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Effects of using locally produced protein feed ingredients in low protein diets to single-phase-fed growing-finishing pigs

Magdalena Presto Åkerfeldt and Leif Göransson

Department of Animal Nutrition and Management, Swedish University of Agricultural Sciences, Uppsala, Sweden

ABSTRACT
In two trials, 358 female and entire male pigs vaccinated against boar taint (YxH) were single-phase-fed with diets that were planned to contain 0.78 g standardized ileal digestible (SID) lysine/MJ net energy and 14.5 g SID CP/g SID lysine. A reference diet with soya bean meal (SBM) as the protein feed ingredient, was replaced with either cereal by-products (CBP), rapeseed meal (RSM), faba beans (FB) or mixtures of 50% CBP and 50% RSM (CBP + RSM) or 50% FB and 50% RSM (FB + RSM) in the experimental diets. Treatments had no effect ($P > 0.05$) on daily weight gain, feed efficiency, carcass weight, lean meat content or dressing percentage and carcass value. Single-phase-fed pigs on diets with local protein ingredients can perform as well as single-phase-fed pigs on diets with soya bean meal, and CBP, RSM, FB have the potential to replace soya bean meal in nutritionally well-balanced diets to growing-finishing pigs.

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Cereal by-product; faba bean; rapeseed meal; protein; lysine; single-phase feeding

Introduction

Use of soya bean meal has world-wide been the most common protein feed ingredient in commercial diets for livestock as it is a reliable source of high-quality protein. On a global level, the debate about environmental issues related to the sourcing of soya and future price uncertainty, has put pressure on the livestock sector to find sustainable and viable alternatives to soya bean meal. In pig production crops of particular interest are peas, faba beans and rapeseed meal (White et al., 2015). However, their content of different kinds of anti-nutritional factors (ANF), such as glucosinolates and condensed tannins limits their dietary value and the amount that can be included in pig rations. Other potential locally produced high protein sources are cereal-based by-products such as wheat middlings and distillers dried grains with solubles (DDGS) (Cromwell et al., 2000; Avelar et al., 2010). These are co-products rich in fibre, which can have a negative impact on nutrient utilization by monogastric animals (Widyaratne and Zijlstra, 2007).

Producing protein feed ingredients locally instead of importing them can lower the greenhouse gas emissions in pig production (Sasu-Boakye et al., 2014) and legumes in rotation have been shown to have environmental benefits (Crépon 2006; Topp et al., 2012; Leinonen et al., 2013). Balancing feeds with commercial pure amino acids (AA) provide an excellent possibility to lower the inclusion of protein in the diet and thereby, a higher amount of cereals and alternative protein resources could be included. Presto Åkerfeldt et al. (2019) demonstrated that crude protein (CP) level may be substantially reduced in cereal based diets when balancing the protein with L-lysine, L-threonine, DL-methionine and L-tryptophane. The results from that study indicated that a reduction from 0.89 to 0.78 g standardized ileal digestible (SID) lysine/MJ net energy (NE) and from 15.5 to 13.8 g of SID CP/g SID lysine did not have a negative effect in terms of daily growth, feed efficiency and carcass traits. Moreover, the results demonstrated that single-phase-fed pigs grew compensatory and ended up with the same performance as two-phase-fed pigs did. Implementing this in practical slaughter pig production diminishes the need for diets with high protein content in the early stage of the growing phase and enables efficient use of locally produced protein feed resources. When making changes in diets or feeding plans, evaluation on the effects on pigs' tail biting behaviour is important, as nutritional deficiencies may trigger this (Beattie et al., 2005).

The objective of the present experiment was to investigate the potential of using locally produced protein ingredients such as rapeseed meal, cereal by-products, faba beans or a combination of them, in growing-

CONTACT M. Presto Åkerfeldt magdalena.akerfeldt@slu.se

finishing pig diets with a low protein content. Our hypothesis was that single-phase-fed pigs given diets with locally produced protein feed ingredients would perform as well as single-phase-fed pigs on a commercial diet with soya bean meal as protein source. The experiment was part of a larger study, which included the effects of reducing dietary content of crude protein and indispensable amino acids on performance and carcass traits of single-phase- and two-phase-fed growing-finishing pigs (Presto Åkerfeldt et al., 2019).

Material and methods

Experimental design

A total of 358 cross-bred (Swedish Yorkshire dams × Hampshire sires) female and entire male (vaccinated against boar taint) pigs from 35 litters were used in two trials (Trial 1 and Trial 2). Trial 1, comprising 4 treatments in 3 consecutive batches with a total of 6 pens per treatment. Trial 2 consisted of 3 treatments in 2 consecutive batches with a total of 5 pens per treatment (Table 1). The pigs were raised in pens with 8–10 pigs in each. The sires were randomly selected from sires available for artificial insemination. The experiment was performed at the Swedish Livestock Research Centre at Funbo-Lövsta, Uppsala. It was carried out in accordance with Swedish regulations on experimental use of pigs, was approved by the local Ethics Committee on Animal Research, Uppsala, and complied with EC Directive 86/609/EEC on animal experiments.

In both trials, the reference diet was formulated as a commercial diet for growing-finishing pigs with soya bean meal (SBM) as the protein supplement. In Trial 1, the protein feed ingredients in the experimental diets consisted of cereal by-products (CBP), rapeseed meal (RSM) or, a mixture of 50% CBP and 50% RSM (CBP + RSM). The CBP diet contained 4% DDGS, 20% wheat middlings and 10% wheat bran. In Trial 2, the experimental diets included faba beans (FB) or a mixture of 50% FB and 50% RSM (FB + RSM). All diets were planned to contain 0.78 g SID lysine/MJ NE and 14.5 g of SID CP/g SID lysine.

At weaning, piglets were randomly allocated to treatments balanced with respect to sex, litter and live weight (LW). The piglets stayed in the farrowing unit until the start of the experiment and were all fed the same piglet diet *ad libitum,* containing 9.6 MJ NE, 163 g CP and 10.6 g lysine per kg feed. At the start of the experiment the pigs were moved to the growing-finishing unit at an average age of 60.9 days (s.d. 5.0 days) in Trial 1 and 59.5 days (s.d. 4.9 days) in Trial 2. The corresponding values for average initial LW were 27.1 kg (s.d. 4.5 kg), and 26.4 kg (s.d. 4.1 kg). Entire male pigs were given two injections of Improvac®, containing a modified form of GnRH (Pfizer Ltd; 2 ml per injection) to eliminate boar taint. The vaccinations were given approximately 8 and 4 weeks before slaughter, according to the manufacturer's recommendation.

Feeding

All pigs were single-phase-fed three times per day according to a restricted feeding regimen for growing-finishing pigs which was 10% higher than the standard regimen for growing-finishing pigs in Sweden (Andersson et al., 1997), that is, the daily feed allowances in MJ of NE 13.6, 15.7, 19.9, 24.0 and 28.2 at 25, 30, 40, 50 and 60 kg LW and thereafter to slaughter, respectively. In feed formulation, data on NE and digestibility coefficients for AA were taken from Sauvant et al. (2004). In each trial, three basic diets were manufactured in a commercial feed plant, as shown in Table 2. The feed ingredients used were chosen from the for the time present available batches of the plant. The faba beans used were a mix of different coloured varieties. The content of threonine, methionine, cysteine and tryptophan was optimized in relation to the lysine content according to recommendations by Göransson et al. (2012). The CBP + RSM and FB + RSM diets were mixed in an automatic computerized feeding system at the research station. On each manufacturing occasion, two samples of each

Table 1. Experimental design of Trial 1 and Trial 2. Number of pens per treatment and batch.

	Trial 1					Trial 2		
	SMB[a]	CBP[b]	RSM[c]	CBP + RSM[d]		SMB[a]	FB[e]	FB + RSM[f]
Batch 1	2	2	2	2	Batch 1	3	3	3
Batch 2	2	2	2	2	Batch 2	2	2	2
Batch 3	2	2	2	2				

[a]Soya bean meal.
[b]Cereal by-products.
[c]Rapeseed meal.
[d]50% cereal by-products and 50% rapeseed meal.
[e]Faba beans.
[f]50% faba bean and 50% rapeseed meal.

Table 2. Inclusion rate of different ingredients and calculated chemical composition of the basic diets[a].

	Trial 1			Trial 2		
	SBM	CBP	RSM	SBM	FB	RSM
Ingredients, %						
Wheat	41.30	13.98	40.70	35.10	30.90	40.90
Barley	41.30	47.90	40.70	35.10	30.90	40.90
Oats				13.40	8.80	
Wheat bran	5.00	10.00		5.00	5.00	
Wheat middling		20.00				
Distillers dried grains with solubles		4.00				
Soy bean meal	8.00			7.20		
Rapeseed meal			14.60			14.25
Faba beans					20.20	
L-lysine sulphate	0.62	0.74	0.63	0.56	0.51	0.61
L-threonine	0.14	0.14	0.10	0.14	0.13	0.10
DL-methionine	0.08	0.05	0.03	0.06	0.12	0.03
L-tryptophane	0.01		0.02	0.01	0.03	0.02
Calcium carbonate	1.26	1.22	1.09	1.23	1.20	1.08
Monocalcium phosphate	0.46	0.19	0.31	0.40	0.43	0.31
Vegetable fat	1.00	1.00	1.00	1.00	1.00	1.00
Sodium chloride	0.38	0.33	0.37	0.35	0.36	0.35
Vitamins and trace elements	0.15	0.15	0.15	0.15	0.15	0.15
Phytase premix	0.30	0.30	0.30	0.30	0.30	0.30
Calculated chemical composition						
MJ NE/kg	9.9	9.1	9.7	9.5	9.6	9.6
Crude protein, g/kg	130	127	133	127	131	132
Lysine, g/kg	8.6	8.1	8.7	8.3	8.5	8.7
SID[b] lysine g/MJ NE	0.78	0.78	0.78	0.78	0.78	0.78
Threonine, g/kg	5.5	5.3	5.6	5.4	5.5	5.7
Tryptophane, g/kg	1.7	1.5	1.7	1.6	1.7	1.7
Calcium, g/kg	6.7	6.1	6.6	6.5	6.5	6.5
Phosphorus, g/kg	4.7	5.2	4.8	4.5	4.6	4.8

[a]SMB = soya bean meal, CB*P* = cereal by-products, RSM = rapeseed meal and FB = faba bean. [b]Standardized ileal digestible.

diet and one sample of faba beans were collected and analysed. The portioning accuracy of the feeding equipment was tested before each batch of pigs entered the experiment.

Housing

Each growing-finishing unit had 12 pens. Each pen had a feeding trough (3.60 m long), two water nipples, 6.48 m^2 of solid floor and a dunging area of 3.96 m^2. The lying area was separated from the dunging area by a wall with an opening of 1.1 m between the two surfaces. Staff monitored all pens every day and cleaned the solid floor when necessary. The pigs had access to straw every day (approx. 1 kg per pen and day).

Recordings and calculations

The weight of all pigs was individually recorded at the start of the experiment and then every two weeks until their final weighing one day prior to slaughter. Feed consumption was recorded on each feeding occasion and feed efficiency was calculated pen-wise. Pigs were sent to slaughter to a local abattoir with good conditions for individual sampling. The pigs were slaughtered by split marketing based on individual LW in the interval 115–120 kg, where the maximal price per kg carcass weight was achieved. Before cooling, carcass weight was recorded and lean meat content was determined with the Hennessy Grading Probe (Hennessy Grading Systems, Auckland, New Zealand; Sather et al., 1991). After slaughter, tail-biting was recorded by an experienced technician using a two-point scale (0: no visible tail damage; 1: tail damage).

Daily lean meat growth from the start of the experiment to slaughter was calculated using the equation: % lean × (carcass weight − (initial weight × 0.72))/days in experiment, with the value 0.72 representing a hypothetical dressing percentage at the start (Andersson et al., 2012). Calculations on income per carcass were based on actual prices for carcass weight and lean meat content, according to the Swedish co-operative slaughterhouse (contract note week 42 October 2018). Prices were converted from SEK into EUR (currency rate 1 SEK = 0.11 EUR).

Chemical analyses

Feed samples were milled through a 1-mm sieve and then analysed for dry matter content by drying at 103°C for 16 h. Ash content was analysed by combustion at 550°C for 3 h. Nitrogen (N) content was determined by the Kjeldahl method (Nordic Committee on Food Analysis, 1976) and CP was calculated as N × 6.25. Correction of the CP content for losses of N at freeze-drying was performed according to the Nordic Feed Evaluation System (Åkerlind et al., 2011). Dietary content of AA was analysed according to Llames and Fontaine (1994), using high-performance liquid chromatography (HPLC).

Condensed tannin content in the faba beans was determined using depolymerization followed by liquid chromatography. Depolymerization was achieved by methanolic hydrochloric acid (HCl) in the presence of cysteamine, separating tannin extension monomers from the terminal monomer. Samples were analysed using HPLC with a diodearray detector (DAD)/fluorescence detector, which separates the reaction products. Mean degree of polymerization (DP) is calculated from the ratio of chromatogram peak area of all units to the peak area of terminal units (Gu, 2012). Vicine and convicine were determined based on a method described by Gutierrez et al. (2006). In brief, samples were extracted in ultrapure water (30 ml) in a hot water bath (90°C) for 3 h. The cooled sample was centrifuged to remove solids. Concentrated HCl (100 µl) was added to the supernatant (10 ml), followed by an additional centrifugation (10 min, 2500 × g). Samples were filtered through 0.45 µm Acrodisc GHP membrane filter (Pall Corporation, Port Washington, NY, USA) before being analysed by an Agilent 1100 series HPLC–DAD (Agilent, Santa Clara, CA, USA). As an analytical column Atlantis T-3 (2.1 × 150 mm, 3 µm) (Waters Corp., Milford, MA, USA) was used with a gradient of 50 mM phosphate buffer and methanol at 0.2 ml/min. Detection of vicine (Sigma-Aldrich, St. Louis, MO, USA) and convicine was done at 280 nm and for the identification purposes spectrum from 190 to 450 nm was recorded. Quantification of convicine was done by using the calibration curve of vicine.

Statistical analyses

Data were analysed with Statistical Analysis System, version 9.4 (SAS Institute, Cary, NC, USA). The effect of treatment on performance, carcass traits and carcass value was evaluated with Proc Mixed, followed by the Tukey's Multiple Comparison test. The model included the fixed factors of protein feed ingredients (SBM, CBP, RSM and CBP + RSM in Trial 1 and SBM, FB and FB + RSM in Trial 2) and the random factor of batch. Pen was the experimental unit for both performance and carcass parameters. Carcass weight was included in the model as a covariate for lean meat content.

The prevalence of tail-biting recorded at slaughter was tested as a logistic regression using a binomial distribution with a logit link function. This analysis was performed with Proc Genmod and the model included the effect of diet and sex. The level of significance was set at $P < 0.05$ and a tendency at $P > 0.05$ and $P < 0.10$.

Results

Three pigs in Trial 1 and five in Trial 2 died or were euthanized due to illness unrelated to the experiment. The average daily weight gain was 965 g/d in Trial 1 and 982 g/d in Trial 2, with low variation between the batches. Slaughter was performed at an average age of 152.7 d (s.d. 11.1 d) and an average LW of 116.7 kg (s.d. 6.6 kg) in Trial 1. Corresponding values for Trial 2 were 151.3 days (s.d. 8.0 days) and 116.5 (s.d. 6.2 kg).

In Trial 1, the analysed feed composition diverged somewhat from that was calculated. The content of CP in SBM, RSM and CBP + RSM diets were higher than the calculated values, whereas the content in CBP diet was slightly lower (Table 3). Lysine in the CBP diet was also somewhat higher than planned. The diets in Trial 2 showed analysis of CP and lysine contents well in line with calculated figures except for a slightly higher lysine content in the FB + RSM diet. The content of condensed tannins, vicine and convicine in the faba beans was analysed to be 4.1, 16.0 and 0.7 g/kg, respectively.

Daily weight gain did not differ between the different diets neither in Trial 1 nor in Trial 2 ($P = 0.932$ and $P = 0.476$, respectively; Tables 4 and 5). Daily feed consumption was on average 24.0 MJ NE and with no difference between pigs on the different diets ($P = 0.506$ in Trial 1 and $P = 0.692$ in Trial 2). Consequently, feed efficiency was not affected and amounted to 0.39 kg weight gain/kg feed for Trial 1 and 2, respectively ($P = 0.314$ and $P = 0.974$). Carcass weight, lean meat content and dressing percentage were unaffected by dietary treatments in Trial 1 and 2 (Tables 4 and 5), and thus no

Table 3. Actual chemical composition of the experimental diets.

Diet	SID[a] Lysine, g/MJ NE	g SID/g SID Lysine			
		CP[b]	Threonine	Methionine + cysteine	Tryptophan
Trial 1					
SBM[c]	0.78	15.8	0.66	0.59	0.22
CBP[d]	0.84	13.9	0.57	0.54	0.19
RSM[e]	0.75	16.0	0.64	0.66	0.22
CBP + RSM[f]	0.76	15.8	0.63	0.61	0.21
Trial 2					
SBM[c]	0.75	14.9	0.61	0.55	0.20
FB[g]	0.79	14.4	0.58	0.57	0.20
FB + RSM[h]	0.83	14.2	0.52	0.55	0.17

[a]Standardized ileal digestible.
[b]Crude protein.
[c]Soya bean meal.
[d]Cereal by-products.
[e]Rapeseed meal.
[f]50% soya bean meal and 50% rapeseed meal.
[g]Faba beans.
[h]50% faba bean and 50% rapeseed meal.

Table 4. Effects of the experimental diets on performance and carcass traits in Trial 1.

	SBM[a]	CBP[c]	RSM[c]	CBP + RSM[d]	SEM	P-value
No. of pens	6	6	6	6		
Initial weight, kg	27.2	27.0	27.6	26.5	0.53	0.484
Final weight, kg	115.4	117.4	117.5	116.3	1.62	0.286
Daily weight gain, g	964	970	960	964	12.61	0.932
Daily feed consumption, MJ NE	23.9	24.2	23.2	23.2	0.69	0.506
Feed efficiency, kg gain/kg feed[e]	0.38	0.40	0.38	0.39	0.01	0.314
Days in experiment	92.0	93.3	94.7	93.6	1.52	0.513
Carcass weight, kg	87.3	88.3	89.1	87.6	1.08	0.103
Lean meat content, %	59.9	59.2	59.3	59.2	0.31	0.202
Dressing percentage	75.4	75.1	75.7	75.3	0.29	0.212
Daily lean meat growth, g	443	436	434	435	5.73	0.553
Carcass value, EUR	155.9	156.8	158.2	155.4	1.99	0.271

Note: Data presented are least square means. Level of significance $P \leq 0.05$. SEM = pooled standard error.
[a]Soya bean meal.
[b]Cereal by-products.
[c]Rapeseed meal.
[d]50% cereal by-products and 50% rapeseed meal.
[e]Feed efficiency (kg gain/kg feed) was calculated based on the actual content of MJ NE in each diet and then recalculated to an average value of 9.6 MJ NE/kg feed.

Table 5. Effects of the experimental diets on performance and carcass traits in Trial 2.

	SBM[a]	FB[b]	FB + RSM[c]	SEM	P-value
No. of pens	5	5	5		
Initial weight, kg	26.4	26.7	26.0	0.57	0.631
Final weight, kg	116.3	117.6	115.7	2.14	0.463
Daily weight gain, g	980	994	972	17.72	0.476
Daily feed consumption, MJ NE	24.3	25.0	24.4	0.69	0.692
Feed efficiency, kg gain/kg feed[d]	0.39	0.39	0.39	0.01	0.974
Days in experiment	92.0	91.2	91.9	0.92	0.827
Carcass weight, kg	87.5	88.2	86.8	1.55	0.448
Lean meat content, %	59.0	59.7	59.6	0.27	0.364
Dressing percentage	75.3	75.0	74.8	0.24	0.389
Daily lean meat growth, g	439	451	442	9.51	0.381
Carcass value, EUR	155.2	157.1	154.7	3.10	0.443

Note: Data presented are least square means. Level of significance $P \leq 0.05$. SEM = pooled standard error.
[a]Soya bean meal.
[b]Faba beans.
[c]50% faba bean and 50% rapeseed meal.
[d]Feed efficiency (kg gain/kg feed) was calculated based on the actual content of MJ NE in each diet and then recalculated to an average value of 9.6 MJ NE/kg feed.

significant difference in carcass value was found ($P = 0.271$ and $P = 0.443$, respectively). The incidence of tail biting recorded at slaughter was on average 4.7% (9 out of 193 pigs) in Trial 1 and 1.4% (3 out of 141) in Trial 2, and did not differ among dietary treatments ($P = 0.733$ and $P = 0.443$, respectively, not tabled). Tail biting occurred significantly more frequently among entire male pigs than among female pigs in Trial 1, and in Trial 2 there was a tendency to a higher frequency ($P = 0.020$ in Trial 1 and $P = 0.091$ in Trial 2, not tabled).

Discussion

When performing experiments with different protein feed ingredients the level of inclusion is decided by the protein content of the main ingredient, most often being cereals, and the planned dietary levels of CP and AA. Other factors to account for are the composition of the protein feed ingredient, applied feeding plan (i.e. two-phase or single-phase feeding) and the price of the feed ingredient. Single-phase feeding enables the use of locally produced protein feed ingredients, can simplify feed manufacturing and feed handling at farm level and potentially also reduce the N output (Presto Åkerfeldt et al., 2019). Based on the results from previous research supporting pigs' capacity for compensatory growth (Fabian et al., 2002, 2004; Reynolds & O'Doherty, 2006; Millet et al., 2011; Millet & Aluwé, 2014) and the previous part of this study (Presto Åkerfeldt et al., 2019), where single-phase-fed pigs showed equal production results as two-phase-fed pigs, single-phase feeding was used in the present experiment. Results from the previous part demonstrated that lower dietary lysine (0.78 g/MJ NE) and lower CP content (13.8 and 14.5 g SID/g SID lysine) than the current national recommendations (Göransson et al., 2012) only marginally affected daily weight gain, feed efficiency, carcass traits and carcass value. As a consequence, low lysine and protein concentration were used in the present experiment and diets were formulated to contain 0.78 g SID lysine/MJ NE and 14.5 g SID protein/g SID lysine. In comparison with other research experiments performed by Partanen et al. (2003), Zijlstra et al. (2008) and Smith et al. (2013), the lysine contents in our experiment can be considered to be low, which was a consequence of a low inclusion of protein feed ingredients in all the experimental diets. Although, the actual CP content in the SBM, RSM and CBP + RSM diets in Trial 1 did not get as low as planned, the CP content in CBP diet (Trial 1) and the diets SBM, FB and FB + RSM in Trial 2 reached the planned values. One possible explanation for not achieving the planned CP content of 14.5 g SID protein/g SID lysine in SBM, RSM and CBP + RSM is higher CP content in the soy bean and rapeseed meal feed ingredients compared with the values used when formulating diets.

Replacement of soya bean meal with other protein ingredients in our experiment did not negatively affect pig performance in terms of growth, feed efficiency or carcass traits. This observation is in accordance with previous research on dietary inclusion of e.g. canola meal or rapeseed meal (Siljander-Rasi et al., 1996; Brand et al., 2001; King et al., 2001; Smit et al., 2014), cereal-based by-products (Avelar et al., 2010; Woyengo et al., 2016) or faba beans (Partanen et al., 2003; Prandini et al., 2011; Smith et al., 2013; Møller, 2014; White et al., 2015; Ivarsson & Neil, 2018). In our experiment, the pigs were fed according to a feeding regimen, which was 10% higher than usually applied in Sweden (Andersson et al., 1997). This regimen was very close to the pigś feed consumption capacity.

High inclusion of ingredients with ANF like faba beans, peas or products from rapeseed, may limit the nutrient digestibility (Jansman, 1993; Roth-Maier et al., 2004) and feed intake and increases the risk of negative effects on performance and health of the pigs. Recommended maximum inclusion levels according to national guidelines are 10% for rapeseed meal and 20% for faba beans (Göransson et al., 2012). The faba beans used in this experiment were a mixture of different colour flowered varieties and was included with 20%. New varieties of faba beans (i.e. white coloured varieties) with lower levels of ANF, especially tannins, have been developed, but these varieties yield less and have a lower resistance for diseases (Martín et al., 1991) and therefore there is an interest for harvesting the coloured varieties. According to Ivarsson & Neil (2018), the content of ANF in faba beans vary considerably among different varieties. They found that cultivar rather than flower colour determines the nutritional value and that 20–30% of both white and coloured faba bean cultivars can successfully be included in nutritionally balanced diets to weaned and growing pigs without negative effect on production and health (Smith et al., 2013; Møller, 2014; Ivarsson and Neil, 2018). Still, if applying two-phase feeding, there is a risk of exceeding the recommended maximum inclusion levels, due to the required high protein and AA content in the early growth phase. In comparison, single-phase feeding can have lower content of protein and AA in the early stage of the growing phase, and thus, the inclusion of protein feed ingredients with ANF may be kept lower than maximum inclusion levels.

The faba beans used in this experiment were expected to have high content of condensed tannins. The content of 4.06 g/kg was in the same range as those reported by Jezierny et al. (2010), but lower than those found by Ivarsson & Neil (2018). The analysed content of vicine was higher, whereas the content of convicine was lower, 16.0 and 0.7 g/kg, respectively, compared with corresponding values ranging from 0.2 to 10.4 and 0.1 to 4.3 g/kg (Duc et al., 1999) and 6.6 to 7.9 and 2.2 to 4.4 g/kg (Ivarsson & Neil, 2018). However, these discrepancies did not seem to have an adverse effect on the performance of the pigs in our experiment, as suggested by Crépon et al. (2010).

In contrast to our results, some studies with growing-finishing pigs found that inclusion of cereal-based by-products such as wheat distillers dried grains with solubles and wheat middlings in the diets decreased the nutrient utilization. Results indicate that 20–25% inclusion of wheat DDGS reduced average daily growth of growing pigs (Avelar et al., 2010; Widyaratne & Ziljstra, 2007) and gain to feed in weaned pigs (Wang et al., 2016). However, Thacker (2006) found that DDGS did not affect growth performance of finishing pigs. Likewise, feed intake was linearly reduced by gradual inclusion of wheat DDGS during the growing period but not during the finishing period. This was reflected in a poorer weight gain and feed conversion ratio during the total period (Thacker, 2012). Inclusion of wheat middlings in a corn-soybean meal-based diet, with or without 30% DDGS, also reduced pig growth performance and carcass yield (Salyer et al., 2012). In comparison, the cereal-based by-product diet in our experiment contained only 4% DDGS, but 20% wheat middlings and 10% wheat bran.

According to Beattie et al. (2005) nutrient deficiencies can lead to pigs starting to tail bite, however, it is known that tail biting is a multi-factorial disease (Fraser et al., 1991; Schröder-Petersen & Simonsen, 2001), thus, housing environment and management also plays a role. If present, it leads to poor welfare and production (Wallgren & Lindahl, 1996). The low frequency of tail biting in all treatments in our experiment indicates that the diets were well-balanced and fulfilled the pigs' nutrient requirements.

Reduction of the dietary CP content also plays a role for the hygiene conditions in the pens and pig housing. Less protein in the diet reduces water intake and urine production, thus, reducing the amount of slurry. A 2%-unit reduction in the CP content in a common dry slaughter pig diet will, according to Nielsen (1995), increase the dry matter content of the slurry by 50%. Presto Åkerfeldt et al., (2019) showed that a reduction in protein content, from 15.5 to 14.5 g SID/g SID lysine, resulted in a reduction of N output by approximately 10%. In the present experiment we exceeded the planned protein content in some of the diets in Trial 1. However, as the planned lower protein contents were achieved in Trial 2, the N emissions could be expected to be reduced according to Presto Åkerfeldt et al. (2019).

The low protein diets fed in a single-phase feeding plan in our experiment aimed at utilizing local protein feed ingredients and increasing cereal inclusion. The results support our hypothesis. Thus, this experiment concludes that single-phase-fed pigs given diets with locally produced protein feed ingredients can perform as well as single-phase-fed pigs on a commercial diet with soya bean meal as the protein feed ingredient. Cereal based by-products, rapeseed meal, faba bean, or a combination of them, have the potential to replace soya bean meal in nutritionally well-balanced diets to growing-finishing pigs.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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ORCID

Magdalena Presto Åkerfeldt http://orcid.org/0000-0002-0616-7763

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