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Gastrointestinal parasites in Swedish pigs: Prevalence and associated risk factors for infection in herds where animal welfare standards are improved

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ABSTRACT

The global pig production has undergone major changes over the past 30 years with larger farms, more intensified production as well as improved hygiene and biosecurity practices. To investigate whether these changes, along with expanded pig welfare, have had an impact on parasite occurrence, a cross-sectional study was conducted in Sweden on farms where the pigs are always loose-housed, floors are solid and bedding material is provided. A total of 1615 faecal samples were collected on 42 conventional indoor farms from a) post-weaning piglets (n = 337); b) growers (n = 345); c) fatteners (n = 308); d) dry sows (n = 277) and e) pre-partum sows (n = 348). Samples were analysed using centrifugal flotation with a saturated glucose-salt solution and a modified McMaster technique, with a lower detection limit of 50 eggs or oocysts per gram. Samples positive for strongyle-type eggs were cultured to third stage larvae for genus identification. Farms also responded to a questionnaire regarding biosecurity, hygienic measures, and other management routines. Risk factors for parasite occurrence were assessed using mixed-effects logistical regression to account for farm-level clustering of samples. Interestingly, the prevalence of *Ascaris suum* was reduced compared to a similar investigation in the 1980s. In the present study *A. suum* was detected only in 43 % of the herds, with the highest prevalence in pre-partum sows (37 %) followed by fatteners (25 %). Small sized farms were associated with higher odds of being positive, compared to large sized farms (OR = 159.1, P = 0.010). *Oesophagostomum* spp. were detected in 64 % of the herds and again mainly in pre-partum sows (63 %). *Trichuris suis* was detected in 10 % of the herds but only in <1% of the samples. Moreover, *Cystoisospora suis* and *Eimeria* spp. were detected on 60 % and 64 % the farms, with the highest prevalence in post-weaning piglets and sows, respectively. Anthelmintic drugs (ivermectin or fenbendazole) were commonly used and administered mainly to pre-partum sows on 93 % of the farms. Toltrazuril against neonatal coccidiosis was administered to piglets on 14 % of the farms. The use of antiparasitic drugs did not significantly affect parasite prevalence. Overall, it appears that the altered farming routines with focus on improved pig welfare have not solely resulted in a higher occurrence of parasites, most likely due to the adequate biosecurity and hygiene practices instituted. Thus, there seems to be no conflict between implementing measures to promote pig welfare and adequately control the more pathogenic and economically important parasites.

1. Introduction

Gastrointestinal parasites are common in pig herds and previous studies have shown that the nematodes *Ascaris suum*, *Oesophagostomum* spp., and *Trichuris suis*, as well as the coccidia *Cystoisospora suis* and *Eimeria* spp. are the most common parasites to be found in pigs (Roepstorff et al., 1998; Eijck and Borgsteede, 2005; Kochanowski et al., 2017; Raue et al., 2017). However, clinical disease is uncommon and mainly occurs in piglets infected with *C. suis* or in growing pigs with heavy burdens of *T. suis* (Beer et al., 1974; Batte et al., 1977; Larsen, 1996).

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Still the consequences of parasite infections can be extensive where even subclinical levels may lead to reduced weight gain, poor feed conversion and organ damage caused by the migrating larvae of *A. suum* which in turn may result in condemnations at slaughter (Kipper et al., 2011; Vlaminck et al., 2015; Martínez-Pérez et al., 2017). Gastrointestinal parasites may hence have negative effects on animal welfare as well as on the sustainability and productivity of the farms.

The global pig production has undergone several changes over the past 30 years. The number of farms has declined but the herds have gradually turned larger with more intensified production systems. Often the subsequent positive result is improved hygiene and biosecurity practices (Maes et al., 2020; Alarcón et al., 2021). Increased biosecurity measures may reduce the risk of pathogens, and larger pig herds have indeed been found to have a lower prevalence of gastrointestinal parasites as compared to small ones (Roepstorff and Jorsal, 1989, 1990; Kochanowski et al., 2017).

However, many factors influence the parasite prevalence in pig herds, such as the type of flooring, the use of bedding material and the wear of the housing facilities (Roepstorff and Jorsal, 1990; Joachim et al., 2001; Sanchez-Vazquez et al., 2010; Kochanowski et al., 2017; Martínez-Pérez et al., 2017). Bearing this in mind, Sweden may be of general interest as the form of pig production differ from other countries in many ways. Following a new animal welfare law, implemented in 1989, Sweden now has one of the strictest animal welfare laws in the world. Pigs are to always be loose-housed, including sows throughout the entire reproductive cycle and during suckling. Manipulative rooting material must be provided to all pigs, fully slatted floors are not allowed and weaning before 28 days of age is not the routine (SJV, 2018, 2019). Dry sows are often group-housed on deep litter straw beds (Einarsson et al., 2014). These more animal welfare-friendly management practices may however favour survival and transmission of gastrointestinal parasites (Roepstorff and Jorsal, 1990; Dangolla et al., 1996; Sanchez-Vazquez et al., 2010; Haugegaard, 2010; Maes et al., 2016; Kochanowski et al., 2017; Martínez-Pérez et al., 2017). Parasite control in pig herds is achieved through a combination of strategic management routines and the use of antiparasitic drugs (Roepstorff and Jorsal, 1990). In Sweden the two anthelmintic substances fenbendazole and ivermectin, as well as toltrazuril for the treatment of neonatal coccidiosis, are registered for the use in pigs (Swedish Medical Products Agency, 2021).

The global trend towards fewer but larger herds has also been evident in Sweden. Today there are approximately 1150 registered pig producers in Sweden, compared to around 14,000 in the 1980s (SJV, 2020) when the previous large survey of parasites in conventional pigs was carried out (Roepstorff et al., 1998). The trend towards larger herds is further elucidated by the fact that 85 % of the total number of sows are found on 26 % of the farms (SJV, 2020). However, updated knowledge of parasite occurrence in pigs is lacking, not only in Sweden but in general. As the consequences of increased herd sizes and the increased animal welfare requirements ought to be of a general interest, the aim of this study was to do a cross-sectional study investigating the prevalence of gastrointestinal parasites in conventional Swedish pig herds, as well as to explore possible risk factors for parasite occurrence.

2. Material and methods

2.1. Study population

A total of 42 pig herds were included in the study. The sample size was calculated based on an expected prevalence of 40 %, and 95 % confidence of achieving a desired precision of 15 % using Epitools Epidemiological Calculators (www.epitools.ausvet.com.au, 2018). In an infinite population, the estimated sample size was a minimum of 41 farms. The farms were selected from a concurrent questionnaire study (Pettersson et al., 2021) where farmers could indicate an interest to participate. Only conventional farms were included in this study in order to be able to identify possible risk factors in the most practiced production type. Organic farms were hence excluded due to having very different rearing systems and requirements.

2.2. Management routines

Management routines were documented in an online questionnaire that was designed and distributed using Questback Essentials (Questback Sweden Ltd, Stockholm, Sweden). The questionnaire included 30 questions regarding husbandry, hygiene and biosecurity routines, the use of antiparasitic drugs, herd health and slaughter notifications. Collected data were handled in accordance with the General Data Protection Regulation (GDPR) (https://eur-lex.europa.eu/eli/reg/2016/679/oj).

2.3. Sample collections

A total of 1615 faecal samples were collected from the following age categories on all farms, when present: a) post-weaning piglets aged 5–6 weeks (n = 337); b) growers aged 6–12 weeks (n = 345); c) fatteners aged 13–24 weeks (n = 308); d) dry sows (n = 277) and e) pre-partum sows (n = 348). Pre-partum sows were sampled individually and from the other age categories, between five and ten sub-samples from the pen floors were collected and pooled into one collective sample per pen. Sampling was conducted by the farmers according to supplied written instructions. The faecal samples were refrigerated in marked airtight plastic bags and sent via mail to the National Veterinary Institute (SVA) of Sweden. The samples were kept at room temperature during transport (<24 h) but were refrigerated upon arrival and until analysis no longer than ten days after sampling. None of the sampled pigs had been treated with anthelmintic drugs during the past eight weeks. Samples were collected from 2018 to 2020, in all seasons of the year. However, as all herds were solely indoors this will thus not influence the results.

2.4. Faecal analysis

Faecal sample analysis was carried out using centrifugal flotation with a saturated glucose-salt solution (specific gravity 1.300) based on 3 g of faeces. Care was taken to include material from several parts of the sample. Nematode eggs and coccidian oocysts were counted separately using a modified McMaster technique, with the lower detection limit of 50 eggs or oocysts per gram (EPG/OPG) of faeces (Coles et al., 1992). All samples positive for strongyle-type eggs were cultured at moist conditions to third stage larvae (L3) for genus identification. Cultured larvae were recovered in accordance with Roberts and O'Sullivan (Roberts and O'Sullivan, 1950) and identified based on morphology criteria as previously described (Thienpont et al., 1979). If coccidian oocysts could not be identified to genus, sporulation was done using 2 % potassium dichromate.

2.5. Data analysis

Data were handled in Microsoft Excel and figures were made using Prisma GraphPad Version 8.4.2 (GraphPad Software, La Jolla California USA). Whenever descriptive data are presented as percentages, they have been calculated based on the number of farms where the question was applicable.

The associations between potential specific risk factors, or protective factors, and the presence of different parasite genera were investigated using logistical regression. Each age-category sampled per farm was considered as one observation. When multiple samples were available in the same age-category per farm, the observation (age group-farm) was considered positive if at least one sample was positive.

Variables significant in the univariable analysis, using a significance level of 20 %, were included in a multivariable model. The causal diagram presented in Fig. 1 was considered, where each of the variables

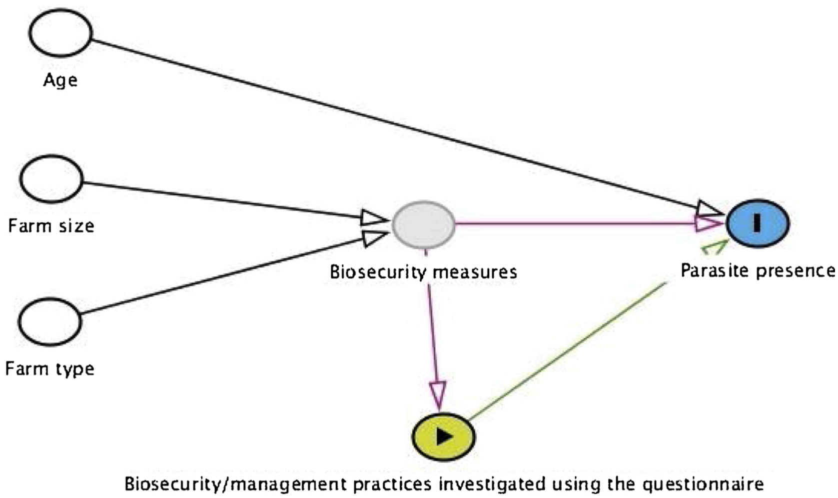

Fig. 1. Causal diagram showing the possible relationships between different variables that may influence the parasite prevalence in the investigated groups of pigs. Age of the pig will influence the prevalence of certain parasite genera due to biological reasons. Farm size (i.e., small, medium, or large) and farm type (i.e., conventional farms or specific pathogen free farms) will likely influence the overall (unmeasured) biosecurity practices on the farms. The causal diagram was generated in DAGitty (Textor et al., 2016).

from the questionnaire represent the biosecurity/management practices measured (independent variables). A final fixed-effect model was sought for each parasite using stepwise selection, dropping the least significant variables, and testing the remaining coefficients for confounding effects. A confounding effect was assumed to be present if coefficients of the variables retained changed more than 20 % upon excluding the potential confounder.

Unobserved or unmeasured general biosecurity measures on a farm may be correlated to type and size of the herds, e.g., large farms may have improved biosecurity practices compared to small farms and may represent potential confounder pathways (Fig. 1). For this reason, farm size and farm type were always initially included in the models and evaluated for potential confounding effects. Age category was retained in all models. Age categories in which only negative samples were found for a specific parasite, were dropped from the model. A 95 % confidence level for retaining variables was used. The final chosen fixed-effects model was then compared to a mixed-effects logistic model in which farm was included as a random variable to account for the effect of individual farm variance on repeated samples within farm, retaining all the same variables. Following correction for the within-farm variance, odds ratios (OR) were calculated within cluster as a fixed effect and averaged at the population level. Results were considered significant if $P < 0.05$.

The statistical analyses were performed in the statistical programming environment R, version 4.0.3 (R Core Team, 2020), the mixed-effect models were fitted using the package *lme4* (Bates et al., 2014). Final models were subjected to goodness-of-fit tests and analysis of residuals. Confidence intervals for the odds ratio were calculated using the profile method (Stryhn and Christensen, 2003).

3. Results

3.1. Study population

Out of the 42 farms, 71 % were one-site production farms and 29 % part of multisite production systems. Of the total number of farms, 57 % were farrow-to-finish farms, 36 % specialised piglet producers, 5% specialised fattener producers and 2% had dry sows only.

The farms were grouped into three categories based on size; a) small herds (7%) with less than 100 sows, corresponding to less than 220 annual farrowings in a multi-site production system, or produced less than 5000 fatteners per year; b) medium herds (64 %) with 100–400 sows, corresponding to 220–880 annual farrowings in a multi-site production system or produced 5,001–10,000 fatteners per year; c) large herds (29 %) with more than 400 sows, corresponding to more than 880 annual farrowings in a multi-site production system or produced more than 10,000 fatteners per year (29 %). Two of the herds (5%) were specific pathogen free (SPF) farms.

3.2. Management routines

The response rate for the questionnaire was 95 %. All responding farms had indoor conventional production and no farm provided outdoor access. Conventional pens, with a minimum of 70 % solid flooring and bedding material, were used on 84 %, 81 % and 96 % of the farms in the farrowing, grower, and fattening units, respectively. Farrow-to-grower pens were used on 16 % of the farms and 3% also used multi-litter pens for the growers, where pigs from several different litters were mixed. Deep litter straw pens were used for fatteners on 4% of the farms and for dry sows on 74 % (Table 1).

Piglets were weaned at four to five weeks of age on 81 % of the farms and at five to six weeks of age on 19 % of the farms. High-dosed zinc oxide (2500 ppm) was used often or always at weaning on 52 % of the

Table 1
General housing and management practices reported by 40 Swedish conventional pig farms surveyed by a questionnaire.

Housing practices	Farrowing units n = 37		Grower units n = 37		Fattening units n = 24		Dry sow units n = 38	
	n	%	n	%	n	%	n	%
Pen type								
Conventional*	31	84	30	81	23	96	13	34
Farrow-to-grower	6	16	6	16	0	0	0	0
Multi-litter**	0	0	1	3	0	0	0	0
Deep litter straw	0	0	0	0	1	4	28	74
Bedding material								
Straw	35	95	32	86	24	100	34	89
Peat	16	43	7	19	1	4	0	0
Wood shavings	19	51	18	49	12	50	3	8
Unknown	0	0	0	0	0	0	1	3
Feed								
Dry	n/a	n/a	9	24	3	13	9	24
Liquid	n/a	n/a	10	27	20	83	23	60
Liquid and dry	n/a	n/a	18	49	1	4	6	16

Some questions had multiple options, why the total response rate could be more than 100 %.
n/a: Not applicable.
[*] Conventional pens in the Swedish context, with a maximum of 30 % slatted floor and a requirement of bedding/rooting material.
[**] Multi-litter pens refer to pens where pigs from several different litters are housed together.

farms to prevent post-weaning diarrhoea. Following weaning, the piglets remained in the farrowing pens until transfer to the fattening units on 19 % of the farms. On 76 % of the farms the piglets were moved to a grower unit at weaning and on 5% of the farms the weaners were transferred to a grower unit 14 days post weaning.

The piglets were sold or transferred to fattening units at a weight of less than 30 kg on 19 % of the farms and when heavier than 30 kg on 81 % of the farms. The average slaughter weight of the fatteners was 80−90 kg (106−120 kg live weight) on 43 % of the farms and 91−96 kg (121−130 kg live weight) on 57 % of the farms. Batch-wise, age-segregated rearing was always practiced in the farrowing units on 95 % of the farms, in the grower units on 92 %, and in the fattening units on 88 % of the farms (Table 2). General housing practices are presented in Table 1 and biosecurity practices in Table 2. Farms used a selection of different disinfectants and only one farm reported to use a substance (cresol-based product) effective against coccidian oocysts and nematode eggs (results not shown).

Regular faecal analysis for parasites was not carried out on any farm, but 13 % of the farms performed parasite analysis sporadically. Anthelmintic drugs (fenbendazole or ivermectin) were used on 93 % of the farms and 58 % treated either more than one age category of pigs or sows at more than one stage of the production cycle (Fig. 2). One satellite farm from a multisite production system and the two specialised fattening farms did not use any anthelmintic drugs at all. Toltrazuril for treatment against neonatal coccidiosis, was administered to piglets on 14 % of the farms that produced piglets (Fig. 2). Treatment with ivermectin, twice or more per year, specifically for sarcoptic mange, was carried out on 5% of the farms.

The average percentages of white spot liver lesions and pneumonic lung lesions, as had been registered at slaughter over the last 12 months, were reported by the farms that produced fatteners (Fig. 3). Diarrhoea was reported to occur in most, or all batches of piglets prior to weaning on 36 % of the farms, in piglets at weaning on 21 %, in growers on 11 % and in fatteners on 4 % of the farms. No farm reported diarrhoea to occur often or always in adult animals.

3.3. Sample collection and faecal analysis

The study included 42 farms, but all age categories were not present in all herds, and from some farms, samples were supplied from age categories that were not normally produced. In total, samples from post-weaning piglets and pre-partum sows were collected at 35 farms, from growers at 36 farms, from fatteners at 32 farms and samples from dry sows at 29 farms.

Overall, *A. suum* was detected on 43 % of the farms and in 5% of the total number of samples and *Oesophagostomum* spp. on 64 % of the farms and in 19 % of the total samples. The corresponding figures for *T. suis* were 10 % of the farms and <1% of the samples. *Eimeria* spp. were detected on 64 % of the farms and in 9% of the samples, whereas *C. suis* was detected on 60 % of the farms and in 5% of the total amount of samples. The results obtained are grouped by age category in Table 3. For *A. suum* the FEC ranged from 50−8,250 EPG, for *Oesophagostomum* spp. the range was 50−8,550 EPG and for *T. suis* it was 50–250 EPG. The faecal oocyst count for *Eimeria* spp. ranged from 50 to 218,300 OPG, and for *C. suis* the range was 50−20,300 OPG. The distributions of faecal EPG/OPG are shown in Figs. 4 and 5.

Table 2
Biosecurity practices reported by 40 Swedish conventional pig farms surveyed by a questionnaire.

Biosecurity practices	Farrowing units n = 37		Grower units n = 37		Fattening units n = 24		Dry sow units n = 28 (d), 13 (c)	
	n	%	n	%	n	%	n	%
Batch production	35	95	34	92	21	88	n/a	n/a
Cleaning between each batch	31	84	34	92	17	77	1, 1	4, 8
Disinfection between each batch	25	68	27	73	10	42	2, 1	7, 8
Down time >4 days between each batch	29	78	26	70	18	75	10, 5	36, 39

d: Deep litter straw beds, c: Conventional pens with limited bedding material.
n/a: Not applicable.

3.4. Risk factor analysis

The final logistic regression models for each parasite are presented in Table 4. As farm-level variance was generally high, only the results of the hierarchical model (accounting for farm-level clustering of observations) are presented. Age was always a significant predictor of parasite presence in faecal samples. As age was retained in every model, age categories in which all samples were negative could not be included in the individual models. This caused exclusion of post-weaning piglets in the model for *A. suum*, as well as post-weaning piglets, growers, and fatteners in the *T. suis* model. In the *C. suis* model only post-weaning piglets, growers and fatteners had positive samples, with the majority concentrated in the post-weaning piglets. As a result, dry sows and pre-partum sows had to be excluded from the model, resulting in a small number of observations, and an impossibility of assessing any age category effect. In all models, few management factors remained as significant predictors for the risk of positive faecal samples. Strict batch-wise production was shown to be a protective factor i.e., associated with lower odds of the samples being positive for *T. suis*. Small-sized farms were however associated with higher odds of the samples being positive for *A. suum,* compared to large-sized farms (Table 4). The use of anti-parasitic drugs did not have a significant impact on the parasite prevalence in any herd, and overall few specific measured factors were shown to be statistically significant. This became even more apparent when the effect of intra-farm clustering was explicitly accounted for. All models (except *C. suis*) showed a very high intra-farm variance, which resulted in the high Intra Cluster Covariation (ICC) values reported in Table 4, which shows that, for most of the models, more than 50 % of the variability observed could be explained by farm-level effects rather than differences in the management practices investigated. The only exception was the model for *C. suis*, where the small number of age categories retained resulted in a smaller number of observations per farm, which explained the small ICC.

As much of the variability was explained by farm-level effects, the number of observations was reduced to 42, i.e., the number of sampled herds, and many of the predictors retained in the models were not significant once clustering per farm was explicitly accounted for (Table 4). This also resulted in wide confidence intervals. The ICC were used to adjust the farm-level fixed effects calculated, and to report population average OR. Population-average OR represents the increase (or decrease) in odds for a hypothetical average farm in the population investigated. The population-average OR were similar to the numerical results observed in fixed-effect models in which farm clustering was not accounted for (results not shown). In practical terms, however, it may be more interesting to observe the effect of measures within farm.

4. Discussion

This is the first larger study on the prevalence of gastrointestinal parasites and associated risk factors for infection in conventional Swedish pig herds since the 1980s. Since the last extensive national prevalence studies (Nilsson, 1982; Roepstorff et al., 1998), major changes in husbandry and management have occurred in the now much intensified global pig production (Maes et al., 2020). A subsequent result has been improved biosecurity and hygiene measures, often with a subsequent decrease in parasite occurrence (Roepstorff and Jorsal, 1989, 1990; Kochanowski et al., 2017; Maes et al., 2020). At the same time, the prevalence of gastrointestinal parasites in Sweden could be

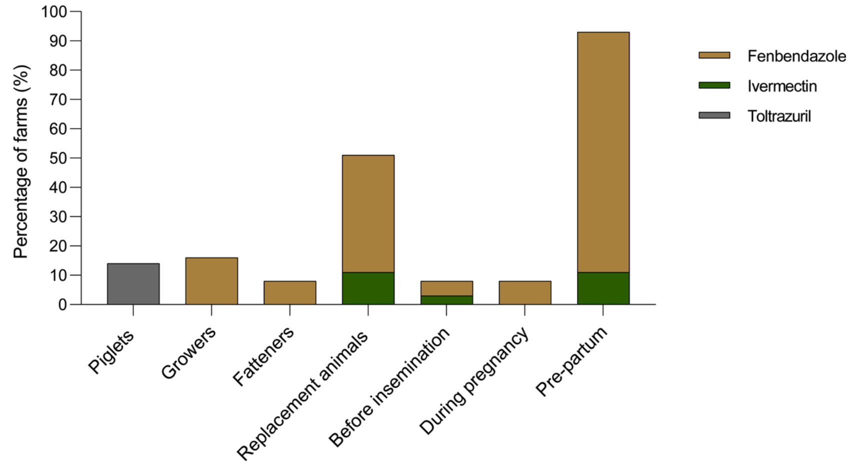

Fig. 2. The use of antiparasitic drugs, reported by the surveyed Swedish pig farms (number of farms with piglets and growers = 37, with fatteners = 24, with adult sows and replacement animals = 38), shown by age category and stage of production.

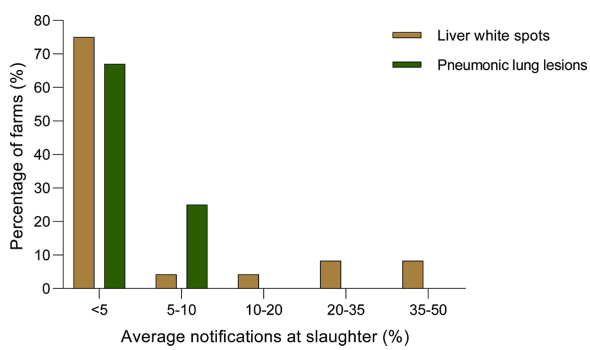

Fig. 3. The percentage of white spot lesions on the liver and pneumonic lung lesions registered at slaughter, over the past one year in the 24 herds rearing fatteners. Two farms (8%) reported to not know the percentage of lung lesions (not included in the figure).
NB. The cause of the lesions was not stated, and hence parasitic origin could not be confirmed.

Table 3
Results from the faecal analysis of pigs of five different age categories, or stages of production collected from 42 Swedish pig farms (post-weaning piglets n = 35 farms, 337 samples, growers n = 36 farms, 345 samples, fatteners n = 32 farms, 308 samples, dry sows n = 29 farms, 277 samples, pre-partum sows n = 35 farms, 348 samples).

Parasite	Age category	Positive herds		Positive samples	
		n	%	n	%
Ascaris suum					
	Post-weaning piglets	0	0	0	0
	Growers	2	6	3	1
	Fatteners	8	25	27	9
	Dry sows	7	24	23	8
	Pre-partum sows	13	37	32	9
Oesophagostomum spp.					
	Post-weaning piglets	6	17	12	4
	Growers	7	19	18	5
	Fatteners	8	25	20	7
	Dry sows	18	62	111	40
	Pre-partum sows	22	63	141	41
Trichuris suis					
	Post-weaning piglets	0	0	0	0
	Growers	0	0	0	0
	Fatteners	0	0	0	0
	Dry sows	3	10	7	3
	Pre-partum sows	3	9	6	2
Eimeria spp.					
	Post-weaning piglets	3	9	7	2
	Growers	5	14	9	3
	Fatteners	6	19	7	2
	Dry sows	13	45	50	18
	Pre-partum sows	17	49	76	22
Cystoisospora suis					
	Post-weaning piglets	21	60	67	20
	Growers	8	22	16	5
	Fatteners	1	3	1	0.3
	Dry sows	0	0	0	0
	Pre-partum sows	0	0	0	0

presumed to be higher than in other countries due to the requirements of solid floors and the access to rooting material to promote the welfare of the pigs. However, it was evident from our results that this was not the case for all parasites. We consider these findings interesting not only from a national perspective, but also for the wider international community as an example of parasite occurrence in pig farms with high requirements on animal welfare.

One of the major findings was the reduced prevalence of *A. suum* in fatteners, compared to when this was last investigated 30 years ago. On a sample level, only 9% of the sampled pens were positive for *A. suum* compared to 35 % in the 1980s (Roepstorff et al., 1998). On a herd level, fatteners on 25 % of the sampled farms were positive for *A. suum* which also was lower than in the 1980s when almost 50 % were positive (Nilsson, 1982). The age group with the highest prevalence of *A. suum* was the pre-partum sows with 37 % of the herds and 9% of the samples being positive. On a sample level, those results are similar to what was found 30 years ago when the corresponding figure was 8% (Roepstorff et al., 1998). A plausible explanation for the reduced prevalence of *A. suum* in fatteners is the common practice of age-segregated batch-wise rearing. Batch-wise production has gradually been implemented in Sweden over the past 30 years, as an initial response to the ban of growth promoting antibiotics (Wallgren, 2009). Persistent contamination of the environment is the major source of *A. suum* eggs to new hosts (Nilsson, 1982). Adequate cleaning, disinfection and drying of the pens, prior to the arrival of new animals are thus essential measures to prevent contamination of the pens. This can only be achieved with batch-wise production and is in agreement with previous studies (Nilsson, 1982; Joachim et al., 2001; Kochanowski et al., 2017). Still, batch-wise production could not be identified as a specific significant protective factor for *A. suum* infections in the present study, possibly due to this being so commonly practiced. However, small farms had a higher risk of being

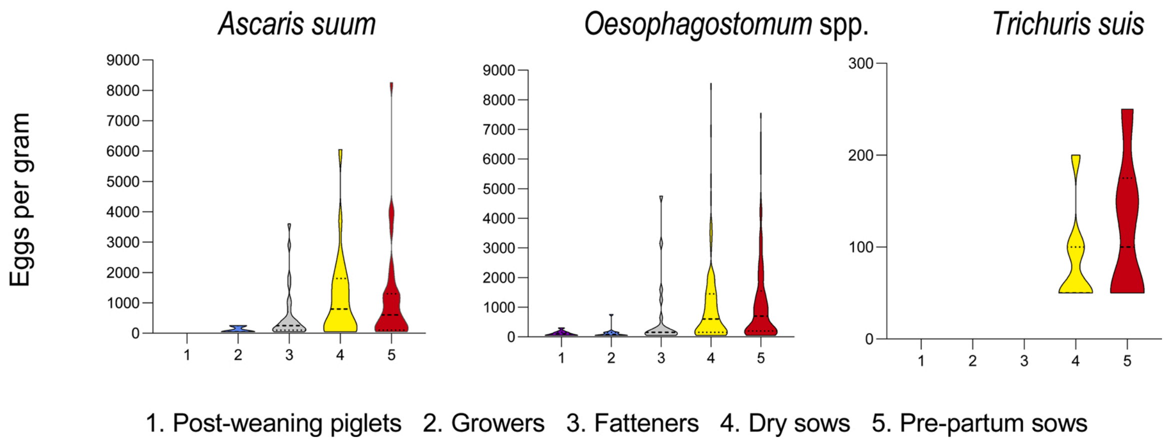

Fig. 4. Faecal egg counts from samples collected from pigs of five different age categories, or stages of production, on 42 Swedish pig farms.
NB. The scale on the y-axis is different for *Trichuris suis* compared to *Ascaris suum* and *Oesophagostomum* spp.
The dashed line indicates the mean, and the dotted lines the first and the third quartiles.

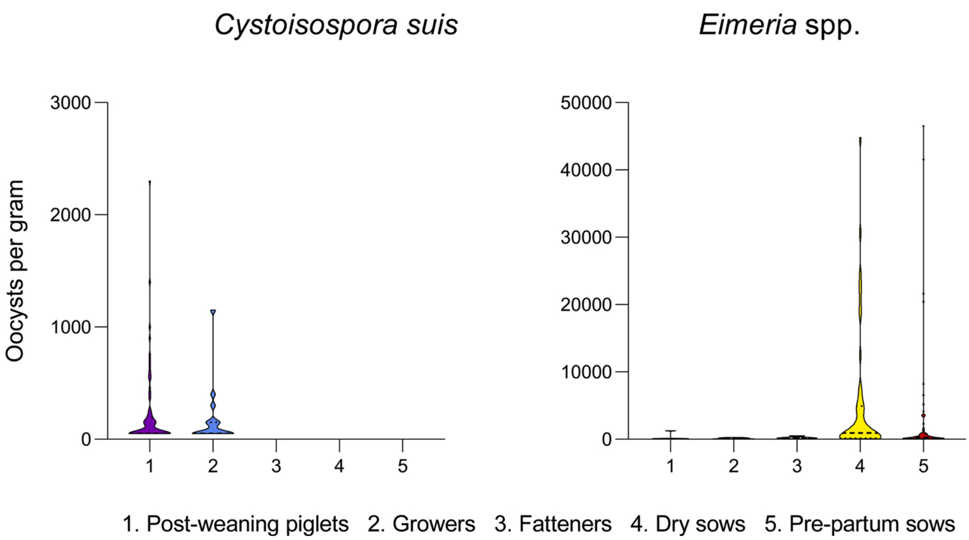

Fig. 5. Faecal oocyst counts from samples collected from pigs of five different age categories, or stages of production, on 42 Swedish pig farms. For ease of visualisation, for *C. suis* four outliers (OPG 20,300, 6,250, 5550 and 3100) were removed from the category post-weaned piglets and for *Eimeria* spp. two outliers (OPG 218,300 and 103,200) were removed from the category dry sows.
NB. The scale on the y-axis is different for *Eimeria* spp. compared to *C. suis.*
The dashed line indicates the mean, and the dotted lines the first and the third quartiles.

positive compared to large farms. As large-sized farms are likely to have superior overall hygiene and biosecurity practices compared to smaller farms, our results were not surprising and in line with previous studies (Roepstorff and Jorsal, 1989, 1990; Kochanowski et al., 2017).

Oesophagostomum spp. were the most prevalent parasites in this study, with 64 % of the herds and 19 % of the total number of samples being positive. Adult animals tend to have the highest prevalence due to the weak immunity evoked by an infection (Murrell, 1986; Roepstorff and Jorsal, 1989), and this was also evident in the present study. The highest prevalence was found in pre-partum sows where 63 % of the herds and 41 % of the samples were positive. This is a marked contrast to the previous national study where 23 % of the samples from lactating sows and 30 % of the samples from dry sows were positive (Roepstorff et al., 1998). Our results also contrasted to findings from Denmark where sows on only 15 % of the examined farms were positive (Haugegaard, 2010) and from the Netherlands where corresponding figure was 22.2 % (Eijck and Borgsteede, 2005). However, our results were more in line with a more recent Polish study where *Oesophagostomum* spp. were found to overall be the most prevalent gastrointestinal parasite, and where the sows were infected on 60 % of the farms (Kochanowski et al., 2017). Very few of the farms in the present study practiced regular cleaning, disinfection, or a downtime period of more than four days between batches in the dry sow units, which may explain the high prevalence of *Oesophagostomum* spp. A likely reason for the reduced hygiene measures in these units, compared to the farrowing, grower, and fattening units, is that sows of different farrowing groups were housed together, creating a continuous production system. This in turn limits the ability of proper hygiene practices, larvae of *Oesophagostomum* spp. can accumulate in the environment and a subsequent continuous parasite transmission system is created. The low prevalence of 4–7 % in post-weaning piglets, growers and fatteners was almost identical to what was found in Sweden 30 years ago (Roepstorff et al., 1998).

Trichuris suis was rarely diagnosed in this study. Overall, it was only detected on 10 % of the farms and in <1% of the total amount of samples, all from adult sows. This was consistent with not only previous findings from Sweden, but also from other European countries, where *T. suis* was uncommon in conventional pig herds (Roepstorff et al., 1998; Joachim et al., 2001; Eijck and Borgsteede, 2005; Haugegaard, 2010). The faecal egg counts were also low, ranging between 50 and 250 EPG, where some may be considered false positives caused by ingestion of non-infective eggs due to coprophagia (Boes et al., 1998).

Infections with *C. suis*, an important cause of diarrhoea in suckling piglets, tend to mainly be detected at eight to ten days of age, but older piglets may also be affected (Stuart et al., 1980; Joachim and Schwarz, 2014; Pettersson et al., 2019). In the present study oocysts from *C. suis* were detected on 60 % of the farms and in 20 % of the samples, mainly in the age group of newly weaned piglets. Pre-weaned piglets were not included in this study, but the result herein resembled a previous

Table 4
Multivariable regression analysis of risk factors associated with gastrointestinal parasite infections in 40 Swedish pig herds. All presented models are hierarchical with random farm-level effects and fixed-effects estimated for the variables of the questionnaire.

Risk factor	Odds ratio		P-value	95 % CI (fixed effects)
	Fixed effects	Population average		
Ascaris suum (n = 127)	ICC* = 48.7 %			
Age			<0.001	
Growers	Reference			
Fatteners	13.6	6.11		1.14 – 162.56
Dry sows	13.4	6.05		1.04 – 173.71
Pre-partum sows	48.3	14.72		3.68 – 635. 29
Farm size			0.010	
Large sized farm	Reference			
Medium sized farm	6.3	3.59		0.79 – 50.42
Small sized farm	159.1	33.62		2.34 – 10826.80
Disinfection between each new batch	0.5	0.61	0.384	0.10 – 2.46
Oesophagostomum spp. (n = 160)	ICC* = 69.0 %			
Age			<0.001	
Post-weaning piglets	Reference			
Growers	4.6	2.3		0.56 – 38.33
Fatteners	2.4	1.6		0.21 – 26.66
Dry sows	287.2	20.3		1.15 – 71517.05
Pre-partum sows	180.2	15.9		4.02 – 8071.74
Strict batch production	0.004	0.05	0.080	0.00 – 1.97
Peat bedding	4.9	2.3	0.117	0.67 – 35.97
Cleaning before each new batch	0.2	0.4	0.212	0.02 – 2.37
Trichuris suis (n = 63)	ICC* = 99.9 %			
Strict batch production	0.04	0.90	0.024	0.038–0.039
Eimeria spp. (n = 160)	ICC* = 96.6 %			
Age			<0.001	
Post-weaning piglets	Reference			
Growers	2.9	1.2		0.27 – 31.39
Fatteners	2.5	1.2		0.18 – 33.81
Dry sows	1.0×10^6	11.2		$1.48 – 7.31 \times 10^{11}$
Pre-partum sows	3.3×10^5	9.2		$13.42 – 8.33 \times 10^9$
Cleaning before each new batch	1.1	1.0	0.961	0.02 – 55.60
Cystoisospora suis (n = 76)	ICC* = 6.09 %			
Age			0.004	
Post-weaning piglets	Reference			
Growers	0.1	0.1		0.03 – 0.53
Disinfection before each new batch	0.3	0.3	0.084	0.08 – 1.17

ICC = Intra Cluster Covariation.

Swedish study where the herd prevalence of *C. suis* was 58 % at two weeks of age and 50 % at four weeks of age (Pettersson et al., 2019). Residual oocysts in the farrowing pens are a main source of infection for new piglets, addressing the importance of hygienic measures in the farrowing units (Sotiraki et al., 2007; Langkjaer and Roepstorff, 2008). Overall hygiene measures were good in the farrowing units, as cleaning and disinfection between each new batch of piglets was commonly practiced, however it should be noted that only one farm reported to use a disinfectant effective against coccidian oocysts.

Eimeria spp. were found in 64 % of the herds and mainly in samples from adult sows, although this parasite was occasionally also detected in the other age categories. Although infections are usually subclinical, heavy burdens may cause gastrointestinal signs such as diarrhoea in younger animals, and poor hygiene is known to be associated with heavy infections (Karamon et al., 2007; Joachim and Schwarz, 2014).

The red stomach worm, *Hyostrongylus rubidus* was not detected in any of the samples in the current study. This was not surprising as this parasite tend to mainly be found in outdoor herds (Nilsson, 1982; Murrell, 1986). Single eggs that may have been from *Strongyloides ransomi* were detected in five samples, but it could not be excluded that these were eggs of free-living nematodes. However, there was also a possibility that *S. ransomi* and *Oesophagostomum* spp. were underdiagnosed, as the samples were kept in room temperature during the transportation, and false negative results cannot be excluded due to hatching of the eggs.

All but one of the sow holdings sampled in this study used anthelmintics regularly, and the majority (82 %) administered either ivermectin (11 %) or fenbendazole (82 %) prior to farrowing. The use of anthelmintics has increased compared to when this was last investigated in the 1980s when only approximately 18 % of the farms used anthelmintics on a regular basis (Nilsson, 1982). It was also evident that the anthelmintics were used by routine, as regular faecal analysis for parasites was not carried out by any farm. Toltrazuril was used as prophylactic treatment for *C. suis* on 14 % of the farms that raised piglets, which was in line with previous reports (Pettersson et al., 2019, 2021). We were not able to identify any significant impact of the use of antiparasitic drugs on the parasite prevalence in any of the sampled herds, likely due to the frequent usage of these drugs. The routine use of antiparasitic drugs does however carry a risk, given the escalating problem with anthelmintic resistance in nematode parasites found in livestock (Wolstenholme et al., 2004; Sangster et al., 2018). Nematodes of pigs are not exempt and there are reports of reduced efficacy to the major anthelmintic drugs the in porcine *Oesophagostomum* spp. (Roepstorff et al., 1987; Bjørn et al., 1990; Gerwert et al., 2002; Macrelli et al., 2019). Recently a reduced efficacy of toltrazuril on *C. suis* has also been identified (Shrestha et al., 2017) and it is hence evident that the routine use of antiparasitic drugs in pig herds ought to be re-evaluated and that drug efficacy should be monitored as part of the strategies into preserving antiparasitic efficacy of the available substances.

Effective parasite control in a pig herd is however achieved using antiparasitic drugs in combination with various strategic hygiene and biosecurity measures (Nilsson, 1982; Roepstorff and Jorsal, 1990; Roepstorff, 1997). In the multivariable regression analysis, we were only able to identify two single significant management practices influencing the risk of parasite infection in any direction. Farm size impacted the prevalence of *A. suum* and strict batch-wise production reduced the risk of *T. suis*. The few specific measured factors shown to be statistically significant was likely due to a small number of observations, a low percentage of positive samples and the similar management routines practiced in most herds. It was evident that more than 50 % of the observed variability in the faecal analysis results could be explained by farm-level effects, with the exception of the results for *C. suis*, further reducing the number of observations as only 42 farms were sampled. The conclusion from this was that the overall parasite load on a farm will have a large impact on the parasite prevalence in the various age groups. Thus, a holistic approach, addressing general biosecurity and hygiene measures, as well as strategic use of antiparasitic drugs, needs to be considered when controlling and preventing gastrointestinal parasites.

5. Conclusion

Overall, it appears that the altered farming routines with focus on improved pig welfare have not solely resulted in more parasites, most likely because adequate biosecurity and hygiene practices have been instituted at the same time. Thus, there seems to be no conflict between promoting measures to improve pig welfare and adequately control the more pathogenic and economically important parasites.

CRediT authorship contribution statement

Emelie Pettersson: Sample analysis, data analysis, writing original draft. **Marie Sjölund:** Conceptualisation, editing. **Fernanda C. Dórea:** Statistical analysis, editing. **Eva Osterman Lind:** Conceptualisation, editing. **Giulio Grandi:** Conceptualisation, editing. **Magdalena Jacobson:** Conceptualisation, editing. **Johan Höglund:** Conceptualisation, methodology and editing. **Per Wallgren:** Conceptualisation, supervision, funding acquisition, editing.

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Declaration of Competing Interest

The authors report no declarations of interest.

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References

Alarcón, L.V., Allepuz, A., Mateu, E., 2021. Biosecurity in pig farms: a review. Porc. Health Manage. 7, 5.
Bates, D., Mächler, M., Bolker, B., Walker, S., 2014. Fitting linear mixed-effects models using lme4. ArXiv e-prints arXiv 1406.
Batte, E.G., McLamb, R.D., Muse, K.E., Tally, S.D., Vestal, T.J., 1977. Pathophysiology of swine trichuriasis. Am. J. Vet. Res. 38, 1075–1079.
Beer, R.J., Sansom, B.F., Taylor, P.J., 1974. Erythrocyte losses from pigs with experimental *Trichuris suis* infections measured with a whole-body counter. J. Comp. Pathol. 84, 331–346.
Bjørn, H., Roepstorff, A., Waller, P.J., Nansen, P., 1990. Resistance to levamisole and cross-resistance between pyrantel and levamisole in *Oesophagostomum quadrispinulatum* and *Oesophagostomum dentatum* of pigs. Vet. Parasitol. 37, 21–30.
Boes, J., Johansen, M.V., Eriksen, L., Bøgh, H.O., Nansen, P., Stephenson, L.S., 1998. False-positive *Trichuris suis* egg counts in pigs in relation to coprophagia. Parasite 5, 91–93.
Coles, G.C., Bauer, C., Borgsteede, F.H., Geerts, S., Klei, T.R., Taylor, M.A., Waller, P.J., 1992. World Association for the Advancement of Veterinary Parasitology (WAAVP) methods for the detection of anthelmintic resistance in nematodes of veterinary importance. Vet. Parasitol. 44, 35–44.
Dangolla, A., Willeberg, P., Bjørn, H., Roepstorff, A., 1996. Associations of *Ascaris suum* and *Oesophagostomum* spp. Infections of sows with management factors in 83 Danish sow herds. Prev. Vet. Med. 27, 197–209.
Eijck, I.A., Borgsteede, F.H., 2005. A survey of gastrointestinal pig parasites on free-range, organic and conventional pig farms in the Netherlands. Vet. Res. Commun. 29, 407–414.
Einarsson, S., Sjunnesson, Y., Hultén, F., Eliasson-Selling, L., Dalin, A.-M., Lundeheim, N., Magnusson, U., 2014. A 25 years experience of group-housed sows–reproduction in animal welfare-friendly systems. Acta Vet. Scand. 56, 37.
Epitools Epidemiological Calculators Sergeant, 2018. ESG, Epitools Epidemiological Calculators. Ausvet, p. 2018. http://www.epitools.ausvet.com.au/.
Gerwert, S., Failing, K., Bauer, C., 2002. Prevalence of levamisole and benzimidazole resistance in *Oesophagostomum* populations of pig-breeding farms in North Rhine-Westphalia, Germany. Parasitol. Res. 88, 63–68.
Haugegaard, J., 2010. Prevalence of nematodes in Danish industrialized sow farms with loose housed sows in dynamic groups. Vet. Parasitol. 168, 156–159.
Joachim, A., Schwarz, L., 2014. Coccidia of swine: *Eimeria* species, *Cystoisospora* (syn. *Isospora*) *suis*. In: Mehlhorn, H. (Ed.), Encyclopedia of Parasitology. Springer, Berlin Heidelberg, Berlin, Heidelberg, pp. 1–5.
Joachim, A., Dülmer, N., Daugschies, A., Roepstorff, A., 2001. Occurrence of helminths in pig fattening units with different management systems in Northern Germany. Vet. Parasitol. 96, 135–146.
Karamon, J., Ziomko, I., Cencek, T., 2007. Prevalence of *Isospora suis* and *Eimeria* spp. In suckling piglets and sows in Poland. Vet. Parasitol. 147, 171–175.
Kipper, M., Andretta, I., Monteiro, S.G., Lovatto, P.A., Lehnen, C.R., 2011. Meta-analysis of the effects of endoparasites on pig performance. Vet. Parasitol. 181, 316–320.
Kochanowski, M., Karamon, J., Dąbrowska, J., Dors, A., Czyżewska-Dors, E., Cencek, T., 2017. Occurrence of intestinal parasites in pigs in Poland - the influence of factors related to the production system. J. Vet. Res. 61, 459–466.
Langkjaer, M., Roepstorff, a., 2008. Survival of *Isospora suis* oocysts under controlled environmental conditions. Vet. Parasitol. 152, 186–193.
Larsen, K., 1996. *Isospora suis*: neonatal coccidiose hos svin. Dansk veterinærtidsskrift 79, 387–392.
Macrelli, M., Williamson, S., Mitchell, S., Pearson, R., Andrews, L., Morrison, A.A., Nevel, M., Smith, R., Bartley, D.J., 2019. First detection of ivermectin resistance in *Oesophagostomum dentatum* in pigs. Vet. Parasitol. 270, 1–6.
Maes, D., Pluym, L., Peltoniemi, O., 2016. Impact of group housing of pregnant sows on health. Porc. Health Manage. 2, 17.
Maes, D.G.D., Dewulf, J., Piñeiro, C., Edwards, S., Kyriazakis, I., 2020. A critical reflection on intensive pork production with an emphasis on animal health and welfare. J. Anim. Sci. 98, S15–s26.
Martínez-Pérez, J.M., Vandekerckhove, E., Vlaminck, J., Geldhof, P., Martínez-Valladares, M., 2017. Serological detection of *Ascaris suum* at fattening pig farms is linked with performance and management indices. Vet. Parasitol. 248, 33–38.
Murrell, K.D., 1986. Epidemiology, pathogenesis, and control of major swine helminth parasites. Vet. Clin. N. Am: Food Animal Practice 2, 439–454.
Nilsson, O., 1982. Ascariasis in the Pig: an Epizootiological and Clinical Study. Diss. Uppsala: Sveriges lantbruksuniv, Uppsala.
Pettersson, E., Hestad, S., Möttus, I., Skiöldebrand, E., Wallgren, P., 2019. Rotavirus and *Cystoisospora suis* in piglets during the suckling and early post weaning period, in systems with solid floors and age segregated rearing. Porc. Health Manag. 5, 7.
Pettersson, E., Sjölund, M., Wallgren, T., Lind, E.O., Höglund, J., Wallgren, P., 2021. Management practices related to the control of gastrointestinal parasites on Swedish pig farms. Porc. Health Manage. 7, 12.
R Core Team, 2020. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.
Raue, K., Heuer, L., Böhm, C., Wolken, S., Epe, C., Strube, C., 2017. 10-year parasitological examination results (2003 to 2012) of faecal samples from horses, ruminants, pigs, dogs, cats, rabbits and hedgehogs. Parasitol. Res. 116, 3315–3330.
Roberts, F., O'Sullivan, P., 1950. Methods for egg counts and larval cultures for strongyles infesting the gastro-intestinal tract of cattle. Aust. J. Agric. Res. 1, 99–102.
Roepstorff, A., 1997. Helminth surveillance as a prerequisite for anthelmintic treatment in intensive sow herds. Vet. Parasitol. 73, 139–151.
Roepstorff, A., Jorsal, S.E., 1989. Prevalence of helminth infections in swine in Denmark. Vet. Parasitol. 33, 231–239.
Roepstorff, A., Jorsal, S.E., 1990. Relationship of the prevalence of swine helminths to management practices and anthelmintic treatment in Danish sow herds. Vet. Parasitol. 36, 245–257.
Roepstorff, A., Bjørn, H., Nansen, P., 1987. Resistance of *Oesophagostomum* spp. In pigs to pyrantel citrate. Vet. Parasitol. 24, 229–239.
Roepstorff, A., Nilsson, O., Oksanen, A., Gjerde, B., Richter, S.H., Örtenberg, E., Christensson, D., Martinsson, K.B., Bartlett, P.C., Nansen, P., Eriksen, L., Helle, O., Nikander, S., Larsen, K., 1998. Intestinal parasites in swine in the Nordic countries: prevalence and geographical distribution. Vet. Parasitol. 76, 305–319.
Sanchez-Vazquez, M.J., Smith, R.P., Kang, S., Lewis, F., Nielen, M., Gunn, G.J., Edwards, S.A., 2010. Identification of factors influencing the occurrence of milk spot livers in slaughtered pigs: a novel approach to understanding *Ascaris suum* epidemiology in British farmed pigs. Vet. Parasitol. 173, 271–279.
Sangster, N.C., Cowling, A., Woodgate, R.G., 2018. Ten events that defined anthelmintic resistance research. Trends Parasitol. 34, 553–563.
Shrestha, A., Freudenschuss, B., Jansen, R., Hinney, B., Ruttkowski, B., Joachim, A., 2017. Experimentally confirmed toltrazuril resistance in a field isolate of *Cystoisospora suis*. Parasit. Vectors 10, 317.
SJV, Swedish Board of Agriculture, 2018. Djurskyddslag (2018:1192). https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/djurskyddslag-20181192_sfs-2018-1192.
SJV, Swedish Board of Agriculture, 2019. Statens Jordbruksverks Föreskrifter Och Allmänna Råd Om Grishållning Inom Lantbruket m.m. (SJVFS 2019:20). Jordbruksverket. https://lagen.nu/sjvfs/2019:20.
SJV, Swedish Board of Agriculture, 2020. Lantbrukets Djur I Juni 2020 Slutlig Statistik. https://jordbruksverket.se/om-jordbruksverket/jordbruksverkets-officiella-statistik/jordbruksverkets-statistikrapporter/statistik/2021-01-29-lantbrukets-djur-i-juni-2020-slutlig-statistik.
Sotiraki, S., Roepstorff, A., Nielsen, J.P., Maddox-Hyttel, C., EnøE, C., Boes, J., Murrell, K.D., Thamsborg, S.M., 2007. Population dynamics and intra-litter transmission patterns of *Isospora suis* in suckling piglets under on-farm conditions. Parasitology 135, 395–405.
Stryhn, H., Christensen, J., 2003. Confidence Intervals by the Profile Likelihood Method, With Applications in Veterinary Epidemiology.
Stuart, B.P., Lindsay, D.S., Ernst, J.V., Gosser, H.S., 1980. *Isospora suis* enteritis in piglets. Vet. Pathol. 17, 84–93.
Swedish Medical Products Agency. 2021. www.lakemdelsverket.se.
Textor, J., van der Zander, B., Gilthorpe, M.S., Liskiewicz, M., Ellison, G.T., 2016. Robust causal inference using directed acyclic graphs: the R package' dagitty'. Int. J. Epidemiol. 45, 1887–1894.
Thienpont, D., Rochette, F., Vanparijs, O., 1979. Diagnosing Helminthiasis by Coprological Examination, 1 edition, Vol. 1. Janssen Research Foundation Beerse, Belgium.
Vlaminck, J., Düsseldorf, S., Heres, L., Geldhof, P., 2015. Serological examination of fattening pigs reveals associations between *Ascaris suum*, lung pathogens and technical performance parameters. Vet. Parasitol. 210, 151–158.
Wallgren, P., 2009. First out to ban feed additives in 1986. Veterinary challenges within Swedish pig production: part I and II. Use of antimicrobials and respiratory diseases and Intestinal and miscellaneous diseases. Pig J. 62, 43–60.
Wolstenholme, A.J., Fairweather, I., Prichard, R., von Samson-Himmelstjerna, G., Sangster, N.C., 2004. Drug resistance in veterinary helminths. Trends Parasitol. 20, 469–476.