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Quantitative Risk Assessment of Human Trichinellosis Caused by Consumption of Pork Meat Sausages in Argentina

G. J. Sequeira[1], M. V. Zbrun[1,2], L. P. Soto[1,2], D. M. Astesana[1,2], J. E. Blajman[1,2], M. R. Rosmini[1,3], L. S. Frizzo[1,2] and M. L. Signorini[1,4]

[1] Department of Public Health, Faculty of Veterinary Science, National University of the Littoral, Esperanza, Santa Fe, Argentina
[2] Laboratorio de Análisis de Alimentos, Instituto de Ciencias Veterinarias del Litoral, Consejo Nacional del Investigaciones Científicas y Técnicas (ICIVET Litoral-CONICET/UNL), Esperanza, Santa Fe, Argentina
[3] Faculty of Agricultural Science, Catholic University of Córdoba, Córdoba, Córdoba, Argentina
[4] National Council of Scientific and Technical Research (CONICET), National Institute of Agricultural Technology (INTA) EEA Rafaela, Rafaela, Santa Fe, Argentina

Impacts

- This quantitative risk assessment identified the proportion of pigs raised in clandestine farms and the prevalence of *Trichinella* larvae in muscle of pigs as the two variables with the greatest impact on the likelihood of human trichinellosis.
- The consumption of pork meat sausages produced and processed clandestinely remains as the main route of trichinellosis transmission.
- More aggressive campaigns have to be implemented to eradicate clandestine pig breeding as well as to educate the consumers of homemade sausages about the risks of being exposed to *Trichinella*.

Keywords:
Trichinellosis; pork meat; quantitative risk assessment

Correspondence:
L. S. Frizzo. Laboratorio de Análisis de Alimentos, Instituto de Ciencias Veterinarias del Litoral, Consejo Nacional del Investigaciones Científicas y Técnicas (ICIVET Litoral-CONICET/UNL), Kreder 2805 (S3080HOF), Esperanza, Santa Fe, Argentina.
Tel.: +54 3496 420639 int 128;
Fax: +54 3496 426304;
E-mail: lfrizzo@fcv.unl.edu.ar

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Summary

In Argentina, there are three known species of genus *Trichinella*; however, *Trichinella spiralis* is most commonly associated with domestic pigs and it is recognized as the main cause of human trichinellosis by the consumption of products made with raw or insufficiently cooked pork meat. In some areas of Argentina, this disease is endemic and it is thus necessary to develop a more effective programme of prevention and control. Here, we developed a quantitative risk assessment of human trichinellosis following pork meat sausage consumption, which may be used to identify the stages with greater impact on the probability of acquiring the disease. The quantitative model was designed to describe the conditions in which the meat is produced, processed, transported, stored, sold and consumed in Argentina. The model predicted a risk of human trichinellosis of 4.88×10^{-6} and an estimated annual number of trichinellosis cases of 109. The risk of human trichinellosis was sensitive to the number of *Trichinella* larvae that effectively survived the storage period ($r = 0.89$), the average probability of infection (P_{Pinf}) ($r = 0.44$) and the storage time (Storage) ($r = 0.08$). This model allowed assessing the impact of different factors influencing the risk of acquiring trichinellosis. The model may thus help to select possible strategies to reduce the risk in the chain of by-products of pork production.

Introduction

Trichinellosis is a foodborne parasitic disease, which not only is responsible for morbidity and mortality, especially in endemic areas, but also causes considerable economic losses in animal production (Gottstein et al., 2009). In Argentina, there are three known species of *Trichinella,* which include *Trichinella spiralis*, *T. pseudospiralis* and *T. patagoniensis* (Krivokapich et al., 2012, 2015). *Trichinella spiralis* is most commonly associated with domestic pigs, and it was identified as the main cause of trichinellosis by the consumption of products made with raw or insufficiently cooked pork meat (Ribicich et al., 2005). The other species mentioned have low relative infectivity for pigs and are primarily of importance because they occur in game animals. *Trichinella spiralis* lives either as an adult in the small intestine of many mammalian species or as encysted larvae in the musculature of these hosts, where it can remain viable for a long time (Gottstein et al., 2009).

The endemicity of the disease in humans is mainly due to cultural patterns in which food consumption containing raw or semi-cooked pork meat in the form of sausages is common. These types of foods are especially risky when the meat used for processing comes from pigs slaughtered and processed in the family, without veterinary inspection or proper diagnosis for the presence of *Trichinella* larvae (Caracostantogolo et al., 2007).

In general, in Argentina, the commercial distribution of pork meat is controlled. However, most outbreaks occur in the family circuit of upbringing and subsistence. In Santa Fe Province, as in other endemic areas of Argentina, several situations, mainly those directly related to sausage production and marketing systems, contribute to the continuous recurrence of the urban cycle of animal trichinellosis (Sequeira, 2001). In this province, a total of 62 trichinellosis outbreaks were reported in the period 1993–1999, with 942 sick people. These outbreaks were epidemiologically associated with the consumption of homemade sausages (31%) and illegal marketing of pork meat (31%), with a seasonal presentation focused in the winter months (23 outbreaks). However, this information presented underreporting because outbreaks are rarely investigated (Sequeira et al., 2013).

The aim of this study was to evaluate the probability of human trichinellosis due to the consumption of sausages made with pork meat in Santa Fe Province (Argentina) using a quantitative risk assessment model.

Materials and Methods

Model development

The prevalence and level of *Trichinella* larvae were modelled at various stages along the food chain of sausage production in Santa Fe Province. The conceptual model upon which the mathematical model was based is shown in Fig. 1. The model was created in Microsoft Excel 2007 with the add-on package @Risk (version 4.0; Palisade Corporation, Newfield, NY, USA). The main output of the model was the probability of human trichinellosis as a consequence of the consumption of sausage prepared with pork meat. This probability was estimated through 5000 iterations with Latin hypercube sampling. The number of iterations provided adequate convergence of the simulation statistics (<1%).

Essentially, the model was developed using inputs derived from data obtained directly by our and others groups from Argentina. However, where Argentina-specific data were not available (e.g. dose–response model), international data and scientific literature were consulted to improve the basis for the model.

The exposure model was divided into five modules (P1–P5) which allowed analysing the different steps in the process of elaboration of pork meat sausages in detail: type of production (official versus non-official), prevalence of *Trichinella* in pork, pork carcasses used for sausage production, pork meat destined to sausage production and proportion of pork meat in the sausage.

All the variables used in this quantitative risk assessment model and their probability distribution and parameters are presented in Table 1.

Swine production system

In 2010, slaughter of pigs in Santa Fe Province amounted to 649 881 animals, approximately 20% of the national production. Most of the slaughterhouses in this province are full cycle, that is in addition to deboning pig carcasses, they sell fresh cuts and some produce sausage products (INTA, 2013).

In the official system of production, the prevalence of trichinellosis in recent years has been very low (Ribicich et al., 2005). Official slaughterhouses apply quality controls in accordance with standards established by the appropriate regulatory agency. A hundred per cent of these establishments reported having performed analysis of trichinellosis using artificial digestion technique (INTA, 2013). In contrast, the non-official system of swine meat production (family production or production of subsistence) has been associated with the human trichinellosis outbreaks. In these production systems, risk factors associated with the presence of trichinellosis, such as the feeding of animals with household waste, exposure of animals to wildlife and the lack of sanitary controls, are commonly identified (Sequeira et al., 2013).

In Santa Fe Province, 91% of the animals are slaughtered in official slaughterhouses, with a stock of 381 326 heads. Eight per cent of pigs (32 987 heads) are slaughtered for household consumption and the other 1% (5952 heads) for subsistence purposes (Caracostantogolo et al., 2007). Based on this information, the probability that the animals come from non-official slaughterhouses or family production (P_{noff}) was modelled using a beta distribution.

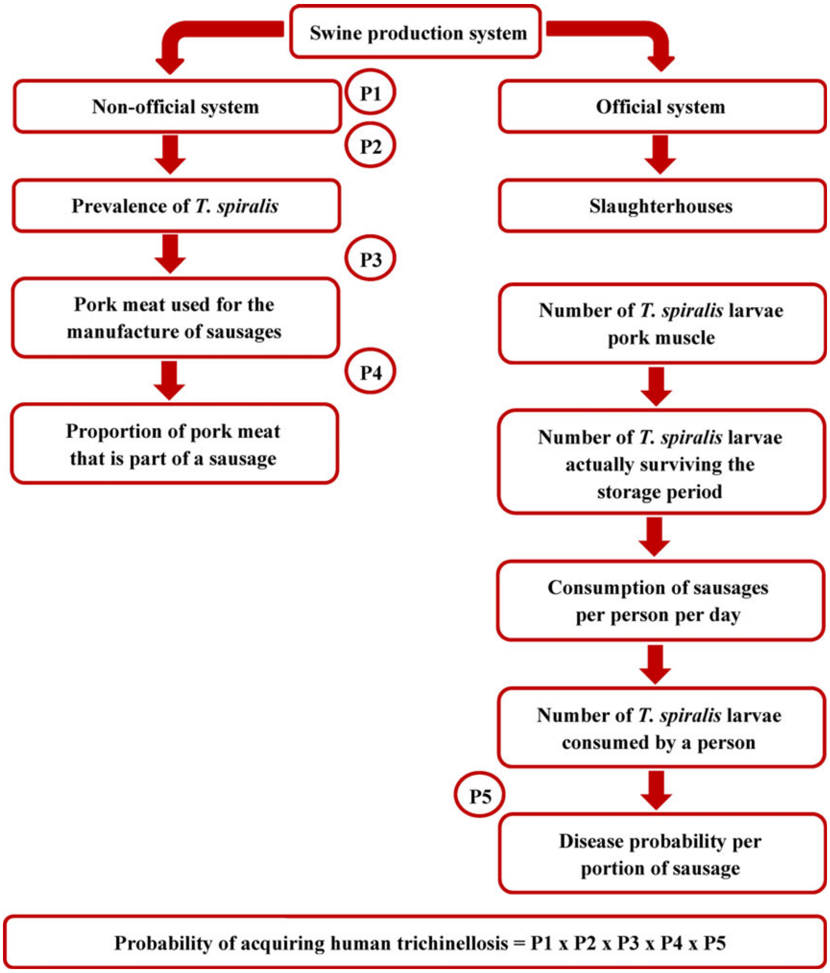

Fig. 1. Flow diagram of the mathematical model of risk assessment for trichinellosis caused by the consumption of pork meat sausages.

Prevalence of *Trichinella* in pigs from the non-official system

Many studies in Argentina have been conducted with the aim to estimate the prevalence of *Trichinella* in non-official pork production (Table 2). This information was used to estimate the pork-prevalence distribution, whose parameters were estimated using the method of moments (Vose, 1996) and assuming that the prevalence could be characterized with a beta distribution ($\mathrm{Pr}_{\mathrm{noff}}$).

Use of pork carcasses

During 2011, pork carcasses were processed for fresh meat and sausage production equally. However, in the period 2001–2011, the consumption of sausage produced with pork meat increased from 314 000 t in 2001 to 422 000 t in 2011 (CAICHA, 2011).

While there is uncertainty about the proportion of pork meat used for the manufacture of sausages (P_{saus}), for the construction of this risk assessment, we considered it as 50%.

Pork meat processed to sausage

The carcass of slaughtered pigs in Argentina has an average weight of 89.04 kg (range 85.7–91.6 kg), with a percentage of yield of lean meat of 55.68% (range 48.0%–60.4%) on average, and variations correspond to the evaluation of different breeds (Landrace, Large White, Duroc, Pietrain, Hampshire) (Gispert et al., 2012).

Taking into account the information available, the proportion of pork derived to sausage production (P_{sap}) was modelled using a PERT distribution, with minimum, most likely, and maximum values of 48%, 55.68% and 60.4%, respectively.

Proportion of pork meat included into the sausage

The main raw materials to produce sausages are meat and fat. In Argentina, sausages produced in official slaughterhouses used lean meat, especially ham, fillet, hindleg, back and sublumbar muscles. However, homemade sausages include in their formulation other muscular groups such as neck, throat and lower jaw. The casings, spices and

Table 1. Model input parameters

Variable	Description	Unit	Distribution/Model
P_{noff}	Non-official slaughterhouses or family production		1 − {RiskBeta (381 326 + 1;420 265 − 381 326 + 1)}
Pr_{noff}	Prevalence of *Trichinella* in non-official pork production		Beta (666 + 1;8301 − 666 + 1)
P_{saus}	Pork meat used for the manufacture of sausages	Fixed	0.5
P_{sap}	Proportion of pork derived to sausage production		PERT (0.48;0.5568;0.604)
P_{meat}	Proportion of pork meat that is part of a sausage		Uniform (0,595;0,85)
N_{larvae}	Average load of *Trichinella* larvae in pork	Larva/g pork muscle	Discrete Uniform (1,2,3,4,5,6,7,8,9) Study 1: Uniform (0.21; 2) (Venturiello et al., 1998) Study 2: Normal (200; 18.3) (Calcagno et al., 2005) Study 3: Uniform (0.33; 2.4) (Costantino et al., 2009) Study 4: Uniform (0.03; 50.6) (Takumi et al., 2009) Study 5: Uniform (3.0; 43.1) (Nockler et al., 2005) Study 6: Uniform (0.67; 0.96) (Avram et al., 2009) Study 7: Cumulative ({0.2,0.9,1}{1, 10, 20}) Pozio and Rossi, 2008) Study 8: Normal (190;53) (Kapel et al., 1998) Study 9: Normal (103.5; 40.6) (Kapel and Gamble, 2000)
M_{larvae}	Loss of viability of *T. spiralis* larvae during storage		Intercept + (Days × Storage) + ($Days_2$ × $(Storage)^2$) + Group + (Days × Group) + Error
Int	Intercept	Model	Normal (−14;10.16)
Days	Days	Model	Normal (2.303;0.07)
$Days_2$	$Days_2$	Model	Normal (0.003;0.0001)
Storage	Shelf life of the sausage during storage	Days	Uniform (30;75)
Group	Group	Model	Normal (−19.3;12.23)
IntGxD	Days × Group	Model	Normal (0.114;0.114)
E	Error	Model	29.64
N_{lsurv}	Number of larvae actually surviving the storage period	Larvae	Poisson ($N_{larvae} \times M_{larvae}$)
Cons	Consumption of sausages per person per day	Grams	PERT (40;50;60)
C_{cpor}	Consumption of pork meat per portion of sausage	Grams	Cons × P_{meat}
N_{lsaus}	Number of *T. spiralis* larvae consumed by a person per portion of sausage	Larvae per portion	$C_{cpor} \times N_{lsurv}$
P_{pinf}	Average probability of infection	$Larvae^{-1}$	PERT (0.0018;0.032;0.37)
P_{dis}	Disease probability per portion of sausage		(($N_{lsaus} \times P_{pinf}$)/10 000)
P_{ill}	Probability of acquiring human trichinellosis		$P_{noff} \times P_{triq} \times Pr_{noff} \times P_{saus} \times P_{pinf}$
N_{ps}	Number of pigs slaughtered in Santa Fe Province	Fixed	649 881
N_{noff}	Number of pigs from non-official productions		$N_{ps} \times P_{noff}$
Weight	Weight of pigs slaughtered in Argentina	k/pork	PERT(85.7; 89.04; 91.6)
Yield	Yield of lean meat		Pert (0.48; 0.5568; 0.604)
Q_{pmeat}	Quantity of pork meat	K	Weight × Yield
Q_{noff}	Quantity of pork meat from non-official slaughterhouses	K	$Q_{pmeat} \times P_{noff}$
Q_{saus}	Quantity of pork meat from non-official slaughterhouses used for the manufacture of sausages	K	$Q_{noff} \times P_{saus}$
C_{saus}	Pork meat derived to sausage	K	$Q_{saus} \times P_{sap}$
Saus	Number of sausages produced	K	$C_{saus} \times P_{meat}$
N_{porc}	Number of portions of sausage consumed		Saus × (Cons/1000)
N_{ill}	Number of cases of trichinellosis		$N_{porc} \times P_{ill}$

additives are also components of the formulation (Rosmini and Schneider, 2000). Regarding the amount of meat included in the formulation to produce sausage (salami) in Argentina, there are different recipes considering the cultural preferences. The salami with the best organoleptic characteristics is made with 100% pork meat, but in some cases, a percentage of beef is added in a pork/beef ratio of 70/30 (INTA, 2013).

When the sausage is prepared only with pork meat and through traditional techniques, in this risk assessment we considered the following formulation: 85% pork meat, 10% lard, 2.6% sodium chloride, 0.4% sugar (sucrose), 1.5% starch, 0.9% binding additives and flavourings, 0.017% nitrite and nitrate (Fontana et al., 2005).

Considering the variability in the sausage formulations in Argentina, the proportion of pork meat that is part of a

Table 2. Prevalence of *T. spiralis* in Argentina

Number of animals	Positive animals		
	Number	Percentage	Reference
220	48	21.82	Larrieu et al. (2004)
1159	107	9.23	Ribicich et al. (2004)
293	16	5.46	Guarnera et al. (2006)
656	82	12.50	Caracostantogolo et al. (2007)
57	14	24.56	Costantino et al. (2009)
212	85	40.09	Municipalidad de Santa Fe, personal communication
706	25	3.54	Bolpe (2006)
1584	123	7.77	Guarnera et al. (2006)
3224	67	2.08	Ribicich et al. (2009)
26	2	7.69	Costantino et al. (2009)
164	97	59.15	Krivokapich et al. (2006)
8301	666	8.02	9
		Total	

sausage (P_{meat}) was modelled using a uniform distribution. The lower limit of the distribution was estimated considering that these products contain at least 70% pork meat and, considering that pork meat represents 85% of the formulation, the parameter was estimated at 59.5%. The upper limit of the distribution was set at 85% to contemplate a formulation with exclusive participation of pork meat.

Number of *Trichinella* larvae in pork muscle

In a trichinellosis foci, in the Buenos Aires Province that affected 30 pigs, 11 tested positive for the infection and the parasite load in muscle was estimated to range from 0.21 to 2 larvae/g, with an average value of 0.38 larvae/g (Venturiello et al., 1998).

In a study conducted during an outbreak of human trichinellosis occurred in the city of Villa Mercedes, San Luis Province (Argentina), the parasitic load in pig muscle was estimated in 200 larvae/g (SD = 18.3 larvae/g) (Calcagno et al., 2005). In another outbreak studied in Entre Ríos Province, considered as an area free of the disease, 2 of 26 animals (7.7%) tested positive for trichinellosis, with a parasite load of 0.33 and 2.40 larvae/g (Costantino et al., 2009).

A study reported by Takumi et al. (2009) evaluated the transmission of *T. spiralis* from wild animals (rats) to the food consumed by humans (pork). This study assessed quantitatively the transmission of larvae following the rat–pig–human route and provided data on the concentration of larvae in the muscles of the pigs affected. The response of infected pigs was between 0.03 and 50.6 larvae/g muscle.

Pozio and Rossi (2008) reported that about 15%–20% of *Trichinella*-positive animals harbour between 0.1 and 1.0 larvae/g muscle, 50% between 1.0 and 10 larvae/g muscle and <10% between 10 and 20 larvae/g muscle.

Other studies (Kapel et al., 1998; Kapel and Gamble, 2000; Nockler et al., 2005; Avram et al., 2009) determined the larval densities of *Trichinella* in selected muscles of experimentally infected pigs.

In this study, these data were used to model the concentration of *T. spiralis* larvae in infected pork meat. Thus, data reported by Venturiello et al. (1998), Nockler et al. (2005), Avram et al. (2009), Costantino et al. (2009) and Takumi et al. (2009) were modelled using uniform distributions. On the other hand, data presented by Kapel et al. (1998), Kapel and Gamble (2000), and Calcagno et al. (2005) were modelled using a normal distribution. Finally, data reported by Pozio and Rossi (2008) were modelled using a cumulative distribution.

To consider the information presented in these nine studies, a discrete uniform distribution was included in the model, so that all studies had the same probability of being selected. With this procedure, the average load of *Trichinella* larvae in pork (N_{larvae}) was modelled from all available studies. The distribution of *Trichinella* larvae in infected pigs has been extensively studied (Kapel et al., 1998, 2005; Ribicich et al., 2001; Nockler et al., 2005). The predilection sites of muscle larvae of *Trichinella* are in the tongue, diaphragm, intercostals and the shoulder. However, a substantial larvae concentration was identified in commercial cuts such as fillet, hindleg, back and sublumbar muscles. It is impossible to determine the type of muscles that are used in the clandestine preparations of sausages although it is likely that during these illegal practices, all the muscles of the slaughtered animal are used. Taking into account that almost all meat cuts are included in the homemade sausage preparation and that even the muscles with low parasitic load used to prepare sausages are infected, this risk assessment model did not consider the differential distribution of *Trichinella* larvae, recognizing that this is a simplification of the model.

Surviving *Trichinella* larvae in the sausage

Trichinella larvae present in the sausages lose their viability as a function of storage time (Randazzo et al., 2011). It is therefore essential to model the load of larvae that actually constitute the dose to which consumers are exposed. Different studies (Smith et al., 1989; Porto-Fett et al., 2010) have demonstrated that the curing processes used in the preparation of salami effectively destroy *T. spiralis* larvae. However, epidemiological studies conducted in Argentina concluded that the consumption of sausages made with raw pork without veterinary control is the principle source of human infection (Bolpe and Boffi, 2001; Ribicich et al., 2005). Therefore, in this model, we considered that the preparation of sausages is not effective in removing the larvae.

However, the loss of viability of *Trichinella* larvae during storage (M_{larvae}) was modelled using data provided by Randazzo et al. (2011). In this study, the effect of different temperatures on the viability of free and encysted larvae of *Trichinella* isolated in the south-west of Buenos Aires Province was estimated. This risk assessment model used data corresponding to the polynomial regression at a storage temperature of 20°C.

The term ‘days’ in this polynomial regression was replaced by the distribution corresponding to the shelf life of the sausage during storage (Storage). This parameter was modelled by a uniform distribution with the parameters minimum 30 days (corresponding to the maturation period of the sausage products) and maximum of 75 days (considering a shelf life of 45 days), according to the data reported by Herrera Cano (2011).

The number of larvae actually surviving the storage period (N_{lsurv}) was estimated from the concentration of *Trichinella* larvae present in the muscle of pigs used as raw material for sausage production (N_{larvae}) and the estimated proportion of larvae surviving during the storage period (M_{larvae}). To capture the variability in the number of infective larvae, the N_{lsurv} value was incorporated to a Poisson distribution.

Regarding the consumption of sausages per person per day (Cons), Chapter 5 of the Argentine Food Code (1971) establishes that a recommended portion of sausages per person is 40–50 g daily, with a maximum of 60 g/day. Based on this information, the weight of the portion of sausage was modelled using a PERT distribution. The number of *T. spiralis* larvae consumed by a person per portion of sausage (N_{lsaus}) was estimated by multiplying the quantity of sausage consumed by the concentration of larvae per gram of sausage surviving storage.

Dose–response assessment

This risk assessment included the dose–response model proposed by Takumi et al. (2009). In this study, the transmission of *T. spiralis* along the rat–pig–human route (considering the natural mechanism of disease transmission) was experimentally simulated.

The average probability of infection (P_{Pinf}) was estimated in 0.032 per larva consumed, with a range from 0.0018 to 0.37. These values were included in a PERT distribution to model the variability in the infection probability per *Trichinella* larva consumed. The disease probability per portion of sausage (P_{dis}) was estimated considering the disease probability per larva (P_{Pinf}) and the probability distribution of the number of larvae per portion of sausage consumed (N_{lsaus}).

Risk characterization

The probability of acquiring human trichinellosis by the consumption of sausages in Santa Fe Province (P_{ill}) was estimated by multiplying the following independent probabilities: probability that the animals come from non-official slaughterhouses or family production (P_{noff}) × prevalence of *Trichinella* in pigs from the non-official system (Pr_{noff}) × proportion of pork meat for the manufacture of sausages (P_{saus}) × proportion of pork meat that is part of a sausage (P_{meat}) × disease probability per portion of sausage (P_{dis}).

To estimate the number of cases of trichinellosis (N_{ill}) that could be expected in Santa Fe Province due to the consumption of sausage, we modelled the number of portions of sausage that were produced annually in the province. This was estimated considering that 649 881 pigs were slaughtered during 2010 (N_{pf}) (INTA, 2013). Then, the number of portions of sausages consumed in the province was estimated as follows: (i) probability that the animals come from non-official slaughterhouses or family production (P_{noff}), (ii) proportion of pork meat for the manufacture of sausages (P_{saus}), (iii) proportion of pork meat that is part of a sausage (P_{meat}) and (iv) consumption of sausages per person per day (Cons).

Sensitivity analysis

To determine the impact of each input variable and the uncertain variables on the output variable (probability of acquiring the disease), a sensitivity analysis was conducted using Pearson’s correlation coefficient to determine the degree of association. The sensitivity analysis was performed using the @Risk® version 4.5 software (Palisade).

Results

Each iteration predicted the probability of acquiring the disease for a single meal of pork meat sausage (Fig. 2). The average probability of human trichinellosis using the dose–response model was 4.88×10^{-6} (95%CI 4.01×10^{-8} to 3.07×10^{-5}).

Considering the number of porks slaughtered and the production of sausage consumed annually in Santa Fe Province [649 881 animals (INTA, 2013)], we estimated that the number of people who could suffer from human trichinellosis was, on average, 109 annually (95% CI 0–671 cases/year). The sensitivity analysis indicated that the risk of human trichinellosis was most sensitive to the number of larvae actually surviving the storage period (N_{lsurv}) ($r = 0.89$), the average probability of infection (P_{Pinf})

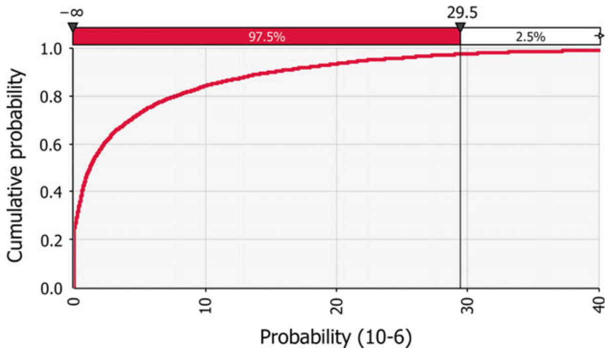

Fig. 2. Cumulative probability distribution for the probabilities of trichinellosis caused by the consumption of pork meat sausage.

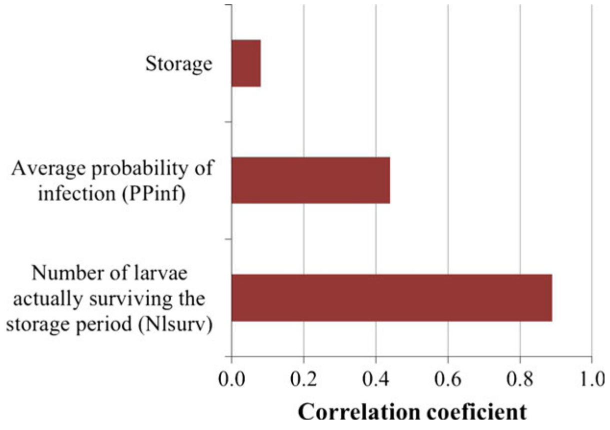

Fig. 3. Correlation coefficient between the estimated probability of trichinellosis and the most important predictive factors.

(r = 0.44) and the storage time (Storage) (r = 0.08) (Fig. 3).

The probability of acquiring human trichinellosis was 2.47×10^{-6} when the number of *Trichinella* larvae consumed considered was 5 larvae/g of sausage (corresponding to the percentile 5% of the distribution). On the other hand, when the dose of *Trichinella* larvae was 19 larvae/g (which corresponded to the percentile 95 of the distribution), the probability of human trichinellosis increased to 9.41×10^{-6}. That is, those who consumed a large number of viable *Trichinella* larvae showed 3.81 times more risk of trichinellosis than those who ate a low level of parasite.

Another variable associated with the probability of acquiring trichinellosis by the consumption of sausage was the storage time of this product. The people who consumed the sausage immediately after its preparation (30 days) had a risk of disease of 5.62×10^{-6}, whereas those who ate the sausages at the end of their shelf life had a risk of disease of 4.06×10^{-6}. That is, individuals who consumed sausage immediately after being processed had 1.38-fold greater trichinellosis risk than those who ate the food after 75 days of storage.

This model had two input variables which were modelled based on scarce data: proportion of pork meat which is derived to sausage production and proportion of pork meat that is part of a sausage. The Pearson's correlation coefficient between the risk of human trichinellosis/sausage serving and both input variables was <0.01. Even considering the existence of uncertainty in these input variables, their impact on the outcome was limited.

Discussion

Achieving food safety as a means to protect public health and promote economic development remains a major challenge for government agencies responsible for implementing risk measures (Signorini, 2010). Until recently, most systems designed to regulate food safety were based on legal definitions of unsafe food, compliance programmes to withdraw unsafe food from the market and penalties for responsible parties after the impact on public health. These traditional systems are not able to respond to existing and emerging food safety challenges because they do not provide or stimulate a preventive approach. During the last decade, there was a transition to risk analysis based on better scientific understanding of foodborne diseases and their causes (Hoornstra and Notermans, 2001).

Risk analysis has become an epidemiological tool that provides a framework to assess, manage and communicate risk effectively in collaboration with diverse stakeholders, and increases the ability of regulatory authorities on animal, plant or public health to develop control or eradication programmes of different diseases based on scientific principles (Signorini et al., 2007).

This is the first quantitative risk assessment designed to assess the probability of suffering from human trichinellosis by the consumption of sausages prepared with pork meat. Additionally, this model identified the variables with the greatest impact on the likelihood of becoming ill.

The historical evolution of the Argentinean industry of sausages is closely linked to the preservation of meat and to the cultural patterns of the Argentine population. This situation led to the marketing of these products with an immediate public acceptance. The pork meat industry (production of sausages) in Argentina is composed of approximately 338 factories which are located in the area close to Buenos Aires city (37%), Buenos Aires city (33%), Buenos Aires Province (18%), Santa Fe Province (7%) and Córdoba Province (5%), with an annual per capita consumption of 10 kg (CAICHA, 2011).

The presentation of human trichinellosis in Argentina due to the consumption of sausages produced in legal industries is under control and the number of outbreaks associated with it is below 1%. In contrast, homemade sausages are the sources of most outbreaks (Ribicich et al., 2005). The slaughter and processing of homemade pork products are under control only when the owner takes samples and sends them to municipal or private laboratories for diagnosis (Caracostantogolo et al., 2007).

During the period 1998–2009, Santa Fe Province presented approximately 89.6 cases of human trichinellosis per year (Sequeira et al., 2013). The number of annual cases estimated by this risk assessment model differed by 19% of the average annual cases recorded in the province. Although both values are close, it is necessary to emphasize that the actual information regarding human trichinellosis presents underreporting of cases, lack of outbreak investigation and lack of an active surveillance system.

Another variable with a great impact on the risk of acquiring human trichinellosis was the number of larvae surviving storage before consumption. The storage time depends on some technical aspects of product maturity and shelf life. The storage period is strict and would not be possible to extend because the organoleptic characteristics of sausages may change and sausages may thus be no longer appropriate for consumption.

Smith et al. (1989) and Porto-Fett et al. (2010) have reported that the fermentation and drying processes in the Genoa salami were effective for inactivating *Trichinella spiralis* larvae. However, epidemiological studies conducted in Argentina concluded that the consumption of locally sausages made with raw pork were linked to human trichinellosis outbreaks (Bolpe and Boffi, 2001; Ribicich et al., 2005). Unfortunately, curing (salting), drying, smoking or microwaving meat alone would not be considered as effective techniques to inactivate *Trichinella* larvae (Gottstein et al., 2009).

The third variable that showed a significant impact on the risk of acquiring human trichinellosis was the number of parasites present in the muscles of infected pigs. As this variable is closely related to the dose of *Trichinella* larvae consumed per serving of sausage, it may be useful to propose different prevention measures and control programmes to ensure the breeding of disease-free animals or through the application of diagnostic tests to determine the number of disease-free animals entering the commercial circuit. Probably the most important limitation of this quantitative risk assessment model was not considering the differential distribution of the load of *Trichinella* larvae. This simplification may have generated an overestimation of the risk. However, homemade sausages in Argentina included almost all meat cuts and even the muscles with low parasitic load might be infected (Ribicich et al., 2001).

Evidently, this model is an oversimplification of a complex reality, based on many assumptions and hypotheses. However, the variables included in this quantitative risk assessment represented the most likely practices carried out in this area of Argentina. Two input variables had the highest degree of uncertainty in this model: proportion of pork meat derived to sausage production and proportion of pork meat that is part of a sausage. The uncertainty present in these variables on the probability of human trichinellosis in spite of the Pearson's correlation coefficient was <0.01. Additional studies should be conducted to reduce the uncertainty about these variables and reduce the variability across the whole model.

Although the results seem reasonable, this model can be improved. It is necessary to establish information systems from reliable data from the various links in the chain of sausage production and consumption. Improving data collection systems of breeding, epidemiological surveillance system at both official and clandestine slaughterhouses and studies of outbreaks in animals or humans are strategies that would be useful to improve the current risk assessment model.

Therefore, this quantitative risk assessment has to be considered as a preliminary approach that has to be improved when more data are available. Despite the uncertainty, this model might be useful for risk managers as a scientific basis to establish different mitigation or intervention strategies.

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