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# Effects of reducing dietary content of crude protein and indispensable amino acids on performance and carcass traits of single-phase- and 2-phase-fed growing-finishing pigs

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ABSTRACT

Effects of reducing dietary content of crude protein (CP) and Lys on performance and carcass traits of growing-finishing pigs were studied in 690 crossbred (Swedish Yorkshire dams x Hampshire sires) female and vaccinated entire male pigs with an average initial live weight (LW) of 32.3 kg. The pigs were raised in pens with mixed sexes and were fed restrictedly using 2 different feeding plans, single-phase and 2-phase. Within each feeding plan, 3 CP contents were investigated: 13.5 (low), 14.5 (medium), and 15.5 (high) g standardized ileal digestible (SID) CP/g SID Lys. Each CP comprised 2 Lys contents. For single-phase-fed pigs this implied either 0.76 or 0.85 g SID Lys/MJ net energy (NE). For 2-phase-fed pigs, the contents were either 0.89 in phase 1 and 0.71 in phase 2 or 0.98 in phase 1 and 0.79 in phase 2 g SID Lys/MJ NE. In low and high Lys, the expected total consumption of digestible Lys from start to slaughter was calculated to be equal for single-phase- and 2-phase-fed pigs. The change of diet in the 2-phase feeding plan was at an average LW of 60.8 kg and slaughter was performed at 117.3 kg. Irrespective of dietary CP and Lys content, 2-phase-fed pigs had higher daily weight gain (DWG) and better feed conversion in phase 1 than single-phase-fed pigs. In phase 2, single-phase-fed pigs fully compensated, so that overall DWG and feed conversion did not differ between single-phase- and 2-phase-fed pigs (1014 vs. 1013 g/d; 24.5 vs. 24.5 MJ NE/kg DWG). Dietary CP content had no effect on DWG and feed conversion in phase 1. However, pigs grew faster and had better feed conversion in phase 2 ($P = 0.002$ and $P = 0.018$, respectively) and during the entire raising period with the high CP content ($P = 0.003$ and $P = 0.006$, respectively). For both single-phase- and 2-phase-fed pigs, high dietary Lys content improved DWG and feed conversion in phase 1 compared with the low content (1002 vs. 968 g/d; $P = 0.001$ and 20.7 vs. 21.5 MJ NE/kg DWG; $P = 0.004$), whereas no difference was observed in phase 2. Overall, Lys content did not affect DWG, while feed conversion was better for pigs fed the high Lys content ($P = 0.035$). Carcass traits were unaffected by feeding plan, CP, and Lys content. Reducing dietary CP content from high to low diminished the N output by approximately 20%. The conclusions are that growing-finishing pigs had the capacity for compensatory growth and can therefore be single-phase-fed, and that the current recommendations of CP and Lys could be reduced.

## 1. Introduction

From an environmental and economic point of view, it is critical to minimise the protein input in animal feed. For pigs, the protein value of each feedstuff is directly correlated to the content of indispensable amino acids (IAA) and their digestibility in the small intestine. Commercially, pure Lys, Thr, Met and to some extent Try and Val are used in feed formulations. These are almost 100% digestible in the small intestine of pigs and provide an excellent possibility to balance the IAA profile of the feed and lower the inclusion of protein and thereby, the amount of protein feedstuffs. The current recommended IAA contents for pigs (NRC, 2012) are based on data obtained in experiments performed under different conditions (e.g., genetic lines, dietary raw materials, health status, management practices). Therefore, these recommendations may need to be adjusted to suit prevailing production conditions. For example, Høøk Presto et al. (2007) found that the amino acid requirements of modern slaughter pigs may be lower than the recommended contents.

With increasing age of the pig, the energy requirement increases and the potential for muscle growth decreases (NRC, 2012). Thus, the

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contents of crude protein (CP) and IAA expressed per kilogram of feed are higher at an early stage of growth than in later stages. To meet the needs for optimal growth, the recommendation is to apply a phase feeding plan. This involves the use of 2 or more feeds containing lower CP and IAA content with increasing age of the pigs. Moreover, there is great variation in live weight (LW) within a batch of slaughter pigs, meaning that most of the pigs will theoretically be either under- or oversupplied with CP and IAA. To overcome this problem, feeds in practice are formulated with higher contents of CP and IAA than commonly recommended, which results in wastage of nutrients and unnecessarily high N emissions.

Research has demonstrated that limiting the supply of IAA during early growth may be fully compensated for by increased protein retention (Martinez-Ramirez et al., 2008, 2009) and faster growth during later growth phases (Fabian et al., 2002, 2004; Millet and Aluwé, 2014; Millet et al., 2011; Reynolds and O'Doherty, 2006). In addition, pigs fed insufficient amounts of IAA in the early growth phase are reported to have improved feed efficiency during the entire raising period and less excretion of N than phase-fed pigs (Fabian et al., 2002, 2004; Reynolds and O'Doherty, 2006). There are also indications that carcass meat content is favoured in pigs expressing compensatory growth (Reynolds and O'Doherty, 2006; Yang et al., 2008) and that the feed amino acid content in the late finishing period determines carcass quality (Millet and Aluwé, 2014; Millet et al., 2011). Pigs expressing compensatory growth may have increased muscle protein turnover compared with conventionally fed pigs (Kristensen et al., 2004; Therkildsen et al., 2004). According to Bee et al. (2007), compensatory growth has a positive effect on the tenderness of pig meat, due to increased proteolytic activity at slaughter. However, Heyer and Lebret (2007) did not find any effect of compensatory growth on meat sensory characteristics.

Our hypothesis was that single-phase-fed pigs with reduced CP and IAA contents would perform as well as 2-phase-fed pigs with a diet according to current recommended contents. The objective of the present study was to investigate the effects of reducing the dietary content of CP and IAA on performance and carcass traits of single-phase- and 2-phase-fed growing-finishing pigs. A reduction of dietary CP and IAA would reduce the N losses to the environment. In addition, soya meal can partly be substituted by cereals and locally produced feedstuffs.

## 2. Material and methods

### 2.1. Experimental design

A total of 690 crossbred (Swedish Yorkshire dams x Hampshire sires) female and entire male (vaccinated against boar taint) pigs from 77 litters were used in 12 experimental treatments, with 56–58 pigs per treatment. The study was run with 6 batches, giving a total of 72 pens. All treatments were repeated in each of the six batches (Fig. 1). The pigs were raised in pens, with 8–10 pigs per pen. The sires were randomly selected from sires available for artificial insemination. The study 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.

2 different feeding plans were compared; single-phase and 2-phase. Single-phase-fed pigs were given the same diet throughout the entire raising period, whereas the 2-phase-fed pigs changed diet from the phase 1 to the phase 2 at a planned average pen live weight (LW) of 60 kg. Within each feeding plan, 3 crude protein (CP) contents were investigated; 13.5 (low), 14.5 (medium) and 15.5 (high) g standardized ileal digestible (SID)/g SID Lys. Each CP content comprised 2 Lys contents. For single-phase-fed pigs this implied either 0.76 (low) or 0.85 (high) g SID /MJ net energy (NE). For 2-phase-fed pigs, the contents of Lys were either 0.89 in phase 1 and 0.71 in phase 2 (low) or 0.98 in phase 1 and 0.79 in phase 2 (high) g SID Lys/MJ NE, respectively (Fig. 1). For 2-phase-fed pigs the high content was very close to the NRC recommendation and the low content was approximately 10% lower. Within low and high Lys content, the expected total consumption of digestible Lys from start to slaughter was calculated to be equal for single-phase- and 2-phase-fed pigs. These calculations were based on historical data of feed consumption from the research station.

At weaning, piglets were randomly allocated to treatments balanced with respect to sex, litter, and 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 Lys per kilogram feed. At the start of the experiment, the pigs were moved to the growing-finishing unit at an average age of 10 w (70.3 ± 3.1 d; mean ± SD) in batches 1 and 2; 9 w (63.1 ± 4.4 d) in batches 3 and 4, and 8.5 w (59.9 ± 5.9 d) in batches 5 and 6. The corresponding values for average initial LW were 36.8 kg (SD 5.2 kg), 31.6 kg (SD 6.1 kg) and 28.3 kg (SD 6.6 kg), respectively. Entire male pigs were given 2 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 w before slaughter, according to the manufacturer's recommendation.

### 2.2. Feeding

All pigs were fed 3 times per d according to a restricted feeding regimen for growing-finishing pigs (Andersson et al., 1997) that is, the daily feed allowances in MJ of NE 12.4, 14.3, 18.1, 21.8, and 25.6 at 25, 30, 40, 50, and 60 kg LW and thereafter to slaughter, respectively. In feed formulation, data on NE and digestibility coefficients for amino acids (AA) were taken from Sauvant et al. (2004). 4 basic feeds, low Lys - low protein, low Lys - high protein, high Lys - low protein and high Lys - high protein, were manufactured on three occasions in a commercial feed plant (Table 1). The content of Thr, Met, Cys, and Try was optimised in relation to the Lys content according to recommendations (Göransson et al., 2012). On each manufacturing occasion, 2 samples of each feed were collected and analyzed. Based on the results, four basic feeds were mixed in an automatic computerised feeding system at the research station, to produce the 12 treatment feed mixtures according to Fig. 1. The portioning accuracy of the feeding equipment was tested before each batch of pigs entered the experiment.

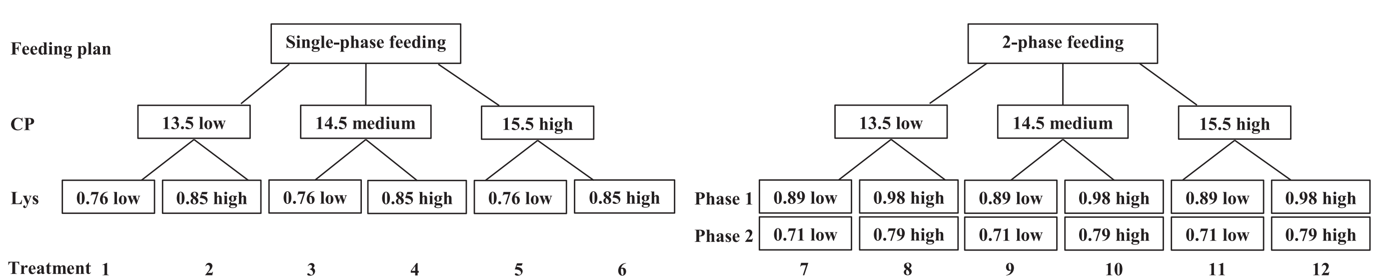


**Fig. 1.** Design of the experimental treatments and calculated content of crude protein (CP; low, medium and high, g standardized ileal digestible (SID)/g SID Lys) and Lys (low and high, g SID/MJ NE) within the feeding plans (single-phase and 2-phase feeding).

**Table 1**
Inclusion rate of different ingredients[a] and calculated chemical composition of the basic feed mixtures.

| | CP[b] Low Lys Low | CP Low Lys High | CP High Lys Low | CP High Lys High |
|---|---|---|---|---|
| Ingredients,% | | | | |
| Wheat | 40 to 50 | 40 to 50 | 50 to 55 | 50 to 55 |
| Barley | 45 to 55 | 25 to 35 | 40 to 45 | 15 to 25 |
| Soybean meal | 0 | 7.0 to 11.0 | 3.1 to 6.0 | 13 to 16 |
| Rapeseed meal | 0 | 3.5 to 5.5 | 1.5 to 5.5 | 6.5 to 8 |
| Potato protein | 0 to 0.2 | 0 | 0 | 0 |
| L-Lys HCl | 0.54 to 0.57 | 0.52 to 0.6 | 0.37 to 0.43 | 0.3 to 0.4 |
| L-Thr | 0.17 to 0.19 | 0.18 to 0.21 | 0.10 to 0.12 | 0.09 to 0.11 |
| Dl-Met | 0.07 to 0.09 | 0.12 to 0.13 | 0.04 to 0.05 | 0.05 to 0.06 |
| L-Try | 0.03 to 0.04 | 0.03 to 0.04 | 0.01 to 0.02 | 0.01 |
| $CaCO_3$ | 1.2 to 1.3 | 1.2 to 1.3 | 1.2 to 1.3 | 1.1 to 1.2 |
| $Ca(H_2PO_4)_2$ | 0.5 to 0.6 | 0.4 to 0.5 | 0.5 to 0.6 | 0.3 to 0.4 |
| Vegetable fat | 0 to 1 | 1.5 to 2.0 | 0.5 to 1.0 | 0 |
| Vitamin-mineral premix | 0.15 | 0.15 | 0.15 | 0.15 |
| Calculated chemical composition | | | | |
| NE, MJ/kg | 9.9 | 9.9 | 9.9 | 9.9 |
| CP, g/kg | 105 to 115 | 150 to 155 | 125 to 130 | 170 to 175 |
| SID[c] Lys, g/MJ NE | 0.71 | 0.98 | 0.71 | 0.98 |
| SID CP/SID Lys, g/g | 13.5 | 13.5 | 15.5 | 15.5 |
| SID Thr/SID Lys, g/g | 0.62 | 0.62 | 0.62 | 0.62 |
| SID Met + Cys/SID Lys, g/g | 0.60 | 0.60 | 0.60 | 0.60 |
| SID Try/SID Lys, g/g | 0.19 | 0.19 | 0.20 | 0.20 |
| Ca, g/kg | 0.75 | 0.75 | 0.75 | 0.75 |
| Digestible P, g/kg | 0.27 | 0.27 | 0.27 | 0.27 |

[a] Phytase was added to all diets, not tabled.
[b] Crude protein.
[c] Standardized ileal digestible.

### 2.3. Housing

Each growing-finishing unit had 12 pens. Each pen had a feeding trough (3.60 m long), 2 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 2 surfaces. Staff monitored all pens every day and cleaned the solid floor when necessary. The pigs were given straw every day (approx. 1 kg per pen and d).

### 2.4. Recordings and calculations

The weight of all pigs was individually recorded at the start of the experiment and then every 2 w until their final weighing 1 d prior to slaughter. Growth rate was calculated for phase1, phase 2, and for the entire raising period. Feed consumption was recorded on each feeding occasion and feed conversion ratio was calculated pen-wise. To estimate the margin feed conversion ratio, i.e., the amount of feed needed to produce 1 additional kg LW, the feed conversion ratio was calculated for each weight interval. Regression of LW on margin feed conversion ratio was then calculated for phases 1 and 2. Pigs were slaughtered by split marketing based on individual LW in the interval 115–120 kg, where the maximal price per kilogram carcass weight is achieved in a Swedish payment system. 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 2-point scale (0: no visible tail damage; 1: tail damage).

Daily lean meat growth from start of the experiment to slaughter was calculated using the formula: % lean × (carcass weight − (initial weight × 0.72)) / d in experiment, with the value 0.72 representing a hypothetical dressing percentage at 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 cooperative slaughterhouse (contract note w 42 October 2017). Prices were converted from SEK into EUR (currency rate 1 SEK = 0.11 EUR). According to the equation described by Vils (2007), the amount of N output from the pigs in our experiment was calculated. The calculations were based on the average LW and slaughter weight of the pigs.

### 2.5. Chemical analyses

Feed samples were milled through a 1-mm sieve and then analyzed for dry matter content by drying at 103 °C for 16 h. Ash content was analyzed by combustion at 550 °C for 3 h. 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 analyzed according to Llames and Fontaine (1994), using high performance liquid chromatography (HPLC).

### 2.6. Statistical analyses

Data were analyzed 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. The model included the fixed factors of feeding plan (single-phase or 2-phase), CP content (low, medium or high), and Lys content (low or high), and the random factor of batch. 2-way interactions were tested, but were found to be non-significant ($P \geq 0.05$) and were therefore excluded from the model. 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 feeding plan, content of CP and Lys, and sex.

## 3. Results

Six pigs died or were euthanized due to illness unrelated to the study. 2-phase-fed pigs changed diet from the phase 1 to the phase 2 at an average pen live weight (LW) of 60.8 kg (SD 8.4 kg). Slaughter was performed at an average age of 148.6 d (SD 9.2 d) and an average LW of 117.3 kg (SD 6.2 kg). Mean daily weight gain (DWG) was high (1023 g/d), with low variation between the batches. The actual feed composition diverged slightly from the calculated composition (Table 2). Thus, the low Lys treatments in phase 2 received somewhat more Lys than the planned content of 0.71 g standardized ileal digestible (SID)/MJ net energy (NE), while the treatments with the low content of protein were supplied with some more protein than intended (13.5 g SID/g SID Lys). The calculated Val:Lys ratio in the diets with low protein content was lower (0.61 g SID/g SID) than the recommended content of 0.67. In terms of total supply of SID Lys, the 2-phase-fed groups of pigs received 1649 (low) and 1782 (high) g/pig. Corresponding figures for single-phase-fed pigs were 1622 and 1797 g/pig, respectively.

In phase 1, irrespective of dietary crude protein (CP) and Lys contents, 2-phase-fed pigs showed significantly higher growth and feed conversion than single-phase-fed pigs (Table 3). However, in phase 2 the single-phase-fed pigs compensated, and the overall DWG and feed conversion did not differ between single-phase- and 2-phase-fed pigs (1014 vs. 1013 g/d; 24.5 vs. 24.5 MJ NE/kg DWG). Feeding plan had no significant effect on carcass traits and, consequently, there was no difference in income per carcass between single-phase- and 2-phase-fed pigs (Table 3).

Dietary CP content had no effect on growth rate and feed conversion

**Table 2**
Actual chemical composition of the experimental diets.

| Treatment | Feeding plan | SID[a] Lys, g/MJ NE | g SID/g SID Lys CP[b] | Thr | Met + Cys | Try | Val | Iso |
|---|---|---|---|---|---|---|---|---|
| 1 | Single | 0.77 | 15.5 | 0.61 | 0.61 | 0.21 | 0.68 | 0.46 |
| 2 | Single | 0.77 | 14.5 | 0.64 | 0.60 | 0.20 | 0.64 | 0.46 |
| 3 | Single | 0.76 | 13.8 | 0.66 | 0.58 | 0.20 | 0.61 | 0.45 |
| 4 | Single | 0.86 | 15.5 | 0.61 | 0.59 | 0.21 | 0.69 | 0.49 |
| 5 | Single | 0.86 | 14.5 | 0.63 | 0.59 | 0.20 | 0.64 | 0.48 |
| 6 | Single | 0.85 | 13.8 | 0.65 | 0.59 | 0.20 | 0.61 | 0.48 |
| 7 | Phase 1 | 0.89 | 15.5 | 0.62 | 0.59 | 0.21 | 0.69 | 0.50 |
| 7 | Phase 2 | 0.75 | 15.5 | 0.61 | 0.61 | 0.21 | 0.68 | 0.45 |
| 8 | Phase 1 | 0.90 | 14.4 | 0.63 | 0.59 | 0.20 | 0.64 | 0.48 |
| 8 | Phase 2 | 0.74 | 14.5 | 0.65 | 0.60 | 0.25 | 0.64 | 0.45 |
| 9 | Phase 1 | 0.89 | 13.7 | 0.64 | 0.59 | 0.20 | 0.60 | 0.49 |
| 9 | Phase 2 | 0.72 | 13.8 | 0.67 | 0.58 | 0.20 | 0.61 | 0.44 |
| 10 | Phase 1 | 0.98 | 15.4 | 0.62 | 0.58 | 0.21 | 0.69 | 0.51 |
| 10 | Phase 2 | 0.80 | 15.5 | 0.61 | 0.60 | 0.21 | 0.69 | 0.47 |
| 11 | Phase 1 | 0.99 | 14.5 | 0.63 | 0.59 | 0.20 | 0.64 | 0.50 |
| 11 | Phase 2 | 0.80 | 14.4 | 0.64 | 0.59 | 0.20 | 0.64 | 0.47 |
| 12 | Phase 1 | 0.99 | 13.8 | 0.63 | 0.59 | 0.20 | 0.61 | 0.51 |
| 12 | Phase 2 | 0.79 | 13.8 | 0.66 | 0.59 | 0.20 | 0.61 | 0.46 |

[a] Standardized ileal digestible.
[b] Crude protein.

in phase 1. However, pigs grew faster and had better feed conversion in phase 2 ($P = 0.002$ and $P = 0.018$) and during the entire raising period ($P = 0.003$ and $P = 0.006$) with the high CP content than with medium and low content. Carcass leanness was unaffected by dietary CP content (Table 3). Carcass weight tended to be higher ($P = 0.067$) for pigs with high CP content than for those with medium and low, and as a consequence income per carcass was improved. The calculated amount of excreted N per pig was 2190, 2408, and 2602 g for pigs fed the low, medium and high CP content, respectively.

For both single-phase- and 2-phase-fed pigs, high dietary Lys content improved DWG and feed conversion in phase 1 compared with low Lys content (1002 vs. 968 g/d, $P = 0.001$; 20.7 vs. 21.5 MJ NE/kg DWG, $P = 0.004$), whereas no difference was observed in phase 2 (Table 3). Overall, Lys content did not significantly affect DWG, however, feed conversion was better in pigs fed the high Lys content ($P = 0.035$). Dietary high Lys content showed a tendency ($P = 0.089$) to improve carcass leanness, which was 59.4% compared with 59.1% for pigs with low content. Income per carcass tended ($P = 0.096$) to be higher for pigs fed the high Lys content than those given the low Lys content (150.5 vs. 149.5 EUR).

Equations for the relationship between LW in pigs and margin feed conversion ratio in the experiment were as follows: MJ NE per kilogram weight gain = 18.44 + (0.05 × kilogram LW) from start to 60.8 kg and 12.00 + (0.18 × kilogram LW) from 60.8 kg to slaughter. The incidence of tail biting recorded at slaughter was on average 3.7% (25 out of 668 pigs) and did not differ between feeding plan ($P = 0.518$), Lys content ($P = 0.262$), CP content ($P = 0.302$) or sex ($P = 0.174$).

## 4. Discussion

Correct balancing of protein and amino acids (AA) in pig diets is important for performance, pig health, production economics, and N emissions. Closely matching supply to requirement is essential for economic and environmental efficiency (Van Milgen et al., 1998). Therefore, it is common to apply phase feeding to meet the requirements and gradually lower dietary indispensable amino acids (IAA) content with increasing age of the pigs. However, from a practical point of view, single-phase feeding during the entire raising period would simplify feed manufacturing, feed handling, and diet formulation at farm level. Contrary, to phase feeding, single-phase feeding implies restricted dietary IAA in the early growing-finishing period, followed by excess dietary IAA during the later finishing period. Recommended amounts of standardized ileal digestible (SID) Lys/MJ NE are sometimes given in a range for the different weight intervals, based on variations in response to the amount added due to sex, health status, environmental factors, and breed (Göransson et al., 2012). Other amino acids and crude protein (CP) are then optimised in relation to Lys. Slaughter pigs are raised in pens with a number of individuals, varying in weight, and therefore, it is impossible to totally adapt the needs of AA on an individual basis. To ensure adequate intake of IAA in lighter pigs, the content of dietary IAA used in practice commonly exceeds the recommendation. However, it has been suggested that modern fast-growing pigs can tolerate lower contents of IAA than recommended (Høøk Presto et al., 2007) and that they can show a compensatory growth response after a period of protein restriction (Fabian et al., 2002, 2004; Millet and Aluwé, 2014; Millet et al., 2011; Reynolds and O'Doherty, 2006; Therkildsen et al., 2004).

The present experiment was designed to compare the effect of

**Table 3**
Effects of feeding plan, dietary content of crude protein (CP) and Lys on performance and carcass traits.

| | Feeding plan Single-phase | 2-phase | SEM | P-value | CP[1] Low | Medium | High | SEM | P-value | Lys[2] Low | High | SEM | P-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of pens | 36 | 36 | | | 24 | 24 | 24 | | | 36 | 36 | | |
| Initial weight, kg | 32.1 | 32.4 | 1.6 | 0.297 | 32.1 | 32.3 | 32.3 | 1.6 | 0.794 | 32.4 | 32.1 | 1.6 | 0.274 |
| Final weight, kg | 117.3 | 117.4 | 0.9 | 0.803 | 116.9 | 117.2 | 118.0 | 0.9 | 0.072 | 117.0 | 117.7 | 0.9 | 0.075 |
| Daily weight gain, g | | | | | | | | | | | | | |
| To 60.8 kg – phase 1 | 961 | 1009 | 14 | 0.001 | 981 | 987 | 987 | 14 | 0.766 | 968 | 1002 | 14 | 0.001 |
| After 60.8 kg – phase 2 | 1045 | 1016 | 10 | 0.005 | $1012^{a}$ | $1022^{a}$ | $1057^{b}$ | 12 | 0.002 | 1031 | 1030 | 10 | 0.939 |
| Start to slaughter | 1014 | 1013 | 7 | 0.883 | $1000^{a}$ | $1009^{a}$ | $1031^{b}$ | 8 | 0.003 | 1008 | 1019 | 7 | 0.113 |
| Feed conversion, NE MJ/kg weight gain | | | | | | | | | | | | | |
| To 60.8 kg – phase 1 | 21.7 | 20.5 | 0.3 | 0.001 | 21.2 | 21.4 | 20.7 | 0.3 | 0.180 | 21.5 | 20.7 | 0.3 | 0.004 |
| After 60.8 kg – phase 2 | 26.0 | 26.5 | 0.3 | 0.097 | $26.7^{a}$ | $26.5^{a}$ | $25.7^{b}$ | 0.3 | 0.018 | 26.4 | 26.1 | 0.3 | 0.373 |
| Start to slaughter | 24.5 | 24.5 | 0.2 | 0.935 | $24.8^{a}$ | $24.7^{a}$ | $24.0^{b}$ | 0.2 | 0.006 | 24.8 | 24.3 | 0.2 | 0.035 |
| Days in experiment | 84.4 | 84.0 | 2.6 | 0.492 | 85.0 | 84.1 | 83.5 | 2.6 | 0.081 | 84.3 | 84.1 | 2.6 | 0.773 |
| Carcass weight, kg | 88.6 | 88.7 | 0.8 | 0.869 | 88.3 | 88.4 | 89.2 | 0.8 | 0.067 | 88.4 | 88.8 | 0.8 | 0.276 |
| Lean meat content,% | 59.2 | 59.3 | 0.3 | 0.366 | 59.2 | 59.2 | 59.4 | 0.3 | 0.628 | 59.1 | 59.4 | 0.3 | 0.089 |
| Dressing percentage | 75.5 | 75.4 | 0.2 | 0.499 | 75.5 | 75.3 | 75.5 | 0.2 | 0.599 | 75.5 | 75.4 | 0.2 | 0.468 |
| Daily lean meat growth, g | 490 | 485 | 11 | 0.558 | 483 | 486 | 494 | 12 | 0.535 | 486 | 490 | 11 | 0.641 |
| Carcass value, € | 149.9 | 150.2 | 1.3 | 0.666 | $149.3^{a}$ | $149.6^{a}$ | $151.1^{b}$ | 1.3 | 0.028 | 149.5 | 150.5 | 1.3 | 0.096 |

Data presented are least square means. Means with different superscripts ($^{a,b}$) within row and feeding plan or Lys level differ $P \leq 0.05$. SEM = pooled standard error.
[1] Content of CP: Low = 13.5; Medium = 14.5; High = 15.5 g standardized ileal digestible (SID) CP/g SID Lys.
[2] Content of Lys: Single-phase Low = 0.76; Single-phase High = 0.85 g SID Lys/MJ NE. Two-phase Low = 0.89 in phase 1 and 0.71 in phase 2; Two-phase High = 0.98 in phase 1 and 0.79 in phase 2 g SID Lys/MJ NE.

single-phase and 2-phase feeding of growing-finishing pigs supplied with low amounts of protein and amino acids, with the aim of evaluating possibilities to minimise the use of soya meal and increase the amount of cereals and locally produced protein feedstuffs in the diet. The experimental diets were formulated with regard to the content of Lys, The, Met, Cys, and Try, the same amino acids as used for feed formulation in the feed industry.

The results demonstrated that single-phase-fed, modern, lean meat-type pigs fully compensated in growth during the end of the growing-finishing period for an initial low CP and AA supply, confirming previous findings (Fabian et al., 2002, 2004; Millet and Aluwé, 2014; Millet et al., 2011; Reynolds and O'Doherty, 2006; Therkildsen et al., 2004). However, contrary to previous findings, we did not observe any improvement in feed conversion during the entire raising period for single-phase-fed pigs compared with 2-phase-fed pigs. However, there was a tendency for improved feed conversion in phase 2, which is in general agreement with results reported by Millet et al. (2011), and Millet and Aluwé (2014).

Restriction of the Lys content did not affect growth from start to slaughter or carcass composition, whereas feed conversion was marginally decreased. As the need of AA is related to the live weight (LW) of the pig, the performance of pigs with low initial LW could be expected to be affected by low AA supply. However, this was not the case in the present study, which indicates that it may be possible to decrease the AA content of the diet even more. In contrast, Millet et al. (2011) found poorer performance among gilts on a lower AA content throughout the early growing to late finishing period. On the other hand, the reduction in Lys was greater in their study, i.e., from 0.84 to 0.62 g SID/MJ NE from early growing to late finishing compared with 0.89 and 0.71 g SID/MJ NE for 2-phase-fed pigs and 0.76 g SID/MJ NE for single-phase-fed pigs in the present study. Decreasing the CP content from 15.5 to 13.8 g SID CP/g SID Lys only slightly affected pig performance, lowering DWG and feed conversion by on average around 3%. There were no interactions between Lys and CP content, which supports use of the same relationship between CP and Lys irrespective of dietary Lys content.

In our study, the vaccinated entire male pigs grew faster than the females, which is in accordance with previous studies (Fábrega et al., 2010; Pauly et al., 2009; Zamaratskaia et al., 2008). Females and barrows have a lower protein deposition capacity than entire male pigs (NRC, 2012) and it seems likely that entire male pigs should have the capacity to grow more efficiently. This might also be the case when fed a restricted content of protein. Results from Martinez-Ramirez et al. (2008a,b) showed that entire male pigs increased their protein deposition rate after a period of AA restriction, while barrows did not. In our study pigs were raised in pens with mixed sexes, therefore, it is not possible to find out whether the difference in growth rate was due to a higher feed intake or a better feed efficiency.

One of the main factors when deciding the optimal slaughter weight to achieve the highest profitability, is the margin feed conversion ratio. The equations in this study were very close to those found by experts at the Swedish commercial feed manufacturer Lantmännen (Sigfridsson, personal communication 2015).

High feed protein content increases the risk of gut health problems (Rist et al., 2013) and the occurrence of pleuritis (Holmgren, 2009). However, the CP contents used in the present study did not have a negative impact on pig health. Moreover, the frequency of tail biting was low and there were no effects of the dietary treatments. Tail biting has multi-factorial causes (Fraser et al., 1991; Schröder-Pedersen and Simonsen, 2001) and leads to poor welfare and production (Wallgren and Lindahl, 1996). A reduction in the dietary CP content will have positive effects on the hygiene conditions in the pig house, since less protein in the diet reduces water intake and urine production, thereby, improving floor conditions and reducing the amount of slurry. According to Nielsen (1995), a 2%-unit reduction in the CP content in a common dry slaughter pig diet will increase the dry matter content of the slurry by 50%.

Single-phase feeding of pigs followed by growth compensation might also reduce N emissions, as it excludes the need for a high protein content in the diet in the early stages of growth. Although pigs fed the low and medium CP content had poorer feed conversion ratio than pigs fed the high CP content, the calculated N excretion from these pigs was lower. The reduction in protein content investigated in this study, from 15.5 to 13.8 g SID/g SID Lys, resulted in a reduction of N output by approximately 20%. In addition, the inclusion of soya meal might be lowered by 50%.

## 5. Conclusions

The main finding in this study was that single-phase-fed growing-finishing pigs had the capacity for compensatory growth and had similar performance and carcass traits to 2-phase-fed growing-finishing pigs. Growth performance and carcass traits in single-phase-fed pigs were only slightly affected by a reduction in dietary crude protein (CP) from 15.5 to 13.8 g SID CP/g SID Lys and a reduction in Lys from 0.86 to 0.76 g standardized ileal digestible (SID) Lys/MJ NE. Consequently, soya meal inclusion could partly be reduced and replaced by cereal and locally produced feedstuffs and thereby, the N losses to the environment could be decreased by 20%.

## Declarations of interest

None.

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