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A multilevel study of the environmental determinants of swine ascariasis in England

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ABSTRACT

Ascariasis is considered a common parasitosis of swine worldwide. The disease causes significant economic losses due to its effect on feed conversion ratio and liver condemnations at slaughter (liver milk spots).

This study aimed to characterise the between-farm and spatial variance in porcine ascariasis in England and to assess the association between the percentage of infected animals and potential environmental risk factors, including production system, socioeconomic deprivation, soil characteristics (pH, topsoil bulk density, topsoil organic matter, topsoil texture class, soil water regime, topsoil available water capacity, and elevation), and climatic conditions (relative humidity, air temperature, and rainfall) before slaughter.

Post-mortem inspection results were provided by the Food Standards Agency and comprised information about the number of rejected livers, the number of animals sent to slaughter and the production system. All farms were georeferenced based on the postcode, which allowed the assessment of the area index of socioeconomic deprivation and the extraction of soil and climatic characteristics available in different online databases. Under a multilevel framework with adjustment for spatial autocorrelation, a standard linear mixed model was fitted to estimate the association between these determinants and the percentage of infected animals.

From 2,513,973 English farmed pigs included in the study, 4.3% had their livers rejected due to milk spots. The percentage of infected pigs per batch ranged from 0% to 100%. The highest percentages were found in Surrey, East and West Sussex (8.9%) and lowest in Leicestershire, Rutland and Northamptonshire (2.0%). Significant associations were found at multivariable analysis between the proportion of infection and the number of animals sent to slaughter ($\beta = -0.005$; 95%CI = -0.005, -0.004), soil texture (peat compared to coarse textured soils; $\beta = -0.516$; 95%CI = -1.010, -0.063), relative humidity ($\beta = 0.011$; 95%CI = 0.006, 0.015), mean temperature ($\beta = 0.007$; 95%CI = 0.003, 0.012), and rainfall ($\beta = 0.022$; 95%CI = 0.004, 0.037).

In conclusion, our findings suggest that ascariasis can be influenced by a complex network of environmental factors. Future research needs to acknowledge these intermingled relationships to guide the development and application of control measures by the industry.

1. Introduction

Ascariasis is the most common parasitosis of swine worldwide and is mainly caused by the helminth *Ascaris suum* (Stewart and Hoyt, 2013). The striking feature of this nematodiasis is the migration of the parasite through the liver, which affects animal welfare and productivity (Stewart and Hoyt, 2013). The pathological consequence is a chronic multifocal interstitial hepatitis that is usually asymptomatic. However, at *post-mortem* inspection, the liver will show multiple, spherical, and whitish foci, which are frequently named "milk spots," rendering it unfit for human consumption (Yoshihara et al., 1983). The detection of milk spots has been used as an indicator of *Ascaris suum* infection (Sanchez-Vazquez et al., 2012). According to Bernardo et al. (1990) the absence of milk spots is a reliable indicator of the absence of an established *Ascaris* infection. The authors reported the following characteristics for the use of milk spots as an indicator of the faecal evacuation of *A. suum* eggs: – sensitivity, 95.8%; – specificity, 23.8%; – positive predictive value, 36.7%; and, – negative predictive value, 92.5%.

According to Roepstorff and Nansen (1994), a small percentage of

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farms are free of the disease. Specific characteristics of the parasite may contribute to its ubiquity: (i) *A. suum* is a direct life cycle parasite, *i.e.*, it does not involve an intermediate host; (ii) the adult female parasite is highly fecund (laying 1 million eggs, or more, daily); and, (iii) the eggs are especially resistant to environmental factors because of their complex and thick shell layers (Stewart and Hoyt, 2013).

A multi-national research study conducted in the Nordic countries found that 21.5% of the fatteners were infected (Roepstorff and Nansen, 1998). In Germany, ten out of 144 (7%) swine farms randomly selected for a cross-sectional survey revealed ascariasis in sows (Gerwert et al., 2004). In England, a five-year monitoring programme found evidence of *A. suum* infection at slaughter (through the detection of milk spots) in 4.2% of 34,168 pigs inspected (Sanchez-Vazquez et al., 2012).

Production and management systems are known determinants of *A. suum* infection. The intensification of swine production systems has been linked to an overall increase in the prevalence of milk spots (Menzies et al., 1994). However, no differences in the prevalence of *A. suum* in pigs between intensive and extensive production systems have also been reported (Lai et al., 2011).

Since sanitation and improvement of hygiene practices represent the best methods to prevent and control the dissemination of infection in both humans and pigs, socioeconomic factors are also major determinants of the disease. The burden of human infection by *A. lumbricoides* is concentrated in low-income countries, where sanitation is poor, and the populations are more socioeconomically deprived (Brooker et al., 2006). For instance, (i) having less than four years of education, (ii) drinking untreated water, (iii) living in highly dense households, and (iv) having a salary below the minimum wage were associated with increased risk of human infection by *A. lumbricoides* in Brazil (Valencia et al., 2005). So, we must consider the possibility that these factors may play a role in the epidemiology of ascariasis in pigs. To the authors' knowledge, this has never been studied before.

In England and other countries, strong spatial inequalities in the distribution of swine ascariasis were observed, which suggests that the geographical location may act as a latent variable encapsulating several biogeophysical and socioeconomic factors (Roepstorff and Nansen, 1998; Sanchez-Vazquez et al., 2010). Accumulated evidence suggests that climatic and soil characteristics might also be possible determinants of the disease (Beaver, 1953; Arene, 1986; Kim et al., 2012; Schüle et al., 2014). For instance, it has been accepted for a long time that *A. suum* eggs do not develop under the temperature of 5 °C and the optimum temperature for cleavage seems to be between 25 and 30 °C (Arene, 1986; Kim et al., 2012), which might explain the comparatively higher incidence of the disease in summer months (Sanchez-Vazquez et al., 2012; McCormick et al., 2013; Neumann et al., 2014). Water and oxygen availability also seem to influence the *Ascaris* life cycle and, consequently, the occurrence of the disease. A cross-sectional study that analysed the environmental determinants of *A. lumbricoides* infection in humans in Tanzania using remotely sensed data found a significant association between the level of rainfall and the prevalence of disease (Schüle et al., 2014). Previously, another study concluded that the "number of wet days" (rain days) could also be used as a predictor of *Ascaris* infection in humans (Gunawardena et al., 2004). In addition to the atmospheric conditions, several physicochemical characteristics of the soil, where part of the life cycle takes place, seem to play a role. Beaver (1953) showed that larvae in direct contact with sunlight and those unable to migrate vertically in compact soils, die quickly. A strong association between soil pH and the frequency of infective forms of intestinal parasites in topsoil samples collected from public squares has also been reported. Using Yule's Q coefficient, Sánchez Thevenet et al. (2004) found that the presence of intestinal parasites was relatively more common in soils with pH values between 7 and 9.

The purpose of this study was then to characterise the between-farm and spatial variation in porcine ascariasis in England and to assess the association between the percentage of infection and previously mentioned potential environmental risk factors. These included (i) farming features (production system and size of the farm), (ii) the neighbourhood socioeconomic context (deprivation); and, (iii) the soil and climatic conditions (relative humidity, air temperature, rainfall, and soil characteristics – soil pH, topsoil bulk density, topsoil organic matter, topsoil texture class, soil water regime, topsoil available water capacity, and elevation).

2. Material and methods

2.1. Post-mortem inspection data

The number of infected animals was estimated using results of *post-mortem* inspection. The *post-mortem* inspection data was provided by the Food Standards Agency (FSA), the non-ministerial body that enforces food safety regulations in food establishments across the United Kingdom. The data included *post-mortem* inspection results of 2014 (1st January–31st December 2014) from 12 pig abattoirs located in different geographical regions across England. These abattoirs were chosen to provide a nationwide representation of farming settlements in England, as done by other authors (Sanchez-Vazquez et al., 2010; Sanchez-Vazquez et al., 2011; Sanchez-Vazquez et al., 2012).

The dataset included the following variables: producer information (*e.g.* internal identification number, county parish holding (CPH), and address), the slapmark/herdmark (*i.e.*, a permanent ink mark with the herd number, applied to each shoulder of the pigs), the type of animals (fattening or cull pigs), the production system (born and reared under controlled housing conditions; born outdoors and reared under controlled housing conditions since weaning; and, born and reared outdoors), the date of slaughter, the number of pigs slaughtered per batch (throughput), and the number of livers rejected per batch due to milk spots. A total number of 21,895 registers, each corresponding to a batch of animals, was available.

A set of selection criteria was applied to meet the requirements of the study, clean the database from missing or misleading data, and improve the representativeness of the sample. The data entries were excluded if (1) the postcode was absent or poor in quality (n = 1895 batches), (2) the batches were from Irish, Scottish or Welsh farms (n = 652), (3) less than five pigs per batch were sent to slaughter (n = 276), (4) the batch was mixed (from markets and different farm origins) (n = 712), (5) the batch was composed of cull pigs (n = 472), and, (6) the producer CPH was absent or incorrect (n = 738). This process resulted in a database comprising 1463 farms, 17,150 batches, and 2,513,973 pigs. Throughout the selection process, no significant spatial differences were observed; except when excluding farms that were located in Northern Ireland, Scotland, and Wales.

Farms were georeferenced based on the postcode of the CPH using ArcGIS (version 10.4.1 – ESRI, Redlands, CA), which then allowed us to characterise geographic patterns and attribute a set of contextual variables (described ahead) to each farm.

2.2. Covariates

We included covariates from three key groups of determinants – farm production and management practices, soil characteristics, and climatic conditions before slaughter.

2.2.1. Production and management conditions of the farm and socioeconomic context

Although a variable about the production system of each farm was available (born and reared under controlled housing conditions; born outdoors and reared under controlled housing conditions since weaning; and, born and reared outdoors), it was incomplete in 70.9% of the registers. Thus, in the absence of detailed and complete information about production and management conditions, the throughput (number of animals sent to slaughter) was used as a representation of farm size.

The characterisation of the socioeconomic context of the farm's