Animal and management factors influencing grower and finisher pig performance and efficiency in European systems: a meta-analysis

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Animal and management factors influencing grower and finisher pig performance and efficiency in European systems: a meta-analysis

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A meta-analysis on the effects of management and animal-based factors on the performance and feed efficiency of growing pigs can provide information on single factor and interaction effects absent in individual studies. This study analysed the effects of such factors on average daily gain (ADG), feed intake (FI) and feed conversion ratio (FCR) of grower and finisher pigs. The multivariate models identified significant effects of: (1) bedding ($P<0.01$), stage of growth ($P<0.001$) and the interaction bedding × lysine ($P<0.001$) on ADG. ADG was higher on straw compared with no bedding (710 v. *605 g/day). (2) FI was significantly affected by stage of growth ($P<0.01$), bedding ($P<0.01$), group composition ($P<0.05$), group size ($P<0.01$), feed CP content ($P<0.01$), ambient temperature ($P<0.01$) and the interaction between floor space and feed energy content ($P<0.001$). Pigs housed on straw had a lower FI in comparison with those without (1.44* v. *2.04 kg/day); a higher FI was seen for pigs separated by gender in comparison with mixed groups (2.05* v. *1.65 kg/day); FI had a negative linear relationship with group size, the CP content of the feed and ambient temperature. (3) Stage of growth ($P<0.001$), feed CP ($P<0.001$) and lysine content ($P<0.001$), ambient temperature ($P<0.001$) and feed crude fibre (CF) content ($P<0.01$) significantly affected FCR; there were no significant interactions between any factors on this trait. There was an improvement in FCR at higher ambient temperatures, increased feed CP and lysine content, but a deterioration of FCR at higher CF contents. For ADG, the interaction of bedding × lysine was caused by pigs housed without bedding (straw) having higher ADG when on a feed lower in lysine, whereas those with bedding had a higher ADG when on a feed higher in lysine. Interaction effects on FI were caused by animals with the least amount of floor space having a higher FI when given a feed with a low metabolisable energy (ME) content, in contrast to all other pigs, which showed a higher FI with increased ME content. The meta-analysis confirmed the significant effect of several well-known factors on the performance and efficiency of grower and finisher pigs, the effects of some less established ones and, importantly, the interactions between such factors.*

Keywords: efficiency, finishers, growers, meta-analysis, pigs

Implications

The effects of management and animal-based factors on daily gain, feed intake (FI) and feed efficiency of grower and finisher pigs were analysed. A number of factors were identified as having significant effects on these traits, including the effects of less well-established ones, such as the effects of grouping by gender on FI. Interactions between factors were also confirmed; for example, the interaction between bedding and feed lysine content on daily gain. The results may contribute towards the improvement of efficiency of pig systems through a better knowledge of the various factors that influence it.

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Introduction

Feed efficiency is one of the major factors that defines the overall efficiency of pig systems (Gaines *et al.*, 2012). In grower and finisher pigs, feed costs can represent as much as 70% of the total production costs (Woyengo *et al.*, 2014), and the efficiency with which feed is converted to pig meat underpins the pig industry's ability to compete internationally. Therefore, finding effective ways to improve feed efficiency and consequentially reduce waste, is essential both on financial and food security grounds. As in most animal systems, inefficiencies associated with feed utilisation will arise from factors associated with the feed itself, the animal and the environment it is kept in (Emmans and Kyriazakis, 2001).

Although there is published information for the effects of some factors on feed efficiency, such as feed-related factors and ambient temperature (Lopez *et al.*, 1991; Renaudeau *et al.*, 2011 and 2012), there is a lack of information for some lesser known factors such as feeder and drinker type, as well as the effect of social stressors on performance (Wellock *et al.*, 2003b). Importantly, less is known about the interaction effects between several factors that may influence feed efficiency. This is despite the fact that there are great benefits to be had from the knowledge of such interactions, for example, whether the same pig genotype will perform similarly or differently in different environments (Brandt *et al.*, 2010). In the United Kingdom, for example, there is great interest in what animals to use and how to treat them in the two very different prevailing systems for growers and finishers (British Pig Executive (BPEX), 2009). This absence of information reflects the difficulty in making systems comparisons.

The better understanding of the effects of the environment, animal characteristics and nutrition on pig feed efficiency will provide useful insights to what housing and feeding system characteristics are likely to improve productivity and animal welfare. The aim of this study was to determine the separate and interactive effects of different factors, relating to pig environment, animal and feed characteristics, on the performance and feed efficiency of grower and finisher pigs; this was done by meta-analysis of scientific papers and industry-provided data.

Material and methods

Data collection

Information regarding the feed efficiency of grower and finisher pigs was collected from a number of studies published in peer-reviewed journals between 1987 and 2013. Production data from controlled, industry-based studies was also used in the same analysis; this was consistent with the methodology used by previous meta-analyses (Agostini *et al.,* 2013). This allowed for the inclusion of a greater number of treatments as well as incorporating multiple sources of data to increase reliability. The peer reviewed studies were gathered using a search engine (SCOPUS) with the terms ('pig' and 'feed efficiency') or ('pig' and 'performance'). The literature cited was also checked to complete the information available. The dependent factors of interest were the average daily gain (ADG), FI and feed conversion ratio (FCR) of grower and finisher pigs (i.e. from 25 kg BW). Manuscripts using only piglets before the growing phase were disregarded and the same applied to papers using rare breeds. Furthermore, only papers from within Europe were taken into account due to differences between continents regarding several practices, including feed ingredients used.

A database was built in Excel, where each individual observation in the database referred to the mean of a treatment group. A total of 152 publications were found, out of which 54 publications were useable (based on the exclusion criteria mentioned previously); these included 190 different useable treatments. In addition, four sets of unpublished data were used, giving 52 more entries leading to a total of 242 (Table 1). The information gathered included the dependent factors (ADG, FI, FCR) and information regarding the animal characteristics, housing, feed characteristics and feeder and drinker type was used as the independent factors.

The factors chosen to be included as independent factors influencing ADG, FI and FCR were (i) animal characteristics: gender (entire male, female, castrated male or a combination of entire males/females or castrated males/females), genotype (discussed below) and stage of production (growers, finishers or a combination), (ii) group characteristics: group size (number of pigs), group composition (mixed or separate genders) and practice of mixing (yes or no), (iii) housing: country where the study was conducted (in EU), floor space allowance expressed in m^2 per and metabolic BW, K ($m^2/BW^{0.667}$), floor type (solid, fully or partially slatted), the use of bedding (straw) (yes or no), ambient temperature (°C), lighting regime (hours of light per 24 h), building type (natural ventilation, mechanical ventilation, automatic control of natural ventilation and climate respiratory chambers) and season (spring/summer, autumn/winter or a combination of the two), (iv) presence of infection (yes or no), (v) feed characteristics: metabolisable energy (ME, MJ/kg), crude protein (CP, g/kg), crude fibre (CF, g/kg) and lysine (g/kg) content, the ratio of lysine: ME, the number of feeds fed throughout the study, feed allowance (*ad libitum*, restricted or a combination of the two) and feed form (pellet, crumble, liquid, expandate, meal or mash), (vi) feeder and drinker characteristics: feeder type (single, multi-space or trough), number of pigs per feeder, feeder space (cm^2), water type (nipple, bowl or at feeder) and number of pigs per drinker.

For both dependent and independent factors, there was large variation in the number of observations available as not all manuscripts reported data for all factors. Data on as many factors as possible were collected, however, there were some cases where either no data were available or there were insufficient numbers to be included in the subsequent analysis (e.g. phosphorous and fat content of the diet). The articles chosen for analysis had to contain data on at least one of the dependent factors (FCR, FI or ADG), as well as most of the independent factors stated above, including at least one in every group, with the exception of the feed characteristics, information on which was not provided by all articles.

The stage of growth was defined as grower (25 to 50 kg), finisher (>50 kg) or a combination. Concerning genetics, the Large White (LW) and Landrace (L) pure breeds, and the Large White × Landrace (LW/L) crosses were grouped into the same category, in accordance with Averós *et al.* (2012). This also included any Landrace/Large White × Meishan crosses. Duroc, Pietrain, Hampshire purebreds and their

Table 1 *Peer reviewed and non-peer reviewed data sources included in the meta-analysis with the number of treatments available per source*

Source	Peer reviewed (yes or no)	Number of treatments[1]
Affentranger *et al.* (1996)	Y	9
Bartussek *et al.* (1993)	Y	4
Beattie *et al.* (2000)	Y	4
BPEX Development Trial 1[1]	N	6
BPEX Development Trial 2[1]	N	10
BPEX Development Trial 3[1]	N	2
BPEX Development Trial 4[1]	N	34
Cameron *et al.* (2003)	Y	5
Cesaro *et al.* (2013)	Y	4
Collin *et al.* (2001)	Y	2
Conte *et al.* (2011)	Y	2
Conte *et al.* (2012)	Y	3
De Boer and Kanis (1991)	Y	3
Defra (2007)	N	2
De Greef *et al.* (1992)	Y	12
De Haer and de Vries (1993a)	Y	2
De Haer and de Vries (1993b)	Y	4
De Haer *et al.* (1993)	Y	2
Edwards *et al.* (1988)	Y	4
Edwards *et al.* (1992)	Y	4
Ekkel *et al.* (1995)	Y	4
Fàbrega *et al.* (2003)	Y	2
Faure *et al.* (2013)	Y	2
Georgsson and Svendsen (2002)	Y	4
Gilbert *et al.* (2007)	Y	2
Guy *et al.* (2002)	Y	4
Henken *et al.* (1991)	Y	2
Jensen *et al.* (1993)	Y	4
Kritas *et al.* (2007)	Y	2
Labroue *et al.* (1997)	Y	2
Latorre *et al.* (2003)	Y	2
Latorre *et al.* (2004)	Y	2
Le Dividich *et al.* (1987)	Y	5
Le Naou *et al.* (2012)	Y	2
Lyons *et al.* (1995)	Y	3
Maes *et al.* (1999)	Y	2
Magowan *et al.* (2007)	Y	2
Magowan *et al.* (2008)	Y	4
McGloughlin *et al.* (1998)	Y	4
Millet *et al.* (2012)	Y	6
MLC (2004a)[1]	N	8
MLC (2004b)[1]	N	2
MLC (2005a)[1]	N	4
MLC (2005b)[1]	N	4
Morales *et al.* (2002)	Y	2
Morrow and Walker (1994)	Y	5
Nielsen *et al.* (1995)	Y	4
Nielsen *et al.* (1996)	Y	2
Pauly *et al.* (2009)	Y	6
Philippe *et al.* (2007)	Y	2
Rinaldo and Le Dividich (1991)	Y	4
Smith *et al.* (2013)	Y	2
Turner *et al.* (1999)	Y	4
Turner *et al.* (2002)	Y	4
Walker (1991)	Y	3
Wellock *et al.* (2009)	Y	8
Whittemore *et al.* (2002)	Y	6

[1]BPEX = British Pig Executive; MLC = Meat and Livestock Commission.
The Defra (2007) final report and MLC (2004a, 2004b, 2005a and 2005b) are available in the literature. The BPEX development trials data are available on request from BPEX.

crosses with LW/L pigs were each placed in a separate category. An additional group was created to account for crosses between Duroc × Pietrain × LW/L. Other breeds were discarded from the analysis due to the low number of observations. The infectious environment was included in a binary form (yes or no presence of infectious challenge) due to the high variation in possible pathogens used. If not mentioned, a disease-free environment was assumed. Health challenges presented through non-routine vaccinations were also included as an 'infectious' challenge.

Feed energy content was converted to ME (MJ/kg fresh feed). If the results were present in DE these were converted to ME using the formula in Wellock *et al.* (2003a):

$$\text{ME} = \text{DE} - 5.63 \times (\text{CP content}/1000),$$

where CP is in g/kg feed. When the results were presented as NE these were converted to ME by dividing by 0.75 (Noblet and van Milgen, 2004; Sauvant *et al.*, 2008). The CP, CF and lysine contents were all presented as g/kg fresh feed.

Statistical analysis

For continuous factors only, descriptive statistics (including normality tests) were completed using the UNIVARIATE procedure of SAS (SAS, version 9.2, Cary, NC, USA). Descriptive statistics for categorical factors (counts of each class) were performed using the FREQUENCY procedure of SAS 9.2. Correlations among independent factors were calculated using the CORR procedure of SAS and used to prevent confounding and multicolinearity in the multivariate models. When factors were correlated they were not used in the same model.

A separate analysis was run for each dependent variable (ADG, FI and FCR). The experiment was included as a random factor in all analyses. To begin with, a mixed model was run containing all main effects and interactions (Averós *et al.*, 2010; Averós *et al.*, 2012), but, as it failed to converge, alternative models were built (Averós *et al.*, 2012; Agostini *et al.*, 2013).

Initially, the effect of each independent variable was analysed separately using the MIXED procedure of SAS. Factors that had $P \leqslant 0.25$ were chosen for inclusion in the multivariate mixed model (Agostini *et al.*, 2013). Subsequently, the model was developed using a manual forward selection stepwise procedure with independent factors added in order of the number of cases (beginning with those factors, which were represented across all studies). All factors with <0.05 were retained in the final multivariate model. The model contained both linear and quadratic effects for continuous factors. Although it would have been beneficial to weight data, insufficient information was available in manuscripts to do this.

Finally, interactions between independent factors were analysed. In the case of factors that were already categorical, the number of categories within each factor was reduced on the basis of the univariate model output; in the case that categories within factors were not significant then these were pooled to create a binomial variable and the model was recalculated. The interactions were added onto the existing model individually; those that were significant were then added to the model together, remaining there if statistically significant ($P < 0.05$). Data are reported as least square means.

Results

Descriptive statistics for continuous dependent and independent factors are shown in Table 2 and for categorical independent factors in Table 3.

ADG

The average ADG was 760 g/day (s.d. 153), with a range of 256 to 1069 g/day. Univariate analysis found a number of factors were influencing the ADG of grower and finisher pigs (Table 4). These were the country ($P < 0.001$), stage of growth ($P < 0.001$), K (m^2/BW$^{0.667}$), bedding ($P < 0.001$), floor space ($P < 0.001$), floor type ($P < 0.001$), ambient temperature ($P < 0.01$), feed lysine content ($P < 0.01$), lysine/ME ($P < 0.001$), drinker type ($P < 0.05$), feeder space ($P < 0.001$) and number of diets fed ($P < 0.001$). In the final multivariate model only stage of growth ($P < 0.001$), bedding ($P < 0.01$) and floor type ($P < 0.05$) significantly influenced ADG. Since floor type and bedding were confounded as pigs kept on slatted or partially slatted floors did not have bedding, floor type was removed from the final model. One significant interaction was observed for ADG that of bedding × lysine ($P < 0.001$).

The highest ADG was achieved by animals in the later stages of growth: finishers (833 g/day) and growers/finishers combined (829 g/day). These were significantly higher than the ADG of growers (661 g/day). The highest ADG was for animals housed with bedding (straw) compared with those without bedding (710 *v.* 605 g/day, $P < 0.001$). The bedding × lysine interactions were due to pigs housed without bedding (straw) having higher ADG when fed a diet lower in lysine content; however, those with bedding had an increased ADG when fed a diet higher in lysine content (Table 5).

FI

The average FI was 1.96 kg/day (s.d. 0.607), with a range of 0.512 to 3.71 kg/day. The univariate analysis found a number of factors were influencing the FI of grower and finisher pigs (Table 4). This included the country ($P < 0.001$), stage of growth ($P < 0.001$), group composition ($P < 0.01$), group size ($P < 0.05$), K (m^2/BW$^{0.667}$) ($P < 0.001$), bedding ($P < 0.01$), floor space ($P < 0.001$), floor type ($P < 0.001$), ambient

Table 2 *Descriptive statistics for the continuous independent and dependent factors included in the meta-analysis*

Variable	n[1]	Minimum	Maximum	Mean	Median	s.d.
Continuous dependent factors						
ADG (g/day)	242	256	1069	760	797	153
FI (kg/day)	242	0.512	3.71	1.96	2.14	0.607
FCR[2]	242	1.02	5.44	2.58	2.6	0.59
Continuous independent factors						
Group size	209	1	215	45.2	12	75.8
K (m^2/BW$^{0.667}$)[3]	150	0.016	0.235	0.060	0.049	0.036
Floor space (m^2)	150	0.3	3.5	1	1	0.52
Lighting regime (h/day)	34	8	24	12.9	12	5.06
Temperature (°C)	82	8	33	19.6	19.5	4.12
Crude fibre (g/kg)	62	2.7	121	43.5	47.0	22.1
CP, (g/kg)	160	100	253	181	180	24.3
ME (MJ/kg)	172	8.97	15.5	12.9	12.8	1.05
Lysine (g/kg)	131	4.1	16	10.4	9.90	2.42
Lysine/ME	122	0.31	1.13	0.78	0.77	0.15
Drinker space (cm^2)	49	1	30	6.24	5	5.84
Feeder space (cm^2)	19	0.43	36.8	15.0	10.2	12.6
Pigs per feeder	74	1	30	6.36	1	7.39

ADG = average daily gain; FI = feed intake; FCR = feed conversion ratio; ME = metabolisable energy.
[1]Total number of observations available for analysis.
[2]Calculated as the ADG divided by the FI.
[3]K was the floor space allowance per unit of metabolic BW.

Table 3 *Descriptive statistics for the categorical factors included in the meta-analysis*

Variable	*n*[1]	Category
Country	13	Belgium
	16	France
	4	Germany
	2	Greece
	4	Ireland
	4	Italy
	18	The Netherlands
	7	Spain
	4	Sweden
	15	Switzerland
	155	United Kingdom
Gender	25	Male
	15	Castrated male
	8	Female
	91	Male and female
	33	Castrated male and female
Genetics	137	Large White (LW)/Landrace (L)
	19	LW/L × Duroc (D) or purebred D
	18	LW/L × Pietrain (P) or purebred P
	28	LW/L × Hampshire
	34	LW/L × D × P
Stage	37	Grower
	44	Finisher
	155	Grower and finisher
Group composition	55	Genders mixed
	96	Genders separated
Mixing	3	Yes
	198	No
Season	30	Winter and Autumn
	20	Summer and Spring
	13	Both
Bedding	102	Yes
	130	No
Building type	40	Mechanically ventilated
	57	Naturally ventilated
	8	Automatic control of natural ventilation
	4	Climate respiratory chamber
Floor type	88	Solid
	77	Fully slatted
	31	Partially slatted
Infectious environment	6	Yes
	236	No
Allowance	223	*Ad libitum*
	14	Restricted
Number of diets	133	1
	36	2
	12	3
	3	4
	2	6
	4	7
Feed form	146	Pellet
	6	Crumble
	18	Liquid
	2	Expandate
	10	Meal
	2	Mash
Feeder type	68	Single
	34	Multi-space
	74	Trough
Water type	51	Nipple
	22	Bowl
	17	At feeder

[1]Total number of observations available for analysis.

Table 4 *The significance and number of observations (total* n *= 242) of the factors influencing the ADG, the average daily FI and the FCR of pigs in the univariate model analysis*

Factor	Number of observations	ADG (g/day)	FI (kg/day)	FCR
Country	242	***	***	***
Gender	172	ns	ns	ns
Genetics	236	ns	ns	ns
Stage	242	***	***	***
Group composition	151	ns	**	*
Group size	209	ns	*	ns
K ($m^2/BW^{0.667}$)	150	***	***	***
Mixing	201	ns	ns	ns
Season	63	ns	ns	ns
Bedding	232	***	**	ns
Building type	109	ns	ns	*
Floor space	150	***	***	***
Floor type	196	***	***	ns
Infectious environment	242	ns	ns	ns
Lighting regime	34	ns	ns	ns
Temperature	82	**	***	***
Crude fibre	62	ns	ns	*
CP	160	ns	***	***
Diet energy	172	ns	ns	**
Feed allowance	242	ns	ns	ns
Feed form	185	ns	ns	ns
Lysine	131	**	***	***
Lysine/ME	122	***	***	***
Drinker space	49	ns	ns	ns
Drinker type	90	*	ns	ns
Feeder space	19	***	*	***
Feeder type	176	ns	*	ns
Number of diets	190	***	***	*
Pigs per feeder	74	ns	ns	ns

ADG = average daily gain; FI = feed intake; FCR = feed conversion ratio; ME = metabolisable energy; ns = non-statistically significant.
$^*P<0.05$; $^{**}P<0.01$; $^{***}P<0.001$.

temperature ($P<0.001$), feed crude protein ($P<0.001$), feed lysine ($P<0.001$), lysine/ME ($P<0.001$), feeder space ($P<0.05$), feeder type ($P<0.05$) and number of diets ($P<0.001$). In the final multivariate model stage of growth ($P<0.01$), bedding ($P<0.01$), group composition ($P<0.05$), group size ($P<0.01$), feed CP content ($P<0.01$) and ambient temperature ($P<0.01$) significantly influenced the FI of grower and finisher pigs. An interaction was found between floor space and feed energy content ($P<0.001$) for FI.

For stage of growth, the average daily FI was 2.37 kg/day for finishers, growers/finishers combined (2.08 kg/day) and growers (1.40 kg/day), all of which were significantly different from each other. Pigs housed with straw had a lower FI compared with those animals without bedding (1.44 *v.* 2.04 kg/day; $P<0.01$). Pigs separated by gender had a higher FI than those which were mixed (2.05 *v.* 1.65 kg/day; $P<0.05$). A negative linear relationship was found between the size of the group and the FI of pigs, with pigs kept in larger group sizes having a lower FI. Similarly, a negative linear relationship was found between the CP content of the feed and the FI, with a decreased FI at higher CP levels. Finally, a negative linear relationship was found between

Table 5 *Parameter estimates (and standard errors) for the multivariate models quantifying the effect of the different factors on the performance factors (ADG, average daily FI and FCR) of grower and finisher pigs[1,2]*

Factor	ADG (g/day)	Significance	FI (kg/day)	Significance	FCR[3]	Significance
Intercept	767 (52.8)	***	3.77 (0.595)	***	1.34 (0.276)	*
Bedding						
Straw	186 (70.6)	**	– 0.628 (0.255)	**	ns	ns
No straw	–	–	–	–	ns	ns
Stage						
Grower	– 166 (42.7)	***	– 0.839 (0.201)	**	0.311 (0.282)	ns
Finisher	5.67 (32.8)	ns	– 0.155 (0.256)	ns	1.30 (0.270)	***
Grower and finisher	–	–	–	–	–	–
Group composition						
Genders mixed	ns	ns	– 0.359 (0.187)	*	ns	ns
Genders separate	ns	ns	–	–	ns	ns
Group size	ns	ns	– 0.022 (0.009)	**	ns	ns
Group size × group size	ns	ns	– 0.001 (0.002)	ns	ns	ns
CP (g/kg)	ns	ns	– 0.001 (0.002)	**	– 0.021 (0.041)	***
CP × CP	ns	ns	– 0.001 (0.000)	ns	0.00001 (0.0001)	ns
Temperature (°C)	ns	ns	– 0.034 (0.021)	**	– 0.039 (0.032)	***
Temperature × temperature	ns	ns	– 0.001 (0.002)	ns	– 0.064 (0.090)	***
Crude fibre (g/kg)	ns	ns	ns	ns	0.005 (0.003)	**
Crude fibre × crude fibre	ns	ns	ns	ns	0.001 (0.001)	ns
Lysine (g/kg)	ns	ns	ns	ns	– 0.175 (0.029)	***
Lysine × lysine	ns	ns	ns	ns	0.095 (0.015)	***
Bedding × lysine	51.4 (44.0)	***	ns	ns	ns	ns
Floor space category × ME	ns	ns	– 1.32 (0.461)	***	ns	ns

ADG = average daily gain; FI = feed intake; FCR = feed conversion ratio; ME = metabolisable energy.
[1]Factors with a *P*-value <0.05 were retained in the multivariate model.
[2]ns = variable not statistically significant ($P > 0.05$) and therefore removed from the multivariate mode.
[3]Calculated as the gain: feed.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

ambient temperature and the FI of pigs, with FI decreasing at higher ambient temperatures. An interaction was found between floor space and feed energy content ($P < 0.001$) with animals provided with the least amount of floor space having a higher FI when given a feed with a lower ME content, which was in contrast to all other pigs, which showed a higher FI with increased ME content.

FCR
The average FCR was 2.58 (s.d. 0.590), with a range of 1.02 to 5.44. Univariate analysis found a number of factors were influencing the FCR of grower and finisher pigs (Table 4). These were the country ($P < 0.001$), stage of growth ($P < 0.001$), group composition ($P < 0.05$), K ($m^2/BW^{0.667}$; $P < 0.001$), building type ($P < 0.05$), floor space ($P < 0.001$), ambient temperature ($P < 0.001$), CF ($P < 0.05$), CP ($P < 0.001$), diet energy ($P < 0.01$), lysine ($P < 0.001$), lysine/ME ($P < 0.001$), feeder space ($P < 0.001$) and number of diets ($P < 0.05$). In the final multivariate model, only stage of growth ($P < 0.001$), feed CP ($P < 0.001$), CF ($P < 0.01$) and lysine content ($P < 0.001$) and ambient temperature ($P < 0.001$) significantly influenced the FCR of pigs. No interactions were noted for FCR.

For stage of growth, finishers had the poorest FCR with an average of 2.45 kg/kg, differing significantly from the growers and finishers combined (2.21). There was a negative linear relationship between CP and FCR, with improved efficiency at higher CP feed content. In contrast, there was a positive linear relationship between CF and FCR, with lower CF feeds leading to an improved FCR. For lysine content of the feed, a negative linear relationship was observed with improved FCR at increased lysine levels. Finally, a negative linear relationship was found between the ambient temperature and the FCR of pigs, with an improvement in efficiency at higher ambient temperatures.

Discussion

The aim of this study was to determine through a meta-analysis the separate and interactive effects of different factors, relating to the environment, the feed and the animal, on the efficiency of grower and finisher pigs. Emphasis in this meta-analysis was given on factors that may influence the efficiency of EU- and UK-based pig systems and for this reason data originating from farm trials was also included. The UK pig systems have some particularities in relation to other EU pig systems, including feeding strategies and housing, such as the use of straw. As a result, this study confirmed the effect of several well-known factors, such as the importance of nutrition and stage of growth; however, it has also shown the effect of a number of potential interactions that should be considered, as well as the influence of some less-established factors.

The meta-analysis in the current study incorporated both univariate and multivariate analysis, with the former yielding a greater number of factors exerting significant effects. This is because the univariate model does not consider correlations between factors and, therefore, has less precise parameter estimates (O'Connell and McCoach, 2008). Similarly in experimental studies only a small number of factors may ever be considered, due to the limitations suggested above, and as a consequence such studies cannot fully answer which factors are affecting efficiency in grower and finisher pig systems.

This study confirmed a number of established factors, which influence feed efficiency. Among these, the stage of growth (i.e. grower or finisher) had a significant effect on all performance outputs, with finisher pigs consistently outperforming both growers in terms of ADG and FI, although they had the expected significantly poorer FCR. Ambient temperature was found to affect the performance of pigs, in particular the FI and FCR, confirming the outcomes of the meta-analysis performed by Renaudeau *et al.* (2011). However, while optimum efficiency was achieved with higher ambient temperatures, there was a decrease in FI as the ambient temperature increased. This would be expected as efficiency is maximised when pigs are kept in their thermoneutral zone. However, if this is exceeded, then a reduction in FI (Wellock *et al.*, 2003a) as well as non-feeding-related activities would occur (Giles, 1992), both of which are essential mechanisms to regulate body temperature (Renaudeau *et al.*, 2012).

Although it could be expected that genetics would have a significant effect on the performance of grower and finisher pigs, there was no significant effect of genetics identified in this study. One possible explanation for the lack of observed effects is that the majority of pigs in the papers were Large White/Landrace crossbreeds and other pig genotypes were underrepresented. This could also account for the lack of an effect of other underrepresented modalities such as feed allowance, mixing and infectious environment and therefore the results in relation to these should be treated with caution.

In addition to the animal characteristics and the environment, feed characteristics also played a key role in affecting efficiency, in particular the CP, ME, lysine and CF content of the feed. High levels of CF were found to result in an increase in FCR, in agreement with previous work (Asmus *et al.*, 2014). However, it is also important to consider that there was a high negative correlation between ME and CF, which may also explain this finding; the lower energy density of high CF diets necessitating a greater daily intake (Kyriazakis and Emmans, 1995). Improved feed efficiency, that is, lower FCR, was found for higher lysine and CP feed content, which is consistent with previous literature (Kyriazakis *et al.*, 1991; Szabó *et al.*, 2001). However, whether feed efficiency would be affected by feed CP content would depend on the basis the feed has been formulated; for example, one can lower the CP content of the feed, while maintaining the essential amino acid levels. There is an argument on whether animals, including pigs are able to regulate their intake depending on the amino acid or protein content in their feed, to the degree they are able to regulate feed energy content (van Milgen *et al.*, 2008). The outcomes of this meta-analysis suggest that as the CP in the feed decreased, FI increased, which supports the view that animals attempt to eat for the first limiting nutrient resource in their diet (Kyriazakis and Emmans, 1991; Kyriazakis *et al.*, 1991). This is further supported by the fact that pigs on lower CP and lysine feeds were also less efficient and presumably fatter, especially in the majority of the studies used pigs had access to one feed throughout the experiment.

The use of bedding to enrich pig environment has been well studied, including its effect on behaviour, performance and welfare (de Jong *et al.*, 1998; Peeters *et al.*, 2006). The results presented here show that the presence of straw improved the ADG of pigs, but also decreased FI. The absence of any effect of straw on FCR may be due to the fact that for each model, it was not the same data analysed, as data were not always present for each independent variable. The effect of straw on ADG and FI is likely a combination of thermal and behavioural effects of the presence of straw on pigs. Provision of straw can increase the ambient temperature and raise the baseline body temperature of pigs (de Jong *et al.*, 1998); this is particularly important when pigs are housed in naturally ventilated buildings and are more susceptible to changes in weather. In addition, nibbling of pen mates and other 'manipulative' behaviour is reduced, which may be because pigs may gain more 'satisfaction' for exploring the straw rather than the pen (and other pigs; de Jong *et al.*, 1998). Although there was also a significant effect of floor type, this was likely due to confounding with bedding, as the majority of pigs kept on solid floors had straw bedding. The decrease in FI observed was likely due to pigs needing less energy to be diverted to thermoregulation (Wellock *et al.*, 2003a) and perhaps consuming some of the straw bedding (Tuyttens, 2005). This is further supported by the fact that the decreased FI had no effect on ADG as those with bedding performed better. However, others have found no such effect of bedding on FI (Averós *et al.*, 2010).

Grouping pigs in larger social groups throughout the production cycle is common practice and can help to reduce housing costs as well as improve management (Turner *et al.*, 2003). However, it is important to consider any potential negative effects of group size and currently the reported effects on welfare, performance and behaviour are mixed (Schmolke *et al.*, 2003; Turner *et al.*, 2003; Street and Gonyou, 2008). Specifically, increasing the group size of pigs may have a major effect on behaviour as the mixing of a large number of unfamiliar pigs can cause an unstable social hierarchy, which can lead to competition at the feeders and drinkers (Finn, 2004). Performance may then be negatively impacted as energy is diverted to competitive behaviour (Finn, 2004). In addition, grower pig feeding duration decreases in larger groups with limited feeders and although feed consumption rate increases there may be negative effects on FI (Hyun and Ellis, 2002; Turner *et al.*, 2003). In agreement with this, the FI of pigs was negatively affected by increasing group size. This suggests that either limited feed and/or increased competition between pen mates is affecting FI. Despite this negative trend, optimum group size is likely to vary between farms depending on buildings and feeding regimes, as it seems that reduction in performance is only observed when feed resources or floor space is inadequate and pigs are then overcrowded (Street and Gonyou, 2008). Allometric space allowance (expressed using K in $m^2/BW^{0.667}$) did not have a significant on FI in the multivariate model, suggesting that group size rather than space allowance was an important factor.

Differences in the growth rate, feed efficiency and nutrient requirements of gilts and barrows have led to the development of split-sex feeding and housing (Hill *et al.*, 2007), in particular for growers and finishers when differences become apparent. Separating by sex and feeding customised diets can be profitable in terms of performance as well as preventing overfeeding of nutrients, which can be costly (de Lange *et al.*, 1994). In a continuous system, it also means an improvement in pen utiliation due to a reduction in BW variation and therefore emptying of pens in a timelier manner (Patience *et al.*, 1999). In the present study, an increase in FI was observed when genders were separated in comparison with when they were mixed. One possible explanation for this is that housing males and females together can result in increased social stress and competition, which can cause a decrease in FI. Specifically, uncastrated male pigs have been shown to have increased sexual behaviour and aggression in comparison with castrated males (Cronin *et al.*, 2003). As a large number of studies used in this meta-analysis originated from the United Kingdom and a greater proportion of male pigs were uncastrated, it could be hypothesised that the behaviour of male pigs in mixed sex housing may have a negative effect on FI. Especially, as the most aggressive behaviour of pigs occurs during feeding (Whittemore and Kyriazakis, 2006), subordinate pigs displaced from feeding by aggressive males have a reduced FI (Schmidt *et al.*, 2011). In addition, due to differences in the ADG of male and female pigs, it is likely that male pigs will reach slaughter weight first. This means that if these pigs are removed and replaced, this will cause disruption of the social hierarchy, which is also likely to affect performance of the remaining pigs (Spoolder *et al.*, 2000). It has been demonstrated, however, that housing pigs in mixed groups (entire males and female) can be beneficial with a reduction in injuries and mounting behaviour (Conte *et al.*, 2010), although this may depend on the BW at which pigs are slaughtered as sexual behaviour may not have yet developed.

A number of novel interactions were identified in this study, one of which was the effect of bedding (straw) and feed lysine content on the ADG of pigs. Although the response to lysine was as expected when bedding was provided, increasing the lysine content of the feed resulted in a decrease in the ADG when bedding was not provided. This is probably because in the latter case more energy would be required to be directed towards maintenance requirements (thermoregulation); this is expected to affect the ratio of ME to digestible lysine available above maintenance and hence have negative effects on the efficiency of lysine use above maintenance (Kyriazakis and Emmans, 1992a and 1992b). This demonstrates the care that needs to be taken of ensuring an appropriate level of metabolisable energy to digestible lysine in the feed for the different environments the pig is kept in.

Similarly, an interaction was identified between floor space and feed energy content, suggesting that animals with the least amount of floor space given a low ME diet increased their FI, in contrast to pigs with increased floor space, which had a higher FI with increased ME. The effect of ME content on FI demonstrates the consequence of low ME levels on the intake of pigs (Kyriazakis and Emmans, 1995; Whittemore *et al.*, 2002); the only exception being the lower FI of pigs on higher ME level at the lowest space allowance. This probably reflects the increased competition at the feeder, which is absent when pigs are given access to bulky feeds (Whittemore *et al.*, 2002). It could also be interpreted as pigs with higher space allowance being more active and therefore have greater ME expenditure and their requirements are higher. However, the increase in the diet ME is insufficient to compensate for their increased requirements and thus FI is increased to compensate.

Conclusions

Overall, this study has confirmed the effect of several well-known factors on pig performance and efficiency, as well as some surprising results, which need to be investigated further, such as the interaction between floor space and feed ME content. In addition, the effects of some less-established factors were noted, such as group composition, which found a decrease in FI when pigs of different genders were housed together.

The results may contribute towards the improvement of the efficiency of pig systems by optimising environmental and nutritional strategies through better knowledge of the various factors that influence this.

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References

Affentranger P, Gerwig C, Seewer GJF, Schwörer D and Künzi N 1996. Growth and carcass characteristics as well as meat and fat quality of three types of pigs under different feeding regimens. Livestock Production Science 45, 187–196.

Agostini PS, Fahey AG, Manzanilla EG, O'Doherty JV, de Blas C and Gasa J 2013. Management factors affecting mortality, feed intake and feed conversion ratio of grow-finishing pigs. Animal 7, 1–7.

Asmus MD, DeRouchey JM, Tokach MD, Dritz SS, Houser TA, Nelssen JL and Goodband RD 2014. Effects of lowering dietary fiber before marketing on finishing pig growth performance, carcass characteristics, carcass fat quality, and intestinal weights. Journal of Animal Science 92, 119–128.

Averós X, Brossard L, Dourmad JY, de Greef KH, Edwards SA and Meunier-Salaun MC 2012. Meta-analysis on the effects of the physical environment, animal traits, feeder and feed characteristics on the feeding behaviour and performance of growing-finishing pigs. Animal 6, 1275–1289.

Averós X, Brossard L, Dourmad JY, De Greef KH, Edge HL, Edwards SA and Meunier-Salaun M 2010. A meta-analysis of the combined effect of housing and environmental enrichment characteristics on the behaviour and performance of pigs. Applied Animal Behaviour Science 127, 73–85.

Bartussek Von H, Steinwender R, Hausleitner A, Schauer A and Solkner J 1993. Influence of keeping restricted fed pigs in groups without or with straw litter at different ambient temperatures on daily gain, feed conversion and carcass quality. Bodenkultu 44, 163–182.

Beattie VE, O'Connell NE and Moss BW 1999. Influence of environmental enrichment on the behaviour, performance and meat quality of domestic pigs. Livestock Production Science 65, 71–79.

Brandt H, Werner DN, Baulain U, Brade W and Weissmann F 2010. Genotype-environment interactions for growth and carcass traits in different pig breeds kept under conventional and organic production systems. Animal 4, 535–544.

British Pig Executive (BPEX) 2009. Defining the benefits of new genotypes. Retrieved May 4, 2014, from http://www.bpex.org.uk/downloads/298215/291093/Defining%20the%20benefits%20of%20new%20genotypes.pdf

Cameron ND, Garth GB, Penman JC and Fiskin A 2003. Sensitivity to dietary lysine: energy content in pigs divergently selected for components of efficient lean growth rate. Animal Science 76, 175–189.

Cesaro G, Gallo L, Carraro L, Tagliapitera F, Bunger L and Schiavon S 2013. Energy balance estimated from individual measurments of body weight and backfat thickness of heavy pigs of four genetic lines fed different diets. Agriculturae Conspectus Sceintificus 78, 221–224.

Collin A, van Milgen J, Dubois S and Noblet J 2001. Effect of high temperature on feeding behaviour and heat production in group-housed young pigs. British Journal of Nutrition 86, 63–70.

Conte S, Boyle LA, Lawlor PG and O'Connell NE 2010. Influence of within pen gender composition and weight variation on the welfare and growth performance of finishing pigs. Advances in Animal Biosciences 1, 184–184.

Conte S, Lawlor PG, O'Connell N and Boyle LA 2012. Effect of split marketing on the welfare, performance, and carcass traits of finishing. Journal of Animal Science 90, 373–380.

Conte S, Boyle LA, O'Connell NE, Lynch PB and Lawlor PG 2011. Effect of target slaughter weight on production efficiency, carcass traits and behaviour of restrictively-fed gilts and intact male finisher pigs. Livestock Science 136, 169–174.

Cronin GM, Dunshea FR, Butler KL, McCauley I, Barnett JL and Hemsworth PH 2003. The effects of immuno- and surgical-castration on the behaviour and consequently growth of group-housed, male finisher pigs. Applied Animal Behaviour Science 81, 111–126.

de Boer A and Kanis E 1991. Effects of recombinant porcine somatotropin* on growth, feed intake and feed efficiency curves from 60 to 140 kg of pigs of three genotypes and two sexes. Livestock Production Science 29, 197–211.

de Greef KH, Kemp B and Verstegen MWA 1992. Performance and body composition of fattening pigs of two strains during protein deficiency and subsequent realimentation. Livestock Production Science 30, 141–153.

de Haer LCM, de Vries AG 1993a. Feed intake patterns of and feed digestibility in growing pigs housed individually or in groups. Livestock Production Science 33, 277–292.

de Haer LCM, de Vries AG 1993b. Effects of genotype and sex on the feed intake pattern of group housed growing pigs. Livestock Production Science 36, 223–232.

de Haer LCM, Luiting P and Aarts HLM 1993. Relations among individual (residual) feed intake, growth performance and feed intake pattern of growing pigs in group housing. Livestock Production Science 36, 233–253.

de Jong IC, Ekkel ED, van de Burgwal JA, Lambooij E, Korte SM, Ruis MA, Koolhaas JM and Blokhuis HJ 1998. Effects of strawbedding on physiological responses to stressors and behavior in growing pigs. Physiology & Behavior 64, 303–310.

de Lange CFM, Piwarski B and Gillis D 1994. Phase and split-sex feeding of growing-finishing pigs. In Prairie Swine Centre Annual Research Report 1994, pp. 22–25. Prairie Swine Centre, Saskatchewan, Canada.

Defra 2007. Sustainable systems for weaner management: AGEWEAN. Retrieved April 15, 2014, from http://www.bpex.org.uk/downloads/300443/297140/AGEWEAN%20final%20report

Edwards SA, Armsby AW and Spechter HH 1988. Effects of floor area allowance on performance of growing pigs kept on fully slatted floors. Animal Production 4, 453–459.

Edwards SA, Wood JD, Moncrieff CB and Porter SJ 1992. Comparison of the Duroc and Large White as terminal sire breeds and their effect on pigmeat quality. Animal Production 54, 289–297.

Ekkel ED, van Doorn CE, Hessing MJ and Tielen MJ 1995. The specific-stress-free housing system has positive effects on productivity, health, and welfare of pigs. Journal of Animal Science 73, 1544–1551.

Emmans G and Kyriazakis I 2001. Consequences of genetic change in farm animals on food intake and feeding behaviour. Proceedings of the Nutrition Society 60, 115–125.

Fàbrega E, Tibau J, Soler J, Fernández J, Font J, Carrión D, Diestre A and Manteca X 2003. Feeding patterns, growth performance and carcass traits in group- housed growing-finishing pigs: the effect of terminal sire line, halothane genotype and age. Animal Science 77, 1357–7298.

Faure J, Lefaucheur L, Bonhomme N, Ecolan P, Meteau K, Coustard SM, Kouba M, Gilbert H and Lebret B 2013. Consequences of divergent selection for residual feed intake in pigs on muscle energy metabolism and meat quality. Meat Science 93, 37–45.

Finn J 2004. Pig group size – what is the optimum? Proceedings of Regional Pig Conferences, pp. 82–90. Kanturk, Kilkenny, Longford, Republic of Ireland.

Gaines AM, Peterson BA and Mendoza OF 2012. Herd management factors that influence whole herd feed efficiency. In Feed efficiency in Swine (ed. JF Patience), pp. 15–39. Wageningen Academic Publishers, Wageningen, The Netherlands.

Georgsson L and Svendsen J 2002. Degree of competition at feeding differentially affects behavior and performance of group-housed growing-finishing pigs of different relative weights. Journal of Animal Science 80, 376–383.

Gilbert H, Bidanel JP, Gruand J, Caritez JC, Billon Y, Guillouet P, Lagant H, Noblet J, Sellier P 2007. Genetic parameters for residual feed intake in growing pigs, with emphasis on genetic relationships with carcass and meat quality traits. Journal of Animal Science 85, 3182–3188.

Giles LR 1992. Energy expenditure of growing pigs at high ambient temperatures. University of Sydney, Sydney, NSW, Australia.

Guy JH, Rowlinson P, Chadwick JP and Ellis M 2002. Growth performance and carcass characteristics of two genotypes of growing-finishing pig in three different housing systems. Animal Science 74, 493–502.

Henken AM, van der Hel W, Brandsma HA and Verstegen MW 1991. Difference in energy metabolism and protein retention of limit-fed growing pigs of several breeds. Journal of Animal Science 69, 1443–1453.

Hill GM, Baido SK, Cromwell GL, Mahan DC, Nelssen JL and Stein HH 2007. Evaluation of sex and lysine during the nursery period. Journal of Animal Science 85, 1453–1458.

Hyun Y and Ellis M 2002. Effect of group size and feeder type on growth performance and feeding patterns in finishing pigs. Journal of Animal Science 80, 568–574.

Jensen MB, Kyriazakis I and Lawrence AB 1993. The activity and straw directed behaviour of pigs offered foods with different crude protein content. Applied Animal Behaviour Science 37, 211–221.

Kritas SK, Alexopoulos C, Kyriakis CS, Tzika E and Kyriakis SC 2007. Performance of fattening pigs in a farm infected with both porcine reproductive and respiratory syndrome (PRRS) virus and porcine circovirus type 2 following sow and piglet vaccination with an attenuated PRRS vaccine. Journal of Veterinary Medicine 54, 287–291.

Kyriazakis I and Emmans GC 1991. Diet selection in pigs – dietary choices made by growing pigs following a period of underfeeding with protein. Animal Production 52, 337–346.

Kyriazakis I and Emmans GC 1992a. The effects of varying protein and energy intakes on the growth and body composition of pigs. 1. The effects of energy intake at constant, high protein intake. British Journal of Nutrition 68, 603–613.

Kyriazakis I and Emmans GC 1992b. The effects of varying protein and energy intakes on the growth and body composition of pigs. 2. The effects of varying both energy and protein intake. British Journal of Nutrition 68, 615–625.

Kyriazakis I and Emmans GC 1995. The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. British Journal of Nutrition 73, 191–207.

Kyriazakis I, Emmans GC and Whittemore CT 1991. The ability of pigs to control their protein intake when fed in three different ways. Physiology and Behavior 50, 1197–1203.

Labroue F, Gueblez R and Sellier P 1997. Genetic parameters of feeding behaviour and performance traits in group-housed Large White and French Landrace growing pigs. Genetics Selection Evolution 29, 451–468.

Latorre MA, Lázaro R, Gracia ML, Nieto M and Meteos GG 2003. Effect of sex and terminal sire genotype on performance, carcass characteristics, and meat quality of pigs slaughtered at 117 kg body weight. Meat Science 65, 1369–1377.

Latorre MA, Lázaro R, Valencia DG, Medel P and Mateos GG 2004. The effects of gender and slaughter weight on the growth performance, carcass traits, and meat quality characteristics of heavy pigs. Journal of Animal Science 82, 526–533.

Le Dividich J, Noblet J and Bikawa T 1987. Effect of environmental temperature and dietary energy concentration on the performance and carcass characteristics of growing-finishing pigs fed to equal rate of gain. Livestock Production Science 17, 235–246.

Le Naou T, Le Floc'h N, Gilbert H and Gondret F 2012. Metabolic changes and tissue responses to selection on residual feed intake in growing pigs. Journal of Animal Science 90, 4771–4780.

Lopez J, Jesse GW, Becker BA and Ellersieck MR 1991. Effects of temperature on the performance of finishing swine: I. Effects of a hot, diurnal temperature on average daily gain, feed intake, and feed efficiency. Journal of Animal Science 69, 1843–1849.

Lyons CAP, Bruce JM, Fowlerb VR and English PR 1995. A comparison of productivity and welfare of growing pigs in four intensive systems. Livestock Production Science 43, 265–274.

Maes D, Deluyker H, Verdonck M, Castryck F, Miry C, Vrijens B, Verbeke W, Viaene J and de Kruif A 1999. Effect of vaccination against Mycoplasma hyopneumoniae in pig herds with an all-in/all-out production system. Vaccine 17, 1024–1034.

Magowan E, McCanna MEE and O'Connell NE 2008. The effect of feeder type and change of feeder type on growing and finishing pig performance and behaviour. Animal Feed Science and Technology 142, 133–143.

Magowan E, McCann MEE, Beattie VE, McCracken KJ, Henry W, Smyth S, Bradford R, Gordon FJ and Mayne CS 2007. Investigation of growth rate variation between commercial pig herds. Animal 1, 1219–1226.

McGloughlin P, Allen P, Tarrant PV and Joseph RL 1998. Growth and carcass quality of crossbred pigs sired by Duroc, Landrace and Large White boars. Livestock Production Science 18, 275–288.

Millet S, Kumar S, De Boever J, Ducatelle R and De Brabander D 2012. Effect of feed processing on growth performance and gastric mucosa integrity in pigs from weaning until slaughter. Animal Feed Science and Technology 175, 175–181.

Meat and Livestock Commission (MLC) 2004a. Finished pigs: system research production trial 1 dry versus liquid feeding in two contrasting finishing systems (fully slatted versus straw basedhousing). MLC, Milton Keynes.

Meat and Livestock Commission (MLC) 2004b. Finished pigs: system research production trial 2 evaluation of phase feeding in two contrasting pig systems (fully slatted versus straw based housing). MLC, Milton Keynes.

Meat and Livestock Commission (MLC) 2005a. Finished pigs: system research production trial 2 controlled fermentation of cereals in liquid diets fed to pigs in two contrasting finishing systems (fully slatted versus straw based housing). MLC, Milton Keynes.

Meat and Livestock Commission (MLC) 2005b. Finished pigs: system research production trial 1 reducing the crude protein content of liquid diets fed to pigs in two contrasting finishing systems (fully slatted versus straw based housing). MLC, Milton Keynes.

Morales J, Perez JF, Baucells MD, Mourot J and Gasa J 2002. Comparative digestibility and lipogenic activity in Landrace and Iberian finishing pigs fed ad libitum corn- and corn–sorghum–acorn-based diets. Livestock Production Science 77, 195–205.

Morrow ATS and Walker N 1994. Effects of number and siting of single-space feeders on performance and feeding behaviour of growing pigs. The Journal of Agricultural Science 122, 465–470.

Nielsen BL, Lawrence AB and Whittemore CT 1995. Effect of group size on feeding behaviour, social behaviour, and performance of growing pigs using single-space feeders. Livestock Production Science 44, 73–85.

Nielsen BL, Lawrence AB and Whittemore CT 1996. Feeding behaviour of growing pigs using single or multi-space feeders. Applied Animal Behaviour Science 47, 235–246.

Noblet J and van Milgen J 2004. Energy value of pig feeds: effect of pig body weight and energy evaluation system. Journal of Animal Science 82 (E-suppl.), E229–E238.

O'Connell AA and McCoach DB 2008. Multilevel modeling of educational data. Information Age Publishing, Charlotte, NC, USA.

Patience JF 2012. Feed efficiency in swine. Wageningen Academic Publishers, the Netherlands, p. 280.

Patience JF, Gonyou HW, Lemay S and Zijlstra R 1999. Improving net income in declining markets. In Factsheet, Prairie Swine Centre, Saskatoon, SK (ed. PS Centre), Praire Swine Centre, Saskatchewan, Canada.

Pauly C, Spring P, O'Doherty JV, Ampuero Kragten S and Bee G 2009. Growth performance, carcass characteristics and meat quality of group-penned surgically castrated, immunocastrated (Improvac) and entire male pigs and individually penned entire male pigs. Animal 3, 1057–1066.

Peeters E, Driessen B, Moons CPH, Ödberg FO and Geers R 2006. Effect of temporary straw bedding on pigs' behaviour, performance, cortisol and meat quality. Applied Animal Behaviour Science 98, 234–248.

Philippe F, Laitat M, Canart B, Vandenheede M and Nicks B 2007. Comparison of ammonia and greenhouse gas emissions during the fattening of pigs, kept either on fully slatted floor or on deep litter. Livestock Science 111, 144–152.

Renaudeau D, Gourdine JL and St-Pierre NR 2011. A meta-analysis of the effects of high ambient temperature on growth performance of growing-finishing pigs. Journal of Animal Science 89, 2220–2230.

Renaudeau D, Collin A, Yahav S, de Basilio V, Gourdine JL, Collier RJ 2012. Adaptation to hot climate and strategies to alleviate heat stress in livestock production. Animal 6, 707–728.

Rinaldo D and Le Dividich J 1991. Assessment of optimal temperature for performance and chemical body composition of growing pigs. Livestock Production Science 29, 61–75.

Sauvant D, Schmidely P, Daudin JJ and St-Pierre NR 2008. Meta-analyses of experimental data in animal nutrition. Animal 2, 1203–1214.

Schmidt T, Calabrese JM, Grodzycki M, Paulick M, Pearce MC, Rau F and von Borell E 2011. Impact of single-sex and mixed-sex group housing of boars vaccinated against GnRF or physically castrated on body lesions, feeding behaviour and weight gain. Applied Animal Behaviour Science 130, 42–52.

Schmolke SA, Li YZ and Gonyou HW 2003. Effect of group size on performance of growing-finishing pigs. Journal of Animal Science 81, 874–878.

Smith LA, Houdijk JG, Homer D and Kyriazakis I 2013. Effects of dietary inclusion of pea and faba beans as a replacment for soybean meal on grower and finisher pig performance and carcass quality. Journal of Animal Science 91, 3733–3741.

Spoolder HA, Edwards SA and Corning S 2000. Aggression among finished pigs following mixing in kennelled and unkennelled accommodation. Livestock Production Science 63, 121–129.

Street BR and Gonyou HW 2008. Effects of housing finishing pigs in two group sizes and at two floor space allocations on production, health, behavior, and physiological variables. Journal of Animal Science 86, 982–991.

Szabó C, Jansman AJ, Babinszky L, Kanis E and Verstegen MW 2001. Effect of dietary protein source and lysine: DE ratio on growth performance, meat quality, and body composition of growing-finishing pigs. Journal of Animal Science 79, 2857–2865.

Turner SP, Edwards SA and Bland VC 1999. The influence of drinker allocation and group size on the drinking behaviour, welfare and production of growing pigs. Animal Science 68, 617–624.

Turner SP, Allcroft DJ and Edwards SA 2003. Housing pigs in large social groups: a review of implications for performance and other economic traits. Livestock Production Science 82, 39–51.

Turner SP, Dahlgren M, Arey DS and Edwards SA 2002. Effect of social group size and initial live weight on feeder space requirement of growing pigs given food ad libitum. Animal Science 75, 1357–7928.

Tuyttens FAM 2005. The importance of straw for pig and cattle welfare: a review. Applied Animal Behaviour Science 92, 261–282.

van Milgen J, Valancogne A, Dubois S, Dourmad JY, Sève B and Noblet J 2008. InraPorc: a model and decision support tool for the nutrition of growing pigs. Animal Feed Science and Technology 143, 387–405.

Walker N 1991. The effects on performance and behaviour of number of growing pigs per mono-place feeder. Animal Feed Science and Technology 35, 3–13.

Wellock IJ, Emmans GC and Kyriazakis I 2003a. Modelling the effects of thermal environment and dietary composition on pig performance: model logic and concepts. Animal Science 77, 255–266.

Wellock IJ, Emmans GC and Kyriazakis I 2003b. Predicting the consequences of social stressors on pig food intake and performance. Journal of Animal Science 81, 2995–3007.

Wellock IJ, Houdijk JGM, Miller AC, Gill BP and Kyriazakis I 2009. The effect of weaner diet protein content and diet quality on the long term performance of pigs to slaughter. Journal of Animal Science 87, 1261–1269.

Whittemore CT and Kyriazakis I 2006. Whittemores's Science and Practice of Pig Production. Blackwell Publishing.

Whittemore EC, Kyriazakis I, Tolkamp BJ and Emmans GC 2002. The short-term feeding behavior of growing pigs fed foods differing in bulk content. Physiology & Behavior 76, 131–141.

Woyengo TA, Beltranena E and Zijlstra RT 2014. Controlling feed cost by including alternative ingredients into pig diets: a review. Journal of Animal Science 92, 1293–1305.