlay BB. *Salmonella*: from pathogenesis to therapeutics. J Bacteriol 2007; 189:1489.

Brenner F, Villar R, Angulo FJ, Tauxe R, Swaminathan B. *Salmonella* nomenclature. J Clin Microbiol 2000; 38:2465.

Buncic S, Sofos J. Interventions to control *Salmonella* contamination during poultry, cattle and pig slaughter. Food Res Int 2011; 45:641-655.

CDC. Center for Disease Control, *et al*. Foodborne illness; 2005.

Center for Disease Control. *Salmonella Surveillance:* Annual Summary. [Access date: January 3, 2014] URL: http://www.cdcgov/ncidod/dbmd/phlisdata [serial online]. 2006.

Center for Disease Control. Foodborne infection. 2007.

Center for Disease Control and Prevention. Vital signs: incidence and trends of infection with pathogens transmitted commonly through food — Foodborne Diseases Active Surveillance Network, 10 U.S. Sites, 1996–2010. Morbidity and Mortality Weekly Report MMWR, 2011; 60:749-755.

CFSPH. The Center for Food Security and Public Health. Animal Disease Factsheets: Salmonellosis. Iowa State University; 2005.

Chiu CH, Su LH, Chu C. *Salmonella* enterica serovar Choleraesuis: epidemiology, pathogenesis, clinical disease, and treatment. Clin Microbiol Rev 2004; 17:311.

Departamento Administrativo Nacional de Encuestas. Censo de la actividad porcícola tecnificada en Colombia; 2003. [Access date: January 3, 2014] URL: http://www.dane.gov.co/files/investigaciones/agropecuario/ena/I-Censo_Porcicola_2003.pdf

Departamento Nacional de Planeación. Conpes 3458; 2007.

Davies P. Food safety and its impact on domestic and export markets. J Swine Health Prod 1997; 5:13-20.

Davies PR, Scott Hurd H, Funk JA, Fedorka-Cray PJ, Jones FT. The role of contaminated feed in the epidemiology and control of *Salmonella* enterica in pork production. Foodborne Pathog Dis 2004; 1:202-215.

Delhalle L, De Sadeleer L, Bollaerts K, Farnir F, Saegerman C, Korsak N, Dewulf J, De Zutter L, Daube G. Risk factors for *Salmonella* and hygiene indicators in the 10 largest Belgian pig slaughterhouses. J Food Prot 2008; 71:1320-1329.

Delhalle L, Saegerman C, Farnir F, Korsak N, Maes D, Messens W, De Sadeleer L, De Zutter L, Daube G. *Salmonella* surveillance and control at post-harvest in the Belgian pork meat chain. Food Microbiol 2009; 26:265-271.

De Busser EV, Maes D, Houf K, Dewulf J, Imberechts H, Bertrand S, De Zutter L. Detection and characterization of *Salmonella* in lairage, on pig carcasses and intestines in five slaughterhouses. Int J Food Microbiol 2011; 145:279-286.

Dickson J, Hurd H, Rostagno MH. *Salmonella* in the Pork Production Chain. National Pork Board. Pork Information Gateway. 2002.

FAOSTAT. Statistics. Food and Agricultural commodities production; 2010.

Fedorka-Cray PJ, Kelley LC, Stabel TJ, Gray JT, Laufer JA. Alternate routes of invasion may affect pathogenesis of *Salmonella* typhimurium in swine. Infect Immun1995; 63:2658.

Fedorka-Cray P, Hogg A, Gray JT, Lorenzen K, Velasquez J, Von Behren P. Feed and feed trucks as sources of *Salmonella* contamination in swine. J Swine Health Prod 1997; 5:189-194.

Fedorka-Cray PJ, Gray JT, Wray C. *Salmonella* Infections in Pigs. In: Wray A, Wray C, editors. *Salmonella* in Domestic Animals. London: CABI; 2000. p. 191-208.

Foley S, Lynne A, Nayak R. *Salmonella* challenges: prevalence in swine and poultry and potential pathogenicity of such isolates. J Anim Sci 2008; 86 Suppl:E149.

Fosse J, Seegers H, Magras C. Prevalence and risk factors for bacterial food borne zoonotic hazards in slaughter pigs: a review. Zoonoses Public Health 2009; 56:429-454.

García-Feliz C, Collazos JA, Carvajal A, Vidal AB, Aladueña A, Ramiro R, de la Fuente M, Echeita MA, Rubio P. *Salmonella enterica* infections in spanish swine fattening units. Zoonoses Public Health 2007; 54:294-300.

Gebreyes W, Thakur S, Davies P, Funk J, Craig A. Trends in antimicrobial resistance, phage types and integrons among *Salmonella* serovars from pigs, 1997-2000. J Antimicrob Chemother 2004; 53:997.

Geverink NA, Bradshaw RH, Lambooij E, Wiegant VM, Broom DM. Effects of simulated lairage conditions on the physiology and behaviour of pigs. Vet Rec 1998; 143:241.

Giovannacci I, Queguiner S, Ragimbeau C, Salvat G, Vendeuvre JL, Carlier V, Ermel G. Tracing of *Salmonella* spp. in two pork slaughter and cutting plants using serotyping and macrorestriction genotyping. J Appl Microbiol 2001; 90:131-147.

Gomez E, Antunes P, Tavares A, Themudo P, Fonseca M, Gärtner F, Costa JM, Peixe L. *Salmonella* cross-contamination in swine abattoirs in Portugal: Carcasses, meat and meat handlers. Int J Food Microbiol 2012; 157:82-87.

Gray JT, Fedorka-Cray P, Stabel T, Kramer T. Natural transmission of *Salmonella* choleraesuis in swine. Appl Environ Microbiol 1996; 62:141-146.

Gray JT, Fedorka-Cray PJ, Stabel TJ, Ackermann MR. Influence of inoculation route on the carrier state of *Salmonella choleraesuis* in swine. Vet Microbiol 1995; 47:43-59.

Greig J, Ravel A. Analysis of foodborne outbreak data reported internationally for source attribution. Int J Food Microbiol 2009; 130:77-87.

Grimont P, Grimont F, Bouvet P. Taxonomy of the genus *Salmonella*. In: Wray C, Wray A, editors. *Salmonella* in Domestic Animals. London: CABI; 2000. p. 1-18.

Grimont P, Weill F. "Antigenic formulae of the *Salmonella* serovars". WHO Collaborating Centre for Reference and Research on *Salmonella*. 2007

Gutiérrez-Cogco L, Montiel-Vázquez E, Aguilera P, Gonzalez M. Serotipos de *Salmonella* identificados en los servicios de salud de México. Salud Públ Méx 2000; 42:490-495.

Hald T, Wingstrand A, Swanenburg M, von Altrock A, Thorberg BM. The occurrence and epidemiology of *Salmonella* in European pig slaughterhouses. Epidemiol Infect 2003; 131:1187-1203.

Helms M, Ethelberg S, Molbak K. International *Salmonella* Typhimurium DT104 infections, 1992-2001. Emerg Infect Dis 2005; 11:859-867.

Hernández M, Gómez J, Luque I, Herrera S, Maldonado A, Reguillo L, Astorga RJ. *Salmonella* prevalence and characterization in a free-range pig processing plant:Tracking in trucks, lairage, slaughter line and quartering. Int J Food Microbiol 2013; 162:48-54.

Heyndrickx M, Pasmans F, Ducatelle R, Decostere A, Haesebrouck F. Recent changes in *Salmonella* nomenclature: the need for clarification. Vet J 2005; 170:275.

Hohmann, E. Nontyphoidal salmonellosis. Clin Infect Dis 2001; 32: 263-269.

Hurd H, Gailey J, McKean J, Rostagno M. Rapid infection in market-weight swine following exposure to a *Salmonella* Typhimurium-contaminated environment. Am J Vet Res 2001; 62:1194-1197.

Hurd H, McKean JD, Griffith RW, Wesley IV, Rostagno M. *Salmonella enterica* infections in market swine with and without transport and holding. Appl Environ Microbiol 2002; 68:2376.

Jensen A, Dalsgaard A, Stockmarr A, Nielsen E, Baggesen DL. Survival and transmission of *Salmonella* enterica serovar Typhimurium in an outdoor organic pig farming environment. Appl Environ Microbiol 2006; 72:1833.

Kich JD, Coldebella A, Morés N, Gomes M, Cardoso M, Fratamico PM, Call JE. Prevalence, distribution, and molecular characterization of *Salmonella* recovered from swine finishing herds and a slaughter facility in Santa Catarina, Brazil. Int J Food Microbiol 2011; 151:307-313.

Langvad B, Skov M, Rattenborg E, Olsen JE, Baggesen DL. Transmission routes of *Salmonella* Typhimurium DT 104 between 14 cattle and pig herds in Denmark demonstrated by molecular fingerprinting. J Appl Microbiol 2006; 101:883-890.

Lo Fo Wong D, Hald T, van der Wolf PJ, Swanemburg M. Epidemiology and control measures for *Salmonella* in pigs and pork. Livest Prod Sci 2002; 76:215-222.

Loynachan A, Harris D. Dose determination for acute *Salmonella* infection in pigs. Appl Environ Microbiol 2005; 71:2753.

Ministerio de Ambiente y Desarrollo Rural. La industria de carnes frescas en Colombia. Observatorio Agrocadenas, 2005.

Majowicz S, Musto J, Scallan E, Angulo F, Kirk M, O'Brien S, Jones T, Fazil A, Hoekstra R. The Global Burden of Nontyphoidal *Salmonella* Gastroenteritis. Clin Infect Dis 2010; 50:882-889.

Mannion C, Egan J, Lynch BP, Fanning S, Leonard N. An investigation into the efficacy of washing trucks following the transportation of pigs--a *Salmonella* perspective. Foodborne Pathog Dis 2008; 5:261-71.

Mannion C, Fanning J, McLernon J, Lendrum L, Gutierrez M, Duggan S, Egan J. The role of transport, lairage and slaughter processes in the dissemination of *Salmonella* spp. in pigs in Ireland. Food Res Int 2012; 45:871-879.

McGlone J, Salak J, Lumpkin EA, Nicholson RI, Gibson M, Norman RL. Shipping stress and social status effects on pig performance, plasma cortisol, natural killer cell activity, and leukocyte numbers. J Anim Sci 1993; 71:888.

Methner U, Rammler N, Fehlhaber K, Rösler U. *Salmonella* status of pigs at slaughter — Bacteriological and serological analysis. Int J Food Microbiol 2011; 151:15-20.

Molla B, Sterman A, Mathews J, Artuso-Ponte V, Abley M, Farmer W, Rajala-Schultz P, Morrow WE, Gebreyes W. *Salmonella* enterica in commercial swine feed and subsequent isolation of phenotypically and genotypically related strains from fecal sample. Appl Environ Microbiol 2010; 76:7188-7193.

Morgan I, Krautil F, Craven J. Effect of time in lairage on caecal and carcass *Salmonella* contamination of slaughter pigs. Epidemiol Infect 1987;98:323-330.

Oliveira C, Carvalho L, Fernandes S, Tavechio A, Domingues Jr FJ. Prevalence of pigs infected by *Salmonella* Typhimurium at slaughter after an enterocolitis outbreak. Int J Food Microbiol 2005; 105:267-271.

Österberg J, Wallgren P. Effects of a challenge dose of *Salmonella* Typhimurium or *Salmonella* Yoruba on the patterns of excretion and antibody responses of pigs. Vet Rec 2008; 162:580-5806.

Österberg J, Lewerin S, Wallgren P. Direct and indirect transmission of four *Salmonella* enterica serovars in pigs. Acta Vet Scand 2010; 52:30-30.

Prendergast DM, Duggan SJ, Gonzales-Barron U, Fanning S, Butler F, Cormican M, Duffy G. Prevalence, numbers and characteristics of *Salmonella* spp. on Irish retail pork. Int J Food Microbiol 2009; 131:233-239.

Proux K, Cariolet R, Fravalo P, Houdayer C, Keranflech A, Madec F. Contamination of pigs by nose-to-nose contact or airborne transmission of *Salmonella* Typhimurium. Vet Res 2001; 32:591-600.

Rajic A, Chow E, Wu J, Deckert A, Reid-Smith R, Manninen K, Dewey C, Fleury M, McEwen S. *Salmonella* infections in ninety Alberta swine finishing farms: serological prevalence, correlation between culture and serology, and risk factors for infection. Foodborne Pathog Dis 2007; 4:169-177.

Rostagno M, Hurd H, McKean JD, Ziemer CJ, Gailey JK, Leite RC. Preslaughter holding environment in pork plants is highly contaminated with *Salmonella* enterica. Appl Environ Microbiol 2003; 69:4489.

Sauli I, Danuser J, Geeraerd AH, Van Impe JF, Rufenacht J, Bissig-Choisat B, Wenk C, Stark KDC. Estimating the probability and level of contamination with *Salmonella* of feed for finishing pigs produced in Switzerland--the impact of the production pathway. Int J Food Microbiol 2005; 100:289-310.

Scallan E, Hoekstra R, Angulo F, Tauxe R, Widdowson MA, Roy S, Jones J, Griffin P. Foodborne illness acquired in the United States—Major Pathogens. Emerg Infect Dis 2011; 17:7-15.

Scherer K, Szabó I, Rösler U, Appel B, Hensel A, Nöckler K. Time course of infection with *Salmonella* typhimurium and its influence on fecal shedding, distribution in inner organs, and antibody response in fattening pigs. J Food Prot 2008; 71:699-705.

Schwartz K. Salmonellosis. In: Straw B, D´Allaire S, Mengeling W and Taylor D, editors. Diseases of Swine. 8th ed. Ames: Iowa State University Press; 1999. p. 535-551.

Swanenburg M, Urlings H, Snijders J, Keuzenkamp D, van Knapen F. *Salmonella* in slaughter pigs: prevalence, serovars and critical control points during slaughter in two slaughterhouses. Int J Food Microbiol 2001; 70:243-254.

Swanenburg M, Urlings HA, Keuzenkamp DA, Snijders JM. *Salmonella* in the lairage of pig slaughterhouses. J Food Prot 2001, 64:12-16.

Swanenburg M, van der Wolf P, Urlings H, Snijders J, van Knapen F. *Salmonella* in slaughter pigs: the effect of logistic slaughter procedures of pigs on the prevalence of *Salmonella* in pork. Int J Food Microbiol 2001; 70: 231-242.

Swartz M. Human diseases caused by foodborne pathogens of animal origin. Clin Infect Dis 2002; 34:111-122.

Van Hoek A, de Jonge R, van Overbeek WM, Bouw E, Pielaat A, Smid JH, Malorny B. A quantitative approach towards a better understanding of the dynamics of *Salmonella* spp. in a pork slaughter-line. Int J Food Microbiol 2012; 153:45-52.

Verbrugghe E, Boyen F, Gaastra W, Bekhuis L, Leyman B, Van Parys A, Haesebrouck F, Pasmans F. The complex interplay between stress and bacterial infections in animals. Vet Mic 2012; 155:115-127.

Vieira-Pinto M, Temudo P, Maritns C. Occurrence of *Salmonella* in the ileum, ileocolic lymph nodes, tonsils, mandibular lymph nodes and carcasses of pigs slaughtered for consumption. J Vet Med B 2005; 52:476-481.

Wegener H, Hald T, Lo Fo Wong D, Madsen M, Korsgaard H, Bager F, Gerner-Smidt P, Mølbak. *Salmonella* control programs in Denmark. Emerg Infect Dis 2003; 9:774-780.

Wilkins W, Rajic A, Waldner C, McFall M, Chow E, Muckle A, Rosengren L. Distribution of *Salmonella* serovars in breeding, nursery, and grow-to-finish pigs, and risk factors for shedding in ten farrow-to-finish swine farms in Alberta and Saskatchewan. Can J Vet Res 2010; 74:81-90.

Wong TL, MacDiarmid S, Cook R. *Salmonella*, Escherichia coli O157:H7 and E. coli biotype 1 in a pilot survey of imported and New Zealand pig meats. Food Microbiol 2009; 26:177-182.

Wood R, Rose R. Populations of *Salmonella* typhimurium in internal organs of experimentally infected carrier swine. Am J Vet Res 1992; 53:653.

Zerby HN, Belk KE, Sofos JN, Schmidt GR, Smith GC. Microbiological sampling of hog carcasses. Final Report. Fort Collins: Colorado State University, 1998.