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Welfare indicators associated with feed conversion ratio and daily feed intake of growing-finishing pigs

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Abstract

Context. Understanding the welfare indicators that affect animal performance can facilitate modifications that improve both animal welfare and profitability.

Aims. A cross-sectional study was conducted to investigate the prevalence of animal welfare indicators and quantify their possible associations with feed conversion ratio (FCR) and daily feed intake (DFI) of growing-finishing pigs (*Sus scrofa*).

Methods. Data from 46 farms were collected. The herds ranged from 360 to 2500 pigs, which were aged between 75 and 173 days, and were managed on an all-in all-out basis. The welfare indicators were evaluated once on each farm using the methodology of the Welfare Quality® assessment protocol for pigs. Multiple linear mixed models were used to assess the associations of welfare with FCR and DFI according to the production stage at which the pigs were evaluated on the farm.

Key results. The welfare indicators with the highest average prevalence were frequency of coughing (35.7%), moderate bursitis (31.1%), and moderate and severe soiling with manure (18.8 and 27.7% respectively). Most of the remaining indicators related to poor welfare had prevalence values of less than 1%. The mean prevalence of positive social behaviour (such as sniffing/nosing/licking) was 14.4% and that of negative social behaviour (NSB; such as aggressive interactions) was 3.1%. The average space allowance (measured in 460 pens) was 1.04 ± 0.13 m^2/pig (ranging from 0.78 to 1.36 m^2/pig). Better FCRs were associated with a low prevalence of NSB ($P < 0.05$), a low prevalence of coughing ($P < 0.01$), absence of lameness problems ($P < 0.001$), and small space allowances ($P < 0.05$). Lower DFI values were associated with a low prevalence of NSB ($P < 0.05$), a high prevalence of moderate hernias ($P < 0.01$), a low prevalence of other active behaviours (such as eating and drinking) ($P < 0.001$), and a high prevalence of animals with wounds on the body ($P < 0.05$).

Conclusions. Few indicators related to the impairment of welfare were detected with a high prevalence, and the results suggest that the conditions related to poor welfare were associated with an impairment in animal performance.

Implications. The results of this study can provide the industry with comparative information to promote improvements in pig welfare. Some welfare indicators could be used on farm as predictors of performance variables; however, these indicators need validation.

Keywords: aggression, animal-based indicators, animal welfare, daily feed intake, farm profitability, feed conversion ratio, productivity, protocol, swine, welfare indicator.

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Introduction

The welfare of livestock animals, at least at a minimum level, is a precondition for animal productivity (Kauppinen *et al*. 2012). Factors that are detrimental to animal welfare have a negative effect on health and performance, which compromises profitability and the quality of the final product (Velarde and Dalmau 2012). Any stress conditions can cause a decrease in feed intake, daily weight gain, and bodyweight (Martínez-Miró *et al*. 2016). Behaviour (Nielsen 1999; Camerlink *et al*. 2013), health (Morris *et al*. 1995; Chedad *et al*. 2001; Jensen *et al*. 2012; Munsterhjelm *et al*. 2015), and housing (Street and Gonyou 2008; Vermeer *et al*. 2014) are indicators of animal welfare, and when used at the correct stages throughout the production cycle, they can be useful for predicting performance.

Animal welfare indicators can be based directly on observations of the animal or resources. When focused on the animal, welfare indicators are also referred to as 'outcomes' (for example, behaviour and physical condition), they provide more reliable information on welfare than indicators based on the resources, which are also called 'inputs' (for example, management practices and facilities) (Main *et al*. 2007; Mullan *et al*. 2009). The protocols for animal welfare assessment of the Welfare Quality® Project are primarily based on animal-based indicators and less on resource-based indicators (Welfare Quality® 2009). In practice, these protocols have been used to identify welfare problems in different breeding systems in the European Union (Temple *et al*. 2011, 2012*a*, 2012*b*, 2013; Meyer-Hamme *et al*. 2016; Czycholl *et al*. 2017; van Staaveren *et al*. 2018); however, their scientific application in countries outside the European Union is still limited.

It is clear that there are important differences between countries in the conditions of intensive pig production systems. Growing-finishing (GF) pig farms built in countries with tropical climates, which is different from those based in Europe and North America, have barns with lighter structures, open sidewalls, and thermal control based on the handling of curtains. These farms commonly adopt compact concrete floors as opposed to the use of bedding material, among other differences. These particularities could influence the prevalence of Welfare Quality® indicators (Temple *et al*. 2012*a*, 2012*b*). In addition, there is a limited number of studies that have observed possible indicators of animal welfare and quantified their effects on performance, contrary to the numerous studies that relate facilities, management, and feeding to production indices (Maes *et al*. 2004; Oliveira *et al*. 2009; Agostini *et al*. 2014).

We hypothesised that a higher prevalence of indicators related to poor animal welfare would be related to worse performance of GF pigs. Therefore, the objectives of this study were to investigate the prevalence of indicators of welfare on Brazilian GF pig farms as well as to identify and quantify which of these indicators were associated with feed conversion ratio (FCR) and daily feed intake (DFI), using the multi-criterion approach of the Welfare Quality® protocol.

Materials and methods

Study design and data collection

The study was approved by the Ethical Committee on Animal Use of State University of Londrina (circular letter number 86/2016). This study was conducted in strict accordance with law 11794 from 8 October 2008, with Decree 6899 from 15 July 2009, and with the standards issued by the National Council for the Control of Animal Experimentation (CONCEA) in Brazil. This was a cross-sectional study involving a sample of 46 batches of pigs (*Sus scrofa*) housed in 46 commercial GF farms (one batch per farm). Participation in the study was voluntary. The farms were integrated into four pork producing companies, all of which were located in western regions of the state of Paraná in Brazil. The pork-producing companies were farmer co-operatives composed of many GF farms from different owners. Twelve farms were evaluated at two pork producer companies (resulting in 24 farms) and 11 farms were evaluated at two pork producer companies (resulting in 22 farms). Although the data were collected at the farm level, farms from different companies were evaluated. Thus, the data were drawn from a hierarchy of different populations whose differences (in, for example, management, facilities, feeding) relate to that hierarchy and could affect animal welfare and performance.

The herd sizes ranged from 360 to 2500 pigs (median = 600, Q1 = 517, Q3 = 1121), totalling ~40 100 animals with commercial genetics. Eight farms housed only females (4252 pigs), eight housed only males (4998 pigs) and 30 housed mixed sexes (30 850 pigs). All pigs were tail docked, and all male pigs were immunologically castrated during the GF phase. The batch was defined as the total number of pigs on a farm, and was formed by the piglets (21.78 ± 1.40 kg) that entered and were kept on the GF farm until slaughter (118.60 ± 4.51 kg). All batches were managed on an all-in all-out basis.

The pigs were kept on concrete floors without bedding; 87% of the farms had solid floors, and 13% had partly slatted floors. All pens in the solid-floor farms had dunging gutter systems. The dunging gutter (called *lâmina d'água*) is a structure planned as part of the housing system that is defined as an accumulation of the water wasted from the drinkers as well as urine from the animals. These structures are usually in the backs of pens and range from 1 to 10 cm in height. The number of animals in the pens ranged from 10 to 69 (mean ± s.d. = 22 ± 10). For the feeding system, 90% of the farms provided feed *ad libitum* and 10% provided feed three or four times a day. All farms used pelleted feed. The environmental temperatures in the pens were recorded using a digital thermometer-hygrometer (AGZ Brasil 2673A, RuralBan, Rio de Janeiro, Brazil) positioned at the height of the animals and ranged from 17.9°C to 34.8°C (median = 30.2°C, Q1 = 29.3°C, Q3 = 32.3°C). The relative humidity on the farms, which was measured after the welfare assessment using the same equipment positioned 1.5 m above the floor of the corridor of the barn, ranged from 47 to 81% (median = 67%, Q1 = 56%, Q3 = 74%).

The welfare indicators (independent variables) were evaluated at each farm using the methodology of the Welfare Quality® assessment protocol for pigs (Welfare Quality® 2009). Twenty animal-based indicators and two resource-based indicators (farm facilities) were assessed. For some indicators, a three-point scale (0–2) was used to quantify the welfare condition: a score of zero (0) was assigned when there was an appropriate welfare condition, 1 when there was some impairment to animal welfare (a moderate problem), and 2 when there was a more critical situation (a severe problem). A two-point scale was employed for other indicators, with values of 0 and 2 representing absence or presence respectively. A description of the welfare indicators evaluated and the number of pens and animals sampled can be found in Table 1. For a detailed description of the welfare assessments, the reader can refer to the Welfare Quality® assessment protocol for pigs (Welfare Quality® 2009).

Table 1. Description of the 22 welfare indicators used, which are included in the Welfare Quality® assessment protocol for pigs (growing pigs)

Indicator	Score and description
Body condition[A]	0 – Animal with a good body condition
	2 – Animal with visible spine, hip and pin bones
Bursitis[A]	0 – No evidence of bursa/swelling
	1 – One or several small bursa on the same limb or one large bursa
	2 – Several large bursa on the same limb, or a very large or ruptured bursa
Manure on the body[A]	0 – Up to 20% of the body surface is soiled
	1 – Between 20–50% of the body surface is soiled
	2 – More than 50% of the body surface is soiled
Lameness[A]	0 – Normal gait or difficulty in walking, but using all legs; shortened stride
	1 – Severely lame, minimal weight–bearing on the affected limb
	2 – No weight–bearing on the affected limb or unable to walk
Wounds on the body[A]	0 – All regions of the animal's body have a maximum of four lesions
	1 – Any region of the body has 5–10 lesions, or at most one region has 11–15 lesions
	2 – Two or more regions of the body with 11–15 lesions or one region with more than 15 lesions
Tail biting[A]	0 – No evidence of fresh blood or oedema on the tail
	2 – Fresh blood on the tail; evidence of swelling/infection; part of the tissue is absent/crusted
Pumping[A]	0 – No evidence of laboured breathing
	2 – Evidence of laboured breathing
Twisted snout[A]	0 – No evidence of twisted snout
	2 – Evidence of twisted snout
Rectal prolapse[A]	0 – No evidence of rectal prolapse
	2 – Evidence of rectal prolapse
Skin condition[A]	0 – No evidence of skin inflammation/discoloration
	1 – Up to 10% of the skin is inflamed/discoloured/spotted
	2 – More than 10% of the skin has an abnormal colour/texture
Hernia[A]	0 – No evidence of hernia
	1 – Hernia present, but the affected area does not bleed/touch the floor/affect the locomotion
	2 – Bleeding hernia/hernia touches the floor
Scouring[B]	0 – No liquid manure visible in pen
	1 – Some liquid manure in some areas of pen
	2 – All faeces visible inside pen are liquid
Fear of humans[C]	0 – Up to 60% of the animals showing a panic response
	2 – More than 60% of the animals showing a panic response
Shivering[D]	0 – No evidence of shivering
	2 – Evidence of shivering
Panting[D]	0 – Animal with normal breathing
	2 – Animal with rapid breathing. Short inhalation/exhalation
Huddling[D,E]	0 – Pig lying with less 50% of its body on top of another pig
	2 – Pig lying with more 50% of its body on top of another pig
Coughing[F]	Average frequency of coughing per animal during a 5-min period
Sneezing[F]	Average frequency of sneezing per animal during a 5-min period
Social behaviour[G]	Positive – sniffing/nosing/licking and moving gently away from the animal, without fight reaction
	Negative – aggressive interaction. Any social behaviour with disturbed animal response
Exploratory behaviour[G]	Pen – sniffing/nosing/licking/chewing any features of the pen
	Enrichment – play/investigation towards straw or other enrichment material
Water supply[H]	Number of animals in the pen divided by the number of clean and working properly drinkers
Space allowance[H]	Total area of the pen divided by the number of pigs, m^2/pig

[A]Evaluation conducted inside the pen. Ten pens were selected, and 15 animals were individually evaluated in each.
[B]Evaluation conducted inside 10 pens. The floor was observed, not the animals.
[C]Evaluation conducted inside 10 pens. The group of animals was observed as a whole.
[D]Evaluation conducted outside 10 pens. The animals were observed from the corridor of the barn.
[E]Only animals at rest at the time of evaluation were considered.
[F]Evaluation was performed at six points on the farm, with 20–40 animals per point. The animals were observed from the corridor of the barn.
[G]Evaluation was performed at three points on the farm, with 50–60 animals per point. The animals were observed from the corridor of the barn. Animals that did not show social or exploratory behaviour were recorded as resting or 'other,' which is defined as 'other active behaviours' such as eating, drinking, or air sniffing.
[H]Evaluation conducted within 10 pens. This was a resource-based indicator.

Before the start of the study, the observer received training from someone with experience in the theory and practice of the protocol and applied the protocol five times on two farms. The on-farm welfare assessments were performed between January and April 2016. Each batch was examined by the same observer between the morning and afternoon of a single day. On the day of the welfare assessment, the pigs' ages ranged from 75 to 173 days (10 to 108 days housed on the farm). When the farm had more than one barn or barns with more than one room, the number of pigs sampled in each room/barn was proportional to the total number of pigs in each room/barn. For example, according to the Welfare Quality® protocol, the sampling for most indicators should be 10 pens, with 15 pigs observed individually in each pen; if a farm with 1500 pigs had two barns – 1 barn with 1000 pigs in 40 pens and the other barn with 500 pigs in 20 pens (both barns with 25 pigs per pen) – 7 pens would be selected in the largest barn and three pens would be selected in the smallest barn. Across the study a total of 6900 pigs were evaluated individually within the pens. The number of hospital pens per farm ranged from 0 to 9 (mean ± s.d. = 3.2 ± 1.8) and usually housed few animals (mean ± s.d. of usable space = 4.1 ± 2.7 m^2/pig) (Pierozan *et al.* 2017). Hospital pens were not considered in the sampling, following the determination of the Welfare Quality® protocol.

After the slaughter of all batches, the production data for each batch were obtained from the management software of the four pork producing companies in which the farms were integrated. The FCR and DFI were used with dependent variables for the statistical analysis. The DFI was calculated from the amount of feed offered to the batch during the GF phase minus the amount of feed remaining in the silos when these animals were sent for slaughter; the difference was divided by the total number of animals in the batch and then divided by the average number of days that the animals had remained on the GF farm. The FCR was calculated by dividing the total feed offered to the batch by the difference between the initial bodyweight and the final bodyweight of the animals. The pigs were weighed by the companies just before entering the GF farm and again in the slaughterhouses just before slaughter. The average final weight and the duration of the GF phase were also obtained.

Statistical analyses

The farm was considered the experimental unit for the statistical analyses (SAS University Edition, SAS Institute Inc., Cary, NC, USA). For welfare indicators, as for the performance continuous variables (FCR, DFI, final weight, and duration of GF phase), the mean, standard deviation, median, and range were determined (PROC MEANS univariate boxplot in SAS) (Tables 2, 3). The prevalence of welfare indicators was then sorted into two or three categories using quantiles (PROC RANK SORT in SAS). The frequencies of farms in each category were assessed (PROC FREQ in SAS). The categorical variables pertaining to less than 15% of farms in a given category were excluded from subsequent statistical analyses. The space allowance (m^2/pig) remained a continuous variable.

The variables FCR and DFI were considered the dependent variables. All other continuous and categorical variables (see Tables 2, 3) were considered independent variables. Spearman's correlation analysis (PROC CORR in SAS) was used to test possible confounding variables (days housed on the farm, temperature, humidity, space allowance, sex, and type of floor) for an effect on welfare indicators (see Table S1, available as Supplementary Material to this paper). The 'days housed on the farm' was moderately correlated (coefficient of correlation $\geq$0.5, $P \leq 0.05$) with eight welfare variables. Therefore, different models for FCR and DFI were constructed considering the total period (10 up to 108 days housed, $n = 46$), initial stage (10 up to 49 days housed, $n = 15$), middle stage (50 up to 84 days housed, $n = 15$), and final stage (85 up to 108 days housed, $n = 16$).

First, the univariate mixed linear models were used to investigate the association between welfare indicators and performance variables, although each explanatory variable was included as a single fixed effect and the pork producing company was included as a random effect for each dependent variable (PROC MIXED in SAS). Variance component estimation was performed using the restricted maximum likelihood procedure. The initial weight, final weight, and duration of the GF period were tested as fixed effects in the FCR and DFI models for the total period. Independent variables with $P < 0.20$ for the F-test in the simple model were selected and subjected to Pearson's and Spearman's correlation analyses (PROC CORR in SAS). When the correlation coefficient was $\geq$0.60, only one variable was kept, which was chosen based on the lowest P-value in the univariate model and its biological relevance to the dependent variable.

In multiple linear regression models, the remaining welfare variables were included as fixed effects and were subjected to manual forward selection, and the pork producing companies were included as random effects (PROC MIXED in SAS). Fixed-effect testing was based on the F-test, and the degrees of freedom of the denominator were approximated by Satterthwaite's procedure. At each step, the variable with

Table 2. Descriptive values of the dependent and independent performance continuous variables included in the final models of feed conversion ratio and daily feed intake at 46 growing-finishing pig farms

Variable	Mean	s.d.	Minimum	Median	Maximum
Feed conversion ratio (kg/kg)	2.38	0.10	2.16	2.37	2.61
Daily feed intake (kg)	2.16	0.10	1.92	2.17	2.45
Duration of growing-finishing period (day)	107	4.04	100	107	113
Average weight at end of fattening period (kg)	118.62	4.51	105.14	118.58	125.93

Table 3. Descriptive values for the welfare indicators in 46 growing-finishing pig farms according the four principles of Welfare Quality® protocols

The results are expressed as the percentage of pigs affected in relation to the number of pigs assessed on each farm

Welfare indicator	Mean	s.d.	Minimum	Median	Maximum
		Principle: *good feeding*			
Poor body condition	0.01	0.10	0	0	0.70
Water supply (animals per drinker)	9.46	1.91	6.65	9.10	14.81
		Principle: *good housing*			
Moderate bursitis	31.09	10.78	5.30	33.00	50.00
Severe bursitis	1.54	1.84	0	1.00	7.30
Moderate manure on the body	18.83	12.03	1.30	17.00	48.00
Severe manure on the body	27.66	25.96	0	22.65	90.00
Shivering	0	0	0	0	0
Panting	0.07	0.20	0	0	0.90
Huddling	0.02	0.09	0	0	0.50
Space allowance (m^2/pig)	1.04	0.13	0.78	1.05	1.36
		Principle: *good health*			
Moderate lameness	0.43	0.63	0	0	2.00
Severe lameness	0.09	0.34	0	0	2.00
Moderate wounds on the body	13.22	8.42	0.70	12.00	35.30
Severe wounds on the body	0.88	1.20	0	0.70	4.70
Tail biting	0.37	1.34	0	0	8.70
Moderate skin condition	2.94	2.88	0	2.00	13.30
Severe skin condition	0.12	0.46	0	0	2.70
Moderate hernia	1.96	1.90	0	1.30	10.00
Severe hernia	0.02	0.10	0	0	0.70
Pumping	0.27	0.59	0	0	3.30
Twisted snout	0	0	0	0	0
Rectal prolapse	0.60	0.20	0	0	0.70
Animals coughing	5.98	3.68	0	5.25	13.60
Frequency of coughs[A]	35.74	26.16	0	30.65	102.00
Animals sneezing	5.24	3.86	0	4.15	20.40
Frequency of sneezing[A]	5.69	4.47	0	4.35	21.90
Moderate scouring in the pen[B]	6.23	10.95	0	0	50.00
Severe scouring in the pen[B]	0	0	0	0	0
		Principle: *appropriate behaviour*			
Fear of humans[B]	7.83	11.91	0	0	50.00
Positive social behaviour[C]	14.40	4.01	7.20	14.20	27.1
Negative social behaviour[C]	3.13	2.14	0.90	2.80	14.80
Pen investigation[C]	35.10	7.98	17.30	35.40	53.10
Exploration of enrichment material[C]	0.81	1.83	0	0	9.20
Other active behaviours[C]	46.60	10.29	25.80	45.95	61.50

[A]Expressed as the percentage of pigs emitting coughs or sneezes in relation to the number of pigs assessed.
[B]Expressed as the percentage of pens affected in relation to the number of pens assessed.
[C]The prevalence of each behaviour was calculated from the total active behaviours (excluding resting animals).

the lower P-value in univariate regression was added to the model. This procedure was continued until all variables were significant ($P < 0.05$). For each variable added, the Akaike information criterion (AIC) was used as an estimator of the relative quality of the model compared with the AIC of the precursor model (lower AIC values are better). For all models, the AIC decreased with each variable added, indicating that the last model had the best quality. This ensured that the criterion for integrating the variables into the model (based on the P-value of the prior univariate analyses) was adequate. For each model, we obtained the determination coefficient (R^2) from the calculation of the proportion of the estimated covariance parameters of the full model (i.e. with all fixed effects with $P < 0.05$ added) in relation to the null model (i.e. without the fixed effect added) (Agostini *et al*. 2014).

In the final models, the interactions between factors were analysed and eliminated if they were not significant ($P \geq 0.05$); no significant interaction was found. For each dependent variable, after constructing models, the residuals were plotted against the predicted values to investigate the homoscedasticity and normality of variances, as well as the presence of outliers, and the data were tested for normality (Shapiro–Wilk, $P \geq 0.05$). The models for FCR in the initial stage and for DFI in the middle stage did not meet the assumptions of linear regression and were disregarded.

Factors with $P < 0.05$ in the final models were considered statistically significant.

Results

Prevalence of welfare indicators

Regarding the welfare indicators that were classified as severe (with a score of 2, indicating a situation of high impairment of animal welfare), only bursitis and manure on the body presented prevalence values higher than 1%, with the prevalence of the latter being higher than 20% (Table 3). Among the indicators classified as moderate (with a score of 1, indicating a moderate impairment), bursitis and manure on the body again presented the highest prevalence, followed by wounds on the body, which had a prevalence of higher than 10%. The indicators classified as moderate that presented prevalence values between 2 and 10% included scouring and the presence of skin conditions and hernias. The frequency of coughing presented a prevalence than >30%; however, the number of animals coughing was lower since the same animal often coughed more than once during an evaluation.

None of the animals evaluated presented a twisted snout or shivering. None of the pens were recorded with severe scouring. The remaining indicators had prevalence values of less than 1%. The average value of active pigs (animals presenting any behaviour other than resting) was 62.3%. The remaining behaviours are expressed in relation to the total number of active pigs (excluding the resting animals). For resource-based indicators, the water supply served 9.46 ± 1.91 animals per clean and adequate-functioning drinker (ranging from 6.65 to 14.81 animals per drinker), and the space allowance per pig was 1.04 ± 0.13 m^2 (ranging from 0.78 to 1.36 m^2).

Possible confounding variables

Spearman's correlation identified that 'days housed on the farm' had a coefficient of correlation ≥ 0.5 ($P \leq 0.05$) with seven welfare indicators (Table S1, Supplementary Material). No other confounding variable tested had correlation coefficients ≥ 0.5 with welfare indicators.

Feed conversion ratio

Considering the total period, the multiple regression model for FCR (Table 4) showed that the farms with low (ranging from 0.9 to 2.1%) or intermediate (ranging from 2.2 to 3.4%) prevalence of negative social behaviour (NSB) had better

Table 4. Multiple linear regression analyses of the associations between welfare indicators and the feed conversion ratio (kg/kg) of growing-finishing pigs

The models were divided according to the production stage at which the pigs were evaluated on the farm. Estimates followed by different letters in the same column were significantly different at the 5% level according to Tukey-Kramer's adjustment. NSB, negative social behaviour; TSB, total social behaviour

Variable	Category	*n*	Estimate	s.e.m	95% coefficient interval		
					Lower	Upper	*P*-value
Total period[A] (*10–108 days housed*, n = *46*)							
Intercept	–	–	2.122	0.102	1.913	2.330	<0.001
NSB (%)	0.9–2.1	14	–0.072a	0.027	–0.127	–0.018	0.010
	2.2–3.4	17	0.048b	0.022	0.003	0.093	0.037
	3.6–14.8	15	0b	–	–	–	–
Normal lameness[B] (%)	96–99.3	21	0.073	0.018	0.036	0.110	<0.001
	100	25	0	–	–	–	–
Animals coughing (%)	0–3.9	15	–0.072a	0.024	-0.121	–0.022	0.006
	4.1–7.9	16	–0.036ab	0.025	-0.086	0.014	n.s
	8.6 –13.6	15	0b	–	–	–	–
Space per pig (m^2)	–	–	0.258	0.097	0.061	0.454	0.012
Middle stage[C] (*50–84 days housed*, n = *15*)							
Intercept	–	–	2.576	0.042	2.481	2.670	<0.001
NSB (%)	0.9–2.1	4	–0.193a	0.042	–0.289	-0.098	0.001
	2.2–3.4	8	–0.071b	0.038	–0.157	0.015	n.s
	3.6–14.8	3	0b	–	–	–	–
Animals coughing (%)	0–3.9	4	–0.152a	0.035	-0.230	-0.073	0.002
	4.1–7.9	5	–0.053b	0.034	–0.130	0.024	n.s
	8.6–13.6	6	0b	–	–	–	–
Final stage[D] (*85–108 days housed*, n = *16*)							
Intercept	–	–	2.467	0.046	2.357	2.576	<0.001
NSB/ TSB (%)	5.3–13.2	9	-0.149a	0.048	–0.253	–0.045	0.009
	14–20	4	-0.027b	0.052	–0.139	0.086	n.s
	20.4–51.2	3	0b	–	–	–	–

[A]Goodness of fit of the model: AIC = –88.1, R^2 = 0.47.
[B]So-called 'normal' variables correspond to a score of '0' in the classification in the protocol Welfare Quality®.
[C]Goodness of fit of the model: AIC = –20.6, R^2 = 0.73.
[D]Goodness of fit of the model: AIC = –28.4, R^2 = 0.23.

FCR values ($P < 0.05$) than the farms with a high prevalence (ranging from 3.6 to 14.8%). In the middle stage, the farms with low prevalence of NSB had better FCR values ($P < 0.01$) than farms with a high prevalence. In the final stage, NSB was not selected for the final model; however, the farms with a low prevalence of NSB/total social behaviour (NSB calculated considering only social behaviours) (ranging from 5.3 to 13.2%) had better FCR values ($P < 0.01$) than the farms with a high (ranging from 20.4 to 51.2%) or intermediate prevalence (ranging from 14 to 20%; Tukey's test, $P < 0.05$).

Three more welfare indicators were included in the total period multiple regression model for the FCR. Farms with 100% of animals with normal levels of lameness (score of 0) presented better FCRs ($P < 0.001$) than farms with some moderate or severe lameness in their animals. Farms with a lower prevalence of animal coughing (ranging from 0 to 3.9%) had better FCRs ($P < 0.01$) than farms with a higher prevalence (ranging from 8.6 to 13.6%). An increase in space per pig was associated with a worse FCR ($P < 0.05$); for each 1 m^2 increase in total space per pig, the estimated FCR was 0.258 kg/kg worse (or 0.026 kg/kg worse per 10 cm^2/pig increase in space). The prevalence of animal coughing was also associated with FCR in the middle stage; farms with a lower prevalence of animal coughing had better FCRs than the high ($P < 0.01$) and an intermediate prevalence farms (Tukey's test, $P < 0.05$).

Daily feed intake

Considering the total period, the farms with a lower prevalence of NSB had lower DFI values than the farms with an intermediate prevalence (Tukey's test, $P < 0.05$) but were not different from farms with a high prevalence of NSB ($P \geq 0.05$) (Table 5). An increase in the duration of the GF phase was associated with a lower DFI value ($P < 0.01$); for each additional day spent in the GF phase, the DFI estimate was reduced by 0.012 kg. However, an increase in final weight (kg) was associated with a higher DFI value ($P < 0.001$); for each additional kilogram in final pig weight, the estimated DFI was 0.015 kg higher.

Considering the middle stage, only one welfare indicator was included in the model. Farms with a low prevalence of moderate hernias (ranging from 0 to 0.7%) had higher DFI values than farms with a high (ranging from 2.7 to 10%) ($P < 0.01$) or an intermediate prevalence (ranging from 1.3 to 2%) (Tukey's test, $P < 0.05$). In the final stage, farms with a lower prevalence of animals showing other active behaviours (ranging from 42.5 to 50.3%) had lower DFI values ($P < 0.001$) than farms with a higher prevalence (ranging from 52.4 to 61.5%). Finally, farms had higher DFI values when they had no severely wounded animals ($P < 0.05$) or when up to 0.7% of the animals (Tukey's test, $P < 0.01$) had severe wounds in comparison to the farms where 1.3 to 4.7% of the animals had severe wounds on the body.

Table 5. Multiple linear regression analyses of the associations between welfare indicators and daily feed intake (kg) of growing-finishing pigs

The models were divided according to the production stage at which the pigs were evaluated on the farm. Estimates followed by different letters in the same column were significantly different at the 5% level according to Tukey-Kramer's adjustment. NSB, negative social behaviour; GF, growing-finishing

Variable	Category	*n*	Estimate	s.e.m	95% coefficient interval		
					Lower	Upper	*P*-value
			Total period[A] (*10–108 days housed*, n = *46*)				
Intercept	–	–	1.639	0.371	0.854	2.423	<0.001
NSB (%)	0.9–2.1	14	–0.026a	0.025	–0.076	0.025	n.s
	2.2–3.4	17	0.045b	0.022	–0.000	0.091	0.05
	3.6–14.8	15	0ab	–	–	–	–
Duration of GF phase (day)	–	–	–0.012	0.003	–0.019	–0.005	0.005
Final weight (kg)	–	–	0.015	0.002	0.011	0.020	<0.001
			Initial stage[B] (*10–49 days housed*, n = *15*)				
Intercept	–	–	2.131	0.043	2.013	2.248	<0.001
Moderate hernia (%)	0–0.7	5	0.171a	0.049	0.061	0.281	0.006
	1.3–2	4	-0.011b	0.057	–0.136	0.113	n.s
	2.7–10	6	0b	–	–	–	–
			Final stage[C] (*85–108 days housed*, n = *16*)				
Intercept	–	–	2.096	0.039	2.005	2.187	<0.001
Other active behaviours (%)	42.5–50.3	6	–0.121	0.026	–0.178	–0.063	<0.001
	52.4–61.5	10	0	–	–	–	–
Severe wounds on the body (%)	0	7	0.100a	0.034	0.025	0.176	0.014
	0.7	6	0.167a	0.042	0.075	0.258	0.002
	1.3–4.7	3	0b	–	–	–	–

[A]Goodness of fit of the model: AIC = –86, R^2 = 0.58.
[B]Goodness of fit of the model: AIC = –15.7, R^2 = 0.33.
[C]Goodness of fit of the model: AIC = –27.1, R^2 = 0.51.

Discussion

Prevalence of welfare indicators

In general, the mean prevalence of indicators related to impaired animal welfare (for example, poor body condition, lameness, wounds on the body, tail biting, fear of humans, negative social behaviour, and others) were similar or even lower than the results obtained for farms in Spain (Temple *et al*. 2011, 2013), Spain and France (Temple *et al*. 2012*a*, 2012*b*), Germany (Meyer-Hamme *et al*. 2016; Czycholl *et al*. 2017), and Ireland (van Staaveren *et al*. 2018), which were evaluated by the same protocol as used in this work. Although the Welfare Quality® protocol does not include hospital pens in the sampling, the evaluation of these pens could be more representative of the real welfare conditions of the animals (Temple *et al*. 2013). The prevalence of rare problems such as tail biting, severe lameness and rectal prolapse may vary more widely between farms compared with more common problems, since they depend on management factors, such as the correct use of hospital pens.

In comparison to the results of the aforementioned studies, dramatically lower prevalences were obtained for huddling (0.02 vs 1.3, 3.5, 0.9, 1.4, 3.5, and 1.3%) (Temple *et al*. 2011, 2012*a*, 2013; Czycholl *et al*. 2017), severe skin conditions (0.1 vs 3.6, 2.1, 5.8, 0.8, and 0.6%) (Temple *et al*. 2011, 2012*b*, 2013; Czycholl *et al*. 2017), severe bursitis (1.5 vs 4.4, 7.8, 6.9, 4.1, 2.7, 4.0, and 4.8%) (Temple *et al*. 2011, 2012*a*, 2013; Meyer-Hamme *et al*. 2016; Czycholl *et al*. 2017), and the frequency of sneezing (5.7 vs 19.7, 17.1, and 13.3%) (Temple *et al*. 2011, 2013). In contrast, markedly higher prevalences were found for severe manure on the body (27.7 vs 3.7, 5.3, 1.8, 1.2, 6.2, and 3.7%) (Temple *et al*. 2011, 2012*a*, 2013; Meyer-Hamme *et al*. 2016; Czycholl *et al*. 2017) and the frequency of coughing (35.7 vs 15.8, 15.5, and 20.4%) (Temple *et al*. 2011, 2013). These contrasting results are possibly due to the differences among farms, which are due to distinct characteristics of different countries, especially in terms of climate.

In the European studies (Temple *et al*. 2011, 2012*a*, 2012*b*, 2013; Meyer-Hamme *et al*. 2016; van Staaveren *et al*. 2018), the animals were kept in pens with partially or totally slatted floors, whereas in the present study, 86.6% of the farms had completely solid floors with a dunging gutter (a structure that accumulates urine and water wasted by the drinkers, usually in the back of the pen). Completely solid floors are related to worse hygiene of the facilities and of the animals, whereas the slatted floors favour lower environmental humidity (Bennemann 2014). However, dunging gutters could reduce the amount of suspended dust in a barn and consequently reduce sneezing, whereas the inherent increase in humidity could amplify coughing, although there are no studies that support these considerations for this type of facility. It is necessary to consider that the results of animal welfare indicators generally reflect a set of possible causal factors related to the environment and their interrelationships (Pandolfi *et al*. 2017), which makes the exploration of isolated causal factors complex and highly subjective.

A similar prevalence of positive social behaviour and a slightly lower prevalence of NSB were obtained in the present study (14.4 and 3.1%) compared with those obtained by Temple *et al*. (2011) (12.2 and 5.4%) and Temple *et al*. (2013) in two consecutive evaluations on 30 European farms (9.9 and 5.1%; 13.6 and 5.6%). However, the prevalence of exploration of enrichment (0.81%) was markedly lower than the 4.4% obtained by Czycholl *et al*. (2017). The low prevalence of this behaviour was expected, since only 13% of the pens had some type of enrichment (mainly metal chains), which was contrary to the cited study, in which 20 of the 24 farms had pens with organic material.

With regard to resource-based indicators, the average space per animal (1.04 m^2/pig) was higher than the 0.66 m^2/pig obtained from 52 farms in France and Spain (Temple *et al*. 2012*b*), the 0.77 m^2/pig from 15 farms in Spain (Temple *et al*. 2013), and the 0.83 m^2/pig from 60 farms in Germany (Meyer-Hamme *et al*. 2016). The average number of animals per clean and functioning drinker was consistent with previous studies (Meyer-Hamme *et al*. 2016; Czycholl *et al*. 2017) and agreed with the value of 10–18 animals per drinker that is generally recommended in the literature (Brustolini 2014) but that lacks scientific support (Brumm 2019).

Possible confounding variables

Several animal welfare indicators were strongly correlated with the number of days that the animals were housed on the farm at the time of the evaluation, which agreed with Temple *et al*. (2012*a*, 2012*b*), who observed that the prevalence of several indicators of the Welfare Quality® protocol were affected by the age of the animals. This finding attested to age being a confounding variable that should be taken into account in future studies.

Associations of FCR and DFI with behaviour and wounds on the body

A lower prevalence of NSB in relation to the total active behaviours was associated with a better FCR and lower DFI when considering the complete evaluation and a better FCR when considering only the middle stage. In the final stage, the NSB/total social behaviour (the NSB calculated considering only social behaviours) was associated with the FCR, although NSB (calculated considering social, exploratory and other active behaviours) was not selected in the final model for the FCR. Therefore, NSB/total social behaviour seemed to be more sensitive to the association with the FCR, since it concentrated on the negative and positive active behaviours. Both the physical activity associated with fighting as well as the psychological stress associated with either losing a fight to a subordinate animal or the threat of losing dominance for a dominant animal cause physiological changes (de Groot *et al*. 2001). This can occur concurrently with the negative effects of the injuries and infections of skin lesions resulting from fighting. NSB is clearly an indicator of poor welfare (Temple *et al*. 2011), and a reduction in agonistic behaviours has been shown to improve animal welfare, health, and productivity (Büttner *et al*. 2015). The worsening of the FCR might be due to the energy expenditure required for disputes and to the consequent physical and/or social stresses (Fàbrega *et al*. 2013).

The mixing of unfamiliar pigs can lead to an increase in aggressive interactions until the establishment of a new hierarchy (Camerlink *et al*. 2013; Boumans *et al*. 2018; Verdon and Rault 2018). Even the removal of an animal or a few animals from a pen can disrupt the established order, leading to fights or stress in the group (Fàbrega *et al*. 2013). In the present study, the mixing of pigs before slaughter to equalise weights was not a common practice. Thus, the associations between NSB and performance were verified in the intermediate and final stages but not in the initial stage. This perhaps occurred because of the limitation of resources in the pens, such as resting and feeding areas, a condition caused by the increase in the size of animals and higher feed intake, culminating in aggressive interactions (Boumans *et al*. 2018; Verdon and Rault 2018).

NSB seemed to be less able to explain the DFI than the FCR; however, an individual assessment of skin injuries might also indicate the aggressive behaviour of animals within a group. In this case, it was observed that in the final stage of housing, farms holding up to 0.7% of animals with severe wounds presented higher DFI values than the farms with a prevalence between 1.3 and 4.7%. Again, excluding the 'mixing animals' factor, it was assumed that the skin injuries observed were due to disputes over resources, which were mainly feed and/or rest areas (Verdon and Rault 2018). Aggressive interactions might prevent some individuals from maintaining the desired DFI (Maselyne *et al*. 2015).

Farms with a higher prevalence of 'other active behaviours' presented higher DFI values, which was consistent with the other results since water and food intake behaviours are included in this behavioural category (Welfare Quality® 2009). However, it is necessary to consider that it is not possible to calculate the DFI by identifying the number of visits to the feeder since this index also depends on the volume ingested at each meal (Nielsen 1999; Maselyne *et al*. 2015; Boumans *et al*. 2018). However, the indicator 'other active behaviours' (which includes feed intake) was sufficient for inclusion as a possible predictive factor for the DFI.

Associations between the FCR and DFI with space allowance

The worsening of the FCR with increased space allowance per animal that was found in this study was contrary to the observations of Street and Gonyou (2008), who reported a worsening of feed efficiency in GF pigs (up to ~95 kg live weight) kept in an area of 0.52 m^2/pig compared with those kept in an area of 0.78 m^2/pig, especially in the last week of the study. However, the maximum space tested (0.78 m^2/pig) was equal to the minimum space observed in the present study. In contrast, Beattie *et al*. (1996) found that piglets between 6 and 12 weeks of age kept in spaces of 0.5, 1.1, and 1.7 m^2/pig had better feed conversions than those kept in spaces of 2.3 m^2/pig. In this sense, GF pigs housed in an area of 1.2 m^2/pig showed less exploratory behaviour and other active behaviours than those maintained at 1.6 and 2.4 m^2/pig (Vermeer *et al*. 2014). Some dietary energy can be used for the exploratory behaviour and animal movement (Turner *et al*. 2003), which might explain the worsening of the FCR in pigs kept in larger spaces since the energy obtained from the diet would not be allocated primarily to weight gain.

Associations between the FCR and DFI with the prevalence of hernias, lameness, and coughing

Farms with a prevalence of animals with moderate hernias (which were mainly represented by umbilical hernias) between 0 and 0.7% had higher DFI values than the farms with a higher prevalence (1.3–2.0 and 2.7–10.0%). Umbilical hernias can compromise pig growth and lead to death when there is intestinal strangulation (Anderson and Mulon 2019). In addition, human studies show that umbilical hernias might be associated with pain (Velasco *et al*. 1999; Rodriguez and Hinder 2004), which can culminate in a reduction in feed intake in pigs (Munsterhjelm *et al*. 2015).

Farms where 100% of animals had normal scores for lameness presented better FCR values than farms where animals were identified as having moderate or severe lameness. Lameness in finishing pigs is often attributed to infectious arthritis, physical injury, or osteochondrosis (Jensen *et al*. 2012). This condition commonly has a low prevalence on farms (Mullan *et al*. 2009), although this perception might not correspond to reality, since animals with this problem are usually directed to hospital pens (Pandolfi *et al*. 2017), which are not included in the Welfare Quality® assessment. However, farmers' perceptions of when a pig with lameness requires hospitalisation are quite different (Thomsen *et al*. 2016; Pandolfi *et al*. 2017; Pierozan *et al*. 2017), even in the face of agreement among experts that limping alone causes pain and might worsen the FCR (Jensen *et al*. 2012).

At the same time, the observation of lame animals in the pens of healthy animals might indicate an accidental neglect of health care, which might lead to worse performance indexes. Producers who recognise the need for differentiated care for a sick animal early on can, due to the provided attention, promote other better conditions that lead to an improvement in the health status and performance of a herd.

A low prevalence of coughing was associated with a better FCR in the general and middle stage models. This clinical sign can be caused by suspended dust and inadequate humidity in the environment (Chedad *et al*. 2001) and by infectious diseases, with *Mycoplasma hyopneumoniae* being one of the most important primary pathogens (Maes *et al*. 2008; Wilson *et al*. 2012). Mycoplasmic pneumonia is manifested clinically by the presence of a non-productive cough (Morris *et al*. 1995) and causes worsening of the FCR of between 2 and 5% (Maes *et al*. 2008).

Health-related problems, such as enzootic pneumonia, can result in worsening growth (Taylor *et al*. 2012), and the reduction in feed intake was considered to be one of the first signs observed in production animals (Forbes 2007). The severity of anorexia depends on the type and pathogenic load in the environment (Kyriazakis and Houdijk 2007). Subclinical disease in swine, which comes from a diverse array of pathogens and infective loads, reduces feed intake by ~25% (Sandberg *et al*. 2006); in clinical conditions, the degree of anorexia increases until the complete refusal of feed (Kyriazakis and Houdijk 2007).

The inclusion of only one indicator related to the 'good health' principle (moderate hernias) in the models for DFI in this study might be due to the insufficient number of farms with clinical manifestations of diseases in which it was possible to detect differences in the DFI.

Conclusions

The results from our study indicate that the prevalence of most indicators related to welfare problems was similar to or lower than those obtained in studies in Europe. Some indicators had markedly different prevalences, probably due to differences between Brazilian and European facilities, which should be taken into account in the interpretation of these results. We found some animal welfare indicators that are associated with FCR and DFI. Conditions related to poorer welfare indicated losses in pig performance, with special attention paid to NSB and coughing, which were indicators associated with performance over more than one evaluation period. These data, based on a recognised welfare assessment protocol for pigs and applied outside the European context, can be used by the industry as comparative information for future assessments and to promote improvements in pig welfare conditions and by the scientific community to validate predictors of performance based on welfare assessment.

Conflicts of interest

The authors declare no conflicts of interest.

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