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LOW-PROTEIN FEED FOR WEANED PIGS REDUCES DIARRHOEA OUTBREAKS

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Main conclusion

Low-protein feed is an efficient intervention against diarrhoea when medicinal zinc is no longer allowed in pig feed. However, too little protein has a negative impact on gain, feed conversion and production value.

Abstract

A low-protein diet is an efficient measure to minimise diarrhoea outbreaks when medicinal zinc is no longer allowed in pig feed.

The effect of a low-protein diet was therefore investigated in a trial designed as shown below.

Group	1	2	3	4	5
	Pos. control 'Old' standard	Neg. control 'Old' standard	Low protein Soy protein conc New stand.	Low protein Soybean meal New stand.	Very low prot. Extra amino acids
Zinc	+	-	-	-	-
	Gram digestible protein/feed unit (FUgp)				
Phase 1: 6-9 kg	145	145	133	133	115
Phase 2: 9-15 kg	146	146	134	134	115
Phase 3: 15-30 kg	149	149	149	149	149

Results demonstrated that feed containing medicinal zinc reduced treatments for diarrhoea by 43% compared to feed with no zinc. The pigs in groups 3 and 4 fed low-protein feed (reduced by approx. 10 g digestible protein/FUgp) the first four weeks did not have significantly fewer treatment days than the pigs given no medicinal zinc. Recordings show a significant drop of 63% in treatments for diarrhoea for the pigs in group 5 given very low protein combined with extra amino acids (beyond those normally added) compared with the pigs given no medicinal zinc.

There were no significant variations in production value at identical feed prices between groups 1-4, whereas the pigs in group 5 (very low protein) had a significantly lower gain, a poorer feed conversion and a lower productivity than the other pigs.

The highest production value at current prices was obtained in group 4 where the diet complied with the new nutrient standards in combination with a high content of soybean meal.

All diets were generally undersupplied in amino acids compared with the expected content: the feed in groups 3, 4 and 5 had a lysine undersupply of 4-5% in the entire trial period, and the feed in groups 1 and 2 had a lysine undersupply of 1%. Based on previous studies and model calculations, this deficiency has likely caused daily gain to drop by 9 g and impaired the feed conversion ratio by 0.02 FUgp/kg gain compared with groups 1 and 2.

The pigs in groups 3 and 4 had a significantly poorer feed conversion compared with the pigs in group 2 (positive control), but this is probably attributed to the amino acid deficiency. It cannot be ruled out that the amino acid deficiency in particular in group 5 widened the gap to the other groups.

Results showed no differences in treatments for diarrhoea and productivity between groups 3 and 4 given soy protein concentrate and soybean meal, respectively, in the feed.

No interaction was found between pigs' start weight and the feeding strategies in terms of productivity or diarrhoea. Significantly fewer of the small pigs were treated for diarrhoea compared with the large pigs, which indicates that small pigs (approx. 6.0 kg) were no more predisposed to diarrhoea than large pigs.

In the finisher period, analyses showed no differences in daily gain or diarrhoea regardless of zinc strategy, ie. there is no evidence of a long-term effect of medicinal zinc on growth.

Background

The EU Commission has decided to terminate the use of zinc for therapeutical purposes (medicinal zinc) by June 2022, at the latest. Multiple studies have confirmed the positive effect of medicinal zinc on diarrhoea, and it is a concern that this ban will lead to an increase in diarrhoea outbreaks and – unless efficient alternatives are developed – to an increase in antibiotic use.

A low protein content is among the measures with the greatest impact on post-weaning diarrhoea; several national and international studies have found a positive effect of low-protein feed on diarrhoea. High-protein feed increases undigested protein in the colon where the undigested protein is fermented. This produces ammonia and toxic nitrogen compounds that damage the gut. Consequently, less 'excess protein' will help overcome this problem.

A comprehensive study made by SEGES Pig Research Centre [1] demonstrated that a low-protein (18%) diet the first four weeks post-weaning led to a 65% drop in diarrhoea outbreaks compared with a high-protein (21%) diet, but this also reduced productivity. In this current trial, the weaned pigs were given medicinal zinc for two weeks, and it is expected that the effect of a low-protein diet – in particular in the first two weeks post-weaning – will be increased when the use of medicinal zinc is terminated.

In another study, the effect of a high (21%) vs low (18%) protein diet the first three weeks post-weaning was combined with the effect of expensive (high digestible, expensive ingredients) vs cheap (low digestible, cheap ingredients) weaning feed in two herds [2]. The greatest effect on diarrhoea was achieved by lowering the protein content, whereas the use of expensive ingredients had no effect. In this study, too, productivity was negatively affected by the low protein content.

A low-protein diet will lead to a deficiency in the most limiting amino acids and thereby a lower productivity. Nowadays, it is possible to add the first five limiting amino acids as free-form amino acids thereby limiting the negative effect on productivity of a low protein content.

An international study [3] where protein content was lowered from 21% to 18% and combined with the addition of free-form amino acids (the most common) revealed an effect on diarrhoea, but as the pigs' need for amino acids was met, productivity was not negatively affected.

It may be necessary to go below 18% protein (approx. 140 g digestible protein per feed unit) to affect diarrhoea and that may compromise the amino acid requirement. As post-weaning diarrhoea is typically observed 6-8 days post-weaning, it is possible that a low-protein diet is only necessary for the first 10-14 days post-weaning when feed intake and growth are low anyway, and to compensate the protein content can then subsequently be increased.

There is evidence that low-protein feed makes pigs less sensitive to diarrhoea-inducing pathogens compared with high-protein feed [4], but this has mainly been investigated in the period 2-3 weeks post-weaning.

Trials made at SEGES Grønhøj trial station have repeatedly confirmed that the majority of all treatments against diarrhoea (and thereby the highest antibiotic use) take place in the period 20-25 days post-weaning. As a result, it is relevant to establish the effect of protein supply in this period also. Once the risk of post-weaning diarrhoea has passed, the amino acid profile can be raised to compensate for the preceding productivity loss. Several national and international studies have found that an increase in protein after the risk period improves productivity, but a small drop in daily gain and feed conversion must be expected from the low-protein strategy [1], [3]. Even a limited negative affect on gain can be a challenge in many Danish herds with a high stocking density in the weaning pens, and an additional 1-2 days in the weaning unit will only make this situation worse.

In 2019, a study [5] revealed a 30% reduction in diarrhoea treatments in the 6-30 kg period when pigs were fed a low-protein diet the first four weeks post-weaning compared with zinc-free feed. In comparison, treatments for diarrhoea dropped by approx. 50% in pigs given medicinal zinc compared with the pigs given no zinc. Even though the synthetic amino acids added to the feed largely matched the standard (6% below), the low-protein supply resulted in a drop in gain and a poorer feed conversion, as the amino acids that are not added in pure form limit productivity. By increasing the protein supply in the period following 15-30 kg period by 5% above the standard, the pigs performed nearly as well as the pigs fed according to the standards, but with an increase in treatment frequency in this period.

In the 2019 study, it was attempted to reduce protein content as cheaply as possible by limiting the use of expensive protein sources such as fishmeal and potato protein concentrate, while keeping soybean meal content relatively high in all three phases (6-9, 9-15 and 15-30 kg). This strategy was based on findings from another study with different soy products that demonstrated no differences in productivity and diarrhoea between various products [6].

Following the 2019 revision of the amino acid profiles for weaner feed, it is relevant to analyse whether the same effect will be found if protein is reduced while maintaining the expensive ingredients in the diets and lowering the soy products in the 'low-protein diets'. It is also relevant to investigate whether protein in phases 1 and 2 can be lowered further by adding additional amino acids (isoleucine, leucine, histidine, phenylalanine and tyrosine) to determine whether this may limit the production losses caused by low-protein feed.

The aim of this current trial was to affect diarrhoea outbreaks and thereby antibiotic use by using low-protein feed. Different protein strategies were compared with a positive and a negative control group (+/- medicinal zinc) to determine the effect on diarrhoea and to establish which strategies have minimum impact on productivity.

Materials and methods

Transfer of pigs and trial design

The trial was conducted at SEGES Pig Research Centre’s trial station Grønhøj (health status: blue SPF). The trial comprised approx. 5,000 pigs assigned to five groups. Pigs were delivered weekly to Grønhøj from the same batches at a weight of 5.5-9.0 kg and finished in the trial at approx. 30 kg.

Upon arrival, the pigs were sorted according to gender and weight to obtain identical distribution of female pigs and castrates. Average start weight varied by max 0.25 kg between pens in a batch. All pigs were vaccinated against PCV2 with 0.5 ml Circovac at transfer to Grønhøj.

Diarrhoea treatments constituted the primary parameter. The trial was designed to identify a drop in treatments for diarrhoea, which often requires more replicates than identifying the effect on, for instance, daily gain. One block (replicate) was constituted by six pens accommodating either 10 or 15 pigs (depending on the sections), and the trial comprised 75 replicates in groups 1 and 3-5 and 148 replicates in the negative control group (group 2), ie. each replicate included two ’group 2 pens’. This design was selected over an ‘all vs all’ design that would generate ten pair-wise comparisons and require more replicates. When group 2 is tested against the other groups, this group must be determined more accurately, and this is done by including group 2 in more replicates. Production traits, however, were subject to an ‘all vs all’ comparison.

The pigs were fed ad lib by a computerised Spotmix feeding system, and there was one dry feeder and one nipple drinker per pen. Pen partitions were closed to minimise faecal contamination between pens.

Trial design and diets

All feed was produced by Danish Agro and delivered as pellets. The pigs were fed three diets matching their weight: phase 1 (approx. 6-9 kg); phase 2 (approx. 9-15 kg) and phase 3 (approx. 15-30 kg).

In the 6-9 kg period (phase 1), the pigs were given control feed containing either 2,500 (positive control) or 0 mg medicinal zinc (negative control) or one of the three trial diets with no zinc (protein strategies). The trial design is shown in table 1. The only difference between the diets in groups 1 and 2 was the addition of medicinal zinc in group 1 in phase 1.

Table 1. Trial design – lysine and protein levels.

Group	**1**	**2**	**3**	**4**	**5**
	Pos. control 'Old' standard	Neg. control 'Old' standard	Low protein Soy prot. conc. New stand.	Low protein Soybean meal New stand.	Very low prot. Extra amino acids
Zinc	+	-	-	-	-
Phase 1: 6-9 kg					
Protein[1)]	145	145	133	133	115
Lysine[2)]	10.6	10.6	10.5	10.5	10.5
Phase 2: 9-15 kg					
Protein[1)]	146	146	134	134	115
Lysine[2)]	10.6	10.6	10.5	10.5	10.5
Phase: 15-30 kg					
Protein[1)]	149	149	149	149	149
Lysine[2)]	10.6	10.6	11.0	11.0	11.0

[1)] Protein = gram digestible crude protein per feed unit

[2)] Lysine = gram digestible lysine per feed unit; Though only lysine is shown in the table, methionine, threonine, tryptophan and valine are also added in standard doses.

Protein strategies

The supply of protein and amino acids was largely identical in all three phases in groups 1 and 2 and followed the amino acid standards before May 2019 [7] – only ingredients differed in the three diets.

In the feed for groups 3 and 4, protein and amino acid profiles were based on the amino acid standards of May 2019, when the inclusion of protein-bound amino acids (such as isoleucine, leucine, histidine etc.) was lowered by 10%. This resulted in a lower protein content, but a largely identical content of the added amino acids. This is seen in particular in the feed for phase 3, where protein in the feed for groups 3, 4 and 5 was level with that in groups 1 and 2, but where the content of added amino acids was higher.

The feed in groups 3 and 4 differed in content of soy products: in group 3, the feed contained a soy protein product (ViloSoy) and in group 4 the feed contained soybean meal in the same amounts as the feed in groups 1 and 2 (see appendix 1).

In group 5, the feed for phases 1 and 2 in group 5 had a very low protein content, but to minimise the production loss, more amino acids, supplied by Evonik, were added (isoleucine, leucine, histidine, phenylalanine and tyrosine, which are very expensive and therefore not commonly used).

All diets included benzoic acid, which inhibits the microbial activity and thereby diarrhoea, and calcium formate, which lowers the acid binding capacity of the feed and is known to improve productivity.

The effect of medicinal zinc and low-protein feed was studied in combination with common additives known to affect post-weaning diarrhoea.

The pigs were fed ad lib and had access to feed 24 hours a day.

The pigs gradually switched to phase 2 feed after approx. 11 days (about 9 kg), when they were weighed, and were fed phase 2 feed exclusively by day 14. From this point, no pigs were given medicinal zinc. When the pigs weighed approx. 15 kg, they gradually switched to phase 3 feed over three days, which was fed in the 15-30 kg period.

Prior to weighing of the pigs, the amount of feed used was routinely recorded.

Analyses of feed

Representative samples of the feed samples were collected at the feedmilll according to the TOS principles. Diets were produced over three rounds, and during each round three samples of each diet were forwarded to Eurofins Steins Laboratory A/S for analysis of energy, protein, calcium, phosphorus, zinc, copper and amino acids.

Recordings

Productivity

All recordings were made at pen level and analysed for each of the three periods: phase 1 from transfer to day 11 after transfer (8.3 kg), phase 2 from day 11 to 30 after transfer (approx. 15 kg) and phase 3 from roughly day 30 to day 48 after transfer (approx. 30 kg), and for the entire period (transfer to 30 kg). Recordings included daily gain, feed intake and feed conversion ratio.

Treatments for disease

Treatments for diarrhoea were recorded as primary parameter and mortality and pigs moved to hospital pens were recorded as secondary parameter. The first two clinically ill pigs in a pen were treated for diarrhoea individually; when it was estimated that more than two pigs in a pen suffered from diarrhoea, the entire pen was medicated via the feed. Section-wise treatments were not practised.

Pigs were treated individually for three days, and flock treatments lasted five days. Treatments for diarrhoea were administered by the staff according to guidelines issued by the herd vet when the following symptoms were observed: dirty hindpart around rectum, sunken eyes, hollow flanks and depression.

All pigs were treated with the same type of antibiotic.

Disease treatments were determined as per cent pens treated and as treatments for diarrhoea per feeding day. Prophylactic treatments with antibiotics against diarrhoea were not practised.

Statistical analyses

Treatment frequency (% flock-treated pens / diarrhoea treatments per feeding day) were subject to analysis in a logistic regression model with group as systematic effect, weight at transfer as covariate, and block as random effect. In these models, all groups were compared with group 2 with no correction made for pairwise comparisons. Consequently, significantly more replicates were made in group 2, as group 2 functioned as control in the four analyses.

The productivity parameters (gain, feed intake, feed conversion ratio and production value) were subject to analysis in a linear mixed model with group as systematic effect, weight at transfer as covariate and block as random effect. All groups were compared with each other, and correction was made for ten pair-wise comparisons using the Bonferroni correction.

Prerequisites for calculation of the production value

The production value (PV) per pig place/day for the entire weaner period was calculated as described below:

Production value in DKK per pig place/day = (value of gain – feed costs) / feeding days.

The calculation included identical feed prices for all groups (5 years prices, September 2014 – September 2019) and the value of 1 kg gain:

Average pig price for 7 kg pigs of DKK 208 per pig ± DKK 10.26 per kg (7-9 kg), ± DKK 7.95 per kg (9-12 kg) and ± DKK 6.22 per kg (12-25 kg).

Average pig price for 30 kg pigs of DKK 362 per pig, kg adjustments of DKK -5.56 per kg (25-30 kg) and DKK +5.58 per kg (30-40 kg).

Weaner feed (7-10 kg): DKK 3.43 per feed unit and (10-30 kg): DKK 1.91 per feed unit, applied in all groups.

Definition of variables:
Value of gain = pig gain, kg, in the trial period x value of 1 kg gain (DKK 6.85 for the entire period).

Feed costs were determined using the below equation and is based on the analysed feed units of the basic diets (EDOMi[1] analyses) and the amount actually used of each basic diet per pen:

Feed costs = (end weight – start weight) x FUgp per kg gain x DKK per FUgp
Feeding days = the number of days a pig was in the trial.

Results and discussion

Analyses of feed

The result of the feed analyses is shown in appendix 2. The results are the average of nine samples as three samples were taken per diet per delivery and feed was delivered three times during the trial.

Overall, all diets contained 1-3% more energy than expected and as a result the content of digestible amino acids per feed unit was lower than expected. Protein content was also 1-3% lower than expected, and consequently the content of lysine, threonine and valine was generally 2-6% below the expected. Analyses revealed a methionine + cystine undersupply of 8-12%.

Analyses revealed a 5-12% undersupply of protein-bound amino acids (isoleucine, leucine, histidine etc.). This undersupply was greater in the feed in group 5 where protein levels were very low in phases 1 and 2, though these amino acids were added in pure form to the feed in this group.

Analyses covering the entire trial period revealed a 4-5% undersupply in the diets in groups 3, 4 and 5 vs 1% in the diets for groups 1 and 2.

The analysis results presented in appendix 2 all originate from Eurofins Steins Laboratory A/S. Samples were also submitted to Evonik (results not shown) and the results from the two laboratories generally agree, though Evonik generally found 0-5% more than Eurofins Steins Laboratory A/S for most amino acids. However, Evonik analyses retrieved 5-6% more valine and 7-8% more isoleucine compared with Eurofins Steins Laboratory A/S.

Treatments for diarrhoea

Table 2 shows treatments diarrhoea and dead/culled pigs. Statistical analysis was only applied for comparison of all groups with group 2 (no zinc), and not for all vs all comparison.

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[1] Enzyme Digestible Organic Matter ileum

Treatments for diarrhoea were analysed as per cent flock-treated pens and as number of treatment days per pig.

In the 6-30 kg period, there were significantly fewer flock-treated pens in group 1 (medicinal zinc) than in group 2 (no medicinal zinc). Analyses did not find significantly fewer flock-treatments in groups 3 and 4 (low protein) than in group 2. There were significantly fewer flock-treatments in group 5 with very low protein content in phases 1 and 2. Flock-treated pens were analysed as number of flock-treated pens, ie. flock-treatment of a pen only counts once, even though the procedure is repeated. This analysis shows the number of pens in which the pigs were so sick that flock-treatment was necessary.

Table 2 also shows the number of diarrhoea treatments per feeding day and the number of treatment days per pig. There were significantly fewer treatments days per pig in the entire growth period in group 1 (43%) given medicinal zinc compared with group 2. Treatments per pig were not significantly lower in groups 3 and 4, but in group 5 treatment days dropped by 63%, which is significant. This provides a better impression of the total number of treatments and thereby the antibiotic use.

Slightly more pigs were culled in group 2 (no medicinal zinc) than in the other groups, but mortality did not differ.

Table 2. Treatment frequency and dead/culled pigs, 6-30 kg

Group	1	2	3	4	5
	Pos. control 'Old' standard	Neg. control 'Old' standard	Low protein Soy prot conc New standard	Low protein Soybean meal New stand	Very low protein Extra amino acids
Pens	75	148	75	75	75
Flock-treated pens, %*	31.8^{b}	53.5^{a}	49.3^{a}	41.3^{a}	21.1^{b}
Diarrhoea, treatments per feeding day *	0.06^{b}	0.10^{a}	0.09^{a}	0.08^{a}	0.03^{b}
Treatment days per pig**	2.6^{b}	4.6^{a}	4.3^{a}	3.7^{a}	1.7^{b}
Treatment days, reduction compared with group 2, %	43	-	7	20	63
Culled and dead, %	4.5^{ab}	5.5^{a}	3.2^{b}	3.5^{b}	3.5^{b}
Of these dead, %	1.0	1.0	0.6	1.0	0.5

*Different superscripts (a,b) indicate significant (P-value <0.05) difference from group 2

**Estimate based on number of pigs at transfer and first and second weighings

In the 6-9 kg period, the number of flock-treatments was generally low, with most treatments found in group 2 (figure 1). In the 9-15 kg period, this increased significantly in all groups, and particularly in group 2. The lowest number of flock-treatments was found in group 1, where pigs were given medicinal zinc in phase 1, and in group 5 where protein levels were very low. In the 15-30 kg period, the curves evened and settled stably for each group.

Figure 2 presents the total number of treatments per pig per feeding day, including individual treatments and flock-treatments. The curves reveal a fairly low occurrence of diarrhoea in the 6-9 kg period followed by a large wave around day 18-25. In all groups, the number of daily treatments increased after day 15, but the increase in group 5 is distinctly less steep than in the other groups.

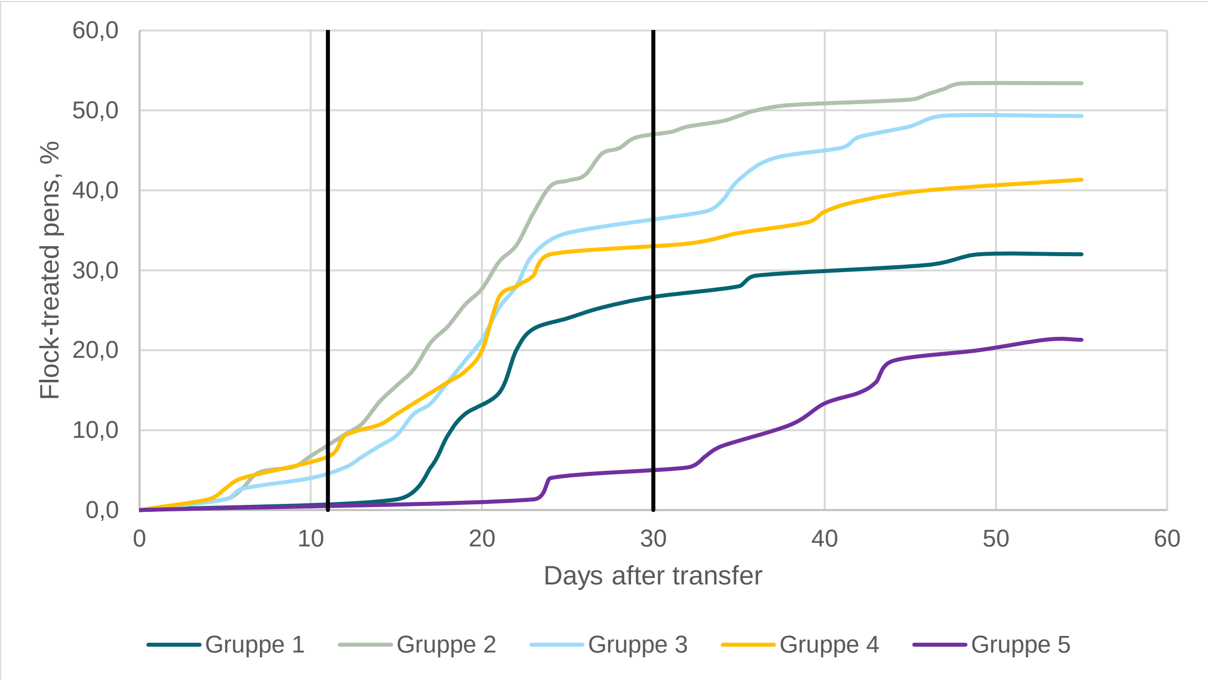

Figure 1: Cumulated percentage of flock-treated pens from days after transfer of pigs. Vertical lines indicate change in diet.

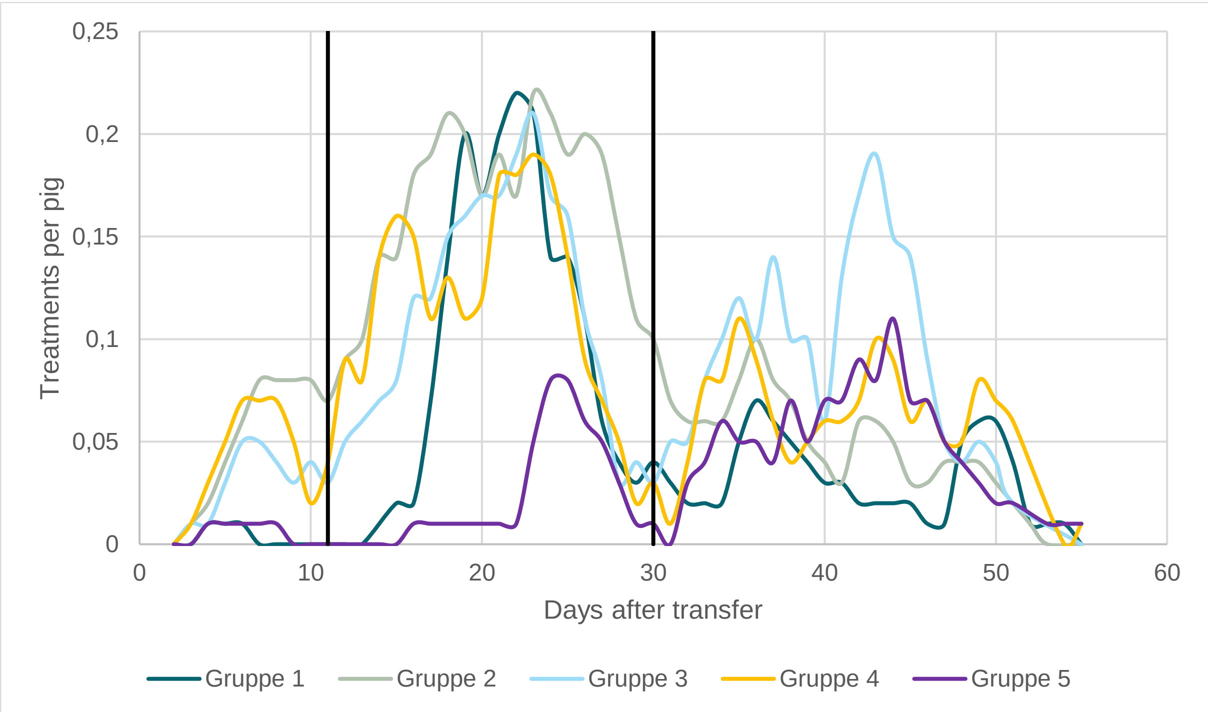

Figure 2: Average number of treatments per feeding day per pig from transfer. Vertical lines indicate change in diet.

Note that for group 1, in phase 2 when zinc was removed from the feed, analyses reveal significantly fewer treatments per pig compared with group 2 without medicinal zinc, which indicates that there may be a positive long-term effect on gut health of zinc. This was also observed in three previous trials [5], [10] and [11]. Zinc is excreted quickly from the body, but medicinal zinc may have a positive effect on the microflora composition or gut health that also lasts into the subsequent period.

Production results

The production results for the five groups (all vs all) are shown in table 3, in which different superscripts within a row indicate significant difference (P value < 0.05).

In phase 1 (transfer to 9 kg), analyses showed no differences in daily gain, feed intake and feed conversion ratio between control groups 1 and 2, ie. the pigs that were given medicinal zinc in this period performed as well as those that got 2,500 mg medicinal zinc. This was also observed in the 2019 trial [5], while other studies, [10], [11], found significantly lower gain (approx. 60 g a day) in pigs that were not given medicinal zinc in phase 1.

In phase 1, the pigs in groups 3 and 4 (low protein) had the same daily gain as the pigs in the two control groups. However, the pigs in group 3 had a significantly poorer FCR compared with the control pigs given medicinal zinc, but no differences were observed between groups 3 and 4, ie. there are no indications that the pigs given soybean meal (group 4) had a lower productivity than the pigs given soy protein concentrate (group 3) in phase 1.

The pigs in group 5 had a significantly lower gain and FCR than any of the other pigs.

In phases 1 + 2 (weaning to 15 kg), there were no differences between the pigs in groups 1-4 in terms of daily gain, but the pigs in groups 3 and 4 (low protein) had a significantly poorer FCR than the pigs in groups 1 and 2. In this period, too, the pigs in group 5 had a significantly poorer gain and FCR than the other pigs.

In the entire trial period (weaning to 30 kg), there were no differences in daily gain, feed intake and feed conversion between the pigs in the two control groups. Previous research found a significantly lower gain (approx. 20 g a day) in pigs given no medicinal zinc [10] and [11], whereas the recent 2019 trial [5] reported no differences between the two groups. The main difference between these four trials was the composition of the feed: in this trial and in the 2019 trial [5], the feed included benzoic acid and calcium formate, but it is unclear whether that affected the outcome.

The pigs in groups 3 and 4 had the same daily gain in the entire 6-30 kg period as the pigs in the control groups, but a poorer feed conversion ratio than the pigs in the positive control group. This may be attributed to the amino acid deficiency, which affects feed conversion ratio in the groups fed close to the pigs' amino acid requirements. This shows that it is crucial that the feed complies with the revised amino acid standards (May 2019) to achieve maximum productivity.

The pigs in groups 3, 4 and 5 had a 4-5% lysine undersupply vs a 1% undersupply in the pigs in groups 1 and 2 in the entire period from transfer to 30 kg. Previous studies and model calculations indicate that it is highly likely that this has led to a 9 g drop in daily gain and a drop of 0.02 FUgp/kg gain compared with groups 1 and 2. The significantly poorer feed conversion ratio observed in groups 3 and 4 compared with the positive control group is largely attributed to the abovementioned amino acid deficiency.

The pigs in group 5 had a significantly lower daily gain and feed conversion ratio in the entire period, despite the additional supply of amino acids. Unfortunately, this group suffered exceptionally from the undersupply of amino acids. Feed production logs confirm that the correct amount of amino acids was added, but this was not retrieved in the analyses. This undersupply may have vitally affected daily gain and feed conversion, particularly in this group where feed in phases 1 and 2 only included 115 g digestible protein per FUgp. However, it may also be that the very low protein content in group 5 was too low (nitrogen) to cover the pigs' need for non-essential amino acids. Consequently, the results may be triggered by a combination of inadequate supply of essential amino acids and too little nitrogen to allow the pigs to synthesize the required non-essential amino acids.

Table 3. Productivity in phase 1 (6-9 kg), phases 1+2 (6-15 kg) and in the entire trial period (6-30 kg)

Group	**1**	**2**	**3**	**4**	**5**
	Pos. control 'Old' standard	Neg. control 'Old' standard	Low protein Soy protein conc New stand.	Low protein Soybean meal New stand.	Very low protein Extra amino acids
Pens	75	148	75	75	75
Pigs at transfer	948	1866	949	948	927
Weight at transfer, kg	6.9	6.9	6.9	6.9	6.9
End weight, kg	30.7^{a}	30.7^{a}	30.8^{a}	30.7^{a}	29.2^{b}
Phase 1: 6-9 kg					
Daily gain, g/day	132^{a}	128^{a}	127^{a}	131^{a}	108^{b}
Feed intake, feed units/day	0.197^{a}	0.205^{ab}	0.212^{b}	0.216^{b}	0.209^{ab}
FCR, feed units/kg gain	1.57^{a}	1.68^{ab}	1.74^{b}	1.71^{ab}	1.99^{c}
Phases 1+2: 6-15 kg					
Daily gain, g/day	294^{a}	286^{a}	280^{a}	290^{a}	217^{b}
Feed intake, feed units/day	0.46^{ab}	0.45^{b}	0.46^{ab}	0.47^{a}	0.42^{c}
FCR, feed units/kg gain	1.59^{a}	1.59^{a}	1.65^{b}	1.63^{b}	1.95^{c}
Entire period: 6-30 kg					
Daily gain, g/day	480^{a}	477^{a}	480^{a}	482^{a}	438^{b}
Feed intake, feed units/day	0.78^{a}	0.78^{a}	0.79^{a}	0.80^{a}	0.75^{b}
FCR, feed units/kg gain	1.63^{a}	1.64^{ab}	1.65^{b}	1.66^{b}	1.71^{c}
Production value, DKK /pig/day (same feed price)	1.71^{a}	1.70^{a}	1.68^{a}	1.68^{a}	1.48^{b}
Index, same feed price 1)	101	100	99	99	87
Production value, current feed price, DKK/pig/day	1.55^{ab}	1.55^{ab}	1.51^{b}	1.58^{a}	**
Index, current feed price 2)	100	100	97	102	**

*Different superscripts (a,b,c) within a row indicate significant difference (P value 0.05)

**Current feed price for group 5 not included as the extra amino acids are currently too expensive for widespread use

1) Minimum definite difference in index (identical feed price): 3.2 index points

2) Minimum definite difference in index (current feed price): 3.0 index points

When the production results are compiled in a production value per pig (PV) using identical feed prices in all groups, table 3 reveals that there were no differences in PV between the two control groups (+/- medicinal zinc). There were no significant differences between groups 3 and 4 and the two control groups. In group 5, production value was significantly lower than in the other groups.

If based on current feed prices, the production value was significantly better in group 4, where soybean meal was the primary protein source, vs group 3, where soy protein concentrate constituted the primary protein source. If the pigs in group 4 (new standard) are compared with the pigs in group 2 (old standard), the marginally poorer feed conversion ratio in group 4 is recovered by a lower feed price, confirming that the new standard is economically optimum.

Effect of start weight

At transfer, the pigs were assigned to blocks according to weight. The data material was divided into large, medium and small pigs to determine whether transfer weight influenced the subsequent productivity and diarrhoea outbreaks. Results showed no interaction between the five groups and pigs' start weight.

There was an average difference of 1 kg between large and medium-sized pigs at transfer and a further 800 g difference down to the small pigs (table 4). The subsequent daily gain and feed intake were significantly affected by this: the large pigs gained more than the medium-sized pigs that in turn gained more than the small pigs in the entire 6-30 kg period. Feed conversion ratio, on the other hand, did not differ significantly, which corresponded with findings in previous trials such as [5]. The variation in production value between large, medium-sized and small pigs reflected the difference in daily gain, in particular.

Table 4. Productivity, the entire 6-30 kg pig according to size at transfer.

Pig size	Small	Medium	Large
Pens	144	144	160
Weight at transfer, kg	6.0	6.8	7.8
Daily gain, g/day*	451^{a}	463^{b}	491^{c}
Daily feed intake, feed units/day*	0.74^{a}	0.77^{b}	0.81^{c}
FCR, feed units/kg gain	1.65	1.67	1.66
Production value, DKK/pig/day (same feed price)	1.60^{a}	1.61^{a}	1.69c

*Different superscripts (a,b) within a row indicate significant difference (P value 0.05).

Table 5 provides an outline of the treatment frequency, flock-treatments as well as individual treatments per feeding day, for large, medium-sized and small pigs. Results showed significantly fewer flock-treatments and treatments per day in the entire 6-30 kg period among small pigs compared with large pigs, while there were no significant differences between medium-sized pigs and small/large pigs. Recordings did not include age of each pig, but pigs were delivered from the same weekly batches.

Table 5. Diarrhoea – treatment frequency in the entire 6-30 kg period according to size at transfer.

Pig size	Small	Medium	Large
Pens	144	144	160
Weight at transfer, kg	6.0	6.8	7.8
Flock-treated pens, %*	32.8^{a}	36.3^{ab}	45.4^{b}
Treatments per feeding day*	0.06^{a}	0.07^{ab}	$0,08^{b}$

*Different superscripts (a,b) within a row indicate significant difference (P value 0.05)

Effect of medicinal zinc on finisher gain

In order to test the theory that the pigs given medicinal zinc post-weaning have a lower productivity in the finisher period, 100 pigs from groups 1 and 2, respectively, were ear-tagged and weighed individually at transfer to the weaner unit, at transfer to the finisher unit and at slaughter. The results are shown in table 6.

Table 6. Daily gain and treatment frequency for selected pigs from groups 1 and 2 monitored until slaughter.

Group	1	2
Medicinal zinc the first two weeks post-weaning	Yes	No
Pigs	106	106
Daily gain, g/day (6-30 kg)	472	466
Daily gain, g/day (30-110 kg)	1,106	1,119
Daily gain, g/day (6-110 kg)	849	855
Pigs included in flock-treatments, % (all flock-treatments administered pre-30 kg)	52.2	63.1
Treatments per pig, 6-110 kg	3.5^{a}	5.3^{b}
Treatments per feeding day/pig, 6-110 kg	0.03^{a}	0.05^{b}
Treatments per feeding day/pig, 30-110 kg	0.004	0.002

*Different superscripts (a,b) within a row indicate significant difference (P value 0.05)

The fact that there were no differences in gain or treatments between the two groups in the finisher period indicates that there was not a subsequent effect of medicinal zinc on finisher gain or diarrhoea frequency.

Conclusion

Treatments for diarrhoea dropped by 43% in pigs given medicinal zinc compared with pigs that were not given medicinal zinc. The pigs in two groups (groups 3 and 4) fed low-protein feed (reduced by approx. 10 g digestible protein per feed unit) in the first four weeks post-weaning did not have significantly fewer treatment days than the pigs given no medicinal zinc. Recordings show a significant drop of 63% in treatments for diarrhoea for the pigs in group 5 given very low protein combined with extra amino acids (beyond those normally added) compared with the pigs given no medicinal zinc

There were no significant variations in production value at identical feed prices between groups 1-4, whereas the pigs in group 5 (very low protein) had a significantly lower gain, a poorer feed conversion and a lower productivity than the other pigs.

The highest production value at current prices was obtained in group 4 where the diet complied with the new nutrient standards in combination with a high content of soybean meal.

All diets were generally undersupplied in amino acids compared with the expected content: the feed in groups 3, 4 and 5 had a lysine undersupply of 4-5% in the entire trial period, and the feed in groups 1 and 2 had a lysine undersupply of 1%. Based on previous studies and model calculations, this deficiency has likely caused a 9 g drop in daily gain and a deterioration of 0.02 FUgp/kg gain compared with groups 1 and 2.

The pigs in groups 3 and 4 had a significantly poorer feed conversion compared with the pigs in group 2 (positive control), but this is probably attributed to the amino acid deficiency. It cannot be ruled out that the amino acid deficiency in particular in group 5 widened the gap to the other groups.

Results showed no differences in treatments for diarrhoea and productivity between groups 3 and 4 given soy protein concentrate and soybean meal, respectively, in the feed.

This trial confirmed that a low-protein diet is an efficient tool for reduction of diarrhoea when the feed no longer includes medicinal zinc.

No interaction was found between pigs' start weight and the feeding strategies in terms of productivity or diarrhoea. Significantly fewer of the small pigs were treated for diarrhoea compared with the large pigs, which indicates that small pigs (approx. 6.0 kg) were no more predisposed to diarrhoea than large pigs.

In the finisher period, analyses showed no differences in daily gain or diarrhoea regardless of zinc strategy, ie. there is no evidence of a long-term effect of medicinal zinc on growth.

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Participants

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Trial no. 1641

//NIRW//

Appendix 1

Composition of each diet, %

Group	1	2	3	4	5
Phase 1: 6-9 kg	Pos. control 'Old' standard	Neg. control 'Old' standard	Low prot. Exp. feed New stand.	Low prot. Cheap feed New stand.	Very prot. Exp. feed New standard
Wheat	46.6	47.7	53.0	51.7	59.4
Barley	20.0	20.0	20.0	20.0	20.0
Soybean meal	7.0	7.0	0.5	7.0	0.5
Soy protein concentrate	6.5	6.4	7.5	2.2	0
Potato protein	4.0	4.0	4.0	4.0	4.0
Fishmeal	2.0	2.0	2.0	2.0	2.0
Dried whey	6.0	6.0	6.0	6.0	6.0
Fatty acid distillates	2.4	2.1	1.7	1.9	1.2
Mono calcium phosphate	1.4	1.2	1.3	1.3	1.5
Sodium chloride	0.6	0.6	0.6	0.6	0.6
Sodium bicarbonate	0.1	0.1	0.1	0.1	0.1
Lysine sulphate 70%	0.69	0.69	0.90	0.86	1.25
Methionine 98%	0.11	0.11	0.15	0.15	0.23
Threonine 98%	0.13	0.13	0.20	0.20	0.33
Tryptophan 99%	0.05	0.05	0.07	0.07	0.12
Valine 96.5%	0.03	0.03	0.05	0.05	0.20
DA Vit fravænning	0.40	0.40	0.40	0.40	0.40
Ronozyme	0.03	0.03	0.03	0.03	0.03
Benzoic acid	0.50	0.50	0.50	0.50	0.50
Calcium formate	1.00	1.00	1.00	1.00	1.00
Microgrits Green	0.05	0	0	0	0
Microgrits Blue	0	0	0.05	0	0
Zinc oxide	0.30	0	0	0	0
Isoleucine 98.5%	0	0	0	0	0.12
Leucine 98.5%	0	0	0	0	0.22
Histidine 98.5%	0	0	0	0	0.08
Phenylalanine 98.5%	0	0	0	0	0.08
Tyrosine 98.5%	0	0	0	0	0.15
Group Phase 2: 9-15 kg	1 + 2		3	4	5
Wheat	52.1		59.1	54.9	65.4
Barley	20.0		20.0	20.0	20.0
Soybean meal	14.0		6.0	14.0	2.2
Soy protein concentrate	2.9		2.6	0.85	0
Potato protein	3.0		3.0	2.0	3.0
Fish meal	0		2.0	0	0.5
Fatty acid distillates	2.7		1.9	2.5	1.5
Feed lime	0.2		0.1	0.2	0.1
Mono calcium phosphate	1.3		1.2	1.3	1.5
Sodium chloride	0.6		0.6	0.6	0.6
Sodium bicarbonate	0.1		0.1	0.1	0.1

Lysine sulphate 70%	0.76	0.93	0.93	1.35
Methionine 98%	0.13	0.15	0.17	0.24
Threonine 98%	0.16	0.22	0.23	0.36
Tryptophan 99%	0.05	0.07	0.06	0.12
Valine 96.5%	0.05	0.07	0.08	0.23
DA Vit fravænning	0.40	0.40	0.40	0.40
Ronozyme	0.03	0.03	0.03	0.03
Benzoic acid	0.50	0.50	0.50	0.50
Calcium formate	1.00	1.00	1.00	1.00
Microgrits Green	0.05	0	0	0
Microgrits Blue	0	0.05	0	0
Isoleucine 98.5%	0	0	0	0.14
Leucine 98.5%	0	0	0	0.26
Histidine 98,5%	0	0	0	0.09
Phenylalanine 98.5%	0	0	0	0.1
Tyrosine 98.5%	0	0	0	0.17

Group Phase 3: 15-30 kg	1 + 2	3 + 4 + 5
Wheat	49.8	49.7
Barley	20.0	20.0
Soybean meal	21.0	22.5
Soy protein concentrate	2.1	0.5
Fatty acid distillates	1.9	2.0
Feed lime	1.5	1.5
Mono calcium phosphate	0.9	0.9
Sodium chloride	0.5	0.5
Sodium bicarbonate	0.1	0.1
Lysine sulphate 70%	0.72	0.81
Methionine 98%	0.14	0.16
Threonine 98%	0.17	0.21
Tryptophan 99%	0.03	0.04
Valine 96.5%	0.06	0.09
DA Vit fravænning	0.40	0.40
Ronozyme	0.03	0.03
Benzoic acid	0.50	0.50
Microgrits Green	0.05	0
Microgrits Blue	0	0.05

Appendix 2

Phase 1: 6-9 kg. Average nutrient content (3 batches, 3 samples from each).
E = Expected, AN = Analysed, Eurofins Steins Laboratory A/S.
Digestible amino acid per FUgp is based on analysed amino acid values and the digestibility coefficient included in the feed formulation.

Group: 6-9 kg	1		2		3		4		5	
	E	AN	E	AN	E	AN	E	AN	E	AN
Feed units/kg	1.16	1.17	1.16	1.18	1.16	1.19	1.16	1.19	1.16	1.19
g crude protein/kg	191.6	187.9	191.9	188.4	176.3	176.0	176.5	175.9	153.5	155.3
g dig. crude protein/FUgp	144.8	140.4	144.9	139.9	132.9	129.5	133.0	129.4	115.8	114.2
g lysine/kg	13.7	12.9	13.7	13.6	13.5	13.2	13.4	13.2	13.2	13.0
g dig. lysine/FUgp	10.6	9.9	10.6	10.4	10.5	10.0	10.5	10.1	10.5	10.1
g threonine/kg	8.7	8.3	8.7	8.5	8.6	8.3	8.6	8.5	8.5	8.2
g dig. threonine/FUgp	6.5	6.2	6.5	6.3	6.5	6.2	6.5	6.3	6.5	6.2
g methionine/kg	4.3	4.2	4.3	4.3	4.5	4.2	4.5	4.3	4.8	4.5
g dig. methionine/FUgp	3.5	3.3	3.5	3.3	3.6	3.3	3.6	3.4	3.9	3.6
g valine/kg	9.2	9.4	9.2	9.4	8.5	8.7	8.6	8.9	8.6	8.6
g dig. valine/FUgp	6.8	6.9	6,.8	6.9	6.3	6.3	6.4	6.4	6.5	6.3
g histidine/kg	4.5	4.1	4.5	4.2	4.0	3.8	4.0	3.8	4.0	3.7
g dig. histidine/FUgp	3.4	3.1	3.4	3.1	3.0	2.8	3.0	2.8	3.0	2.7
g phenylalanine/kg	9.3	9.1	9.3	9.2	8.4	8.4	8.4	8.4	7.5	7.3
g dig phenylalanine/FUgp	7.2	6.9	7.2	6.9	6.4	6.3	6.4	6.3	5.7	5.4
g isoleucine/kg	7.9	7.3	7.9	7.4	7.0	6.7	7.0	6.8	6.6	6.1
g dig. isoleucine/FUgp	6.0	5.5	6.0	5.5	5.3	4.9	5.3	4.9	5.0	4.5
g leucine/kg	14.4	13.7	14.4	13.9	12.9	12.6	13.0	12.8	12.5	12.0
g dig. leucine/FUgp	11.0	10.4	11.0	10.4	9.8	9.4	9.8	9.5	9.5	9.0
g met-cys/kg	7.6	7.1	7.6	7.2	7.6	6.9	7.5	7.1	7.5	6.9
g dig. met-cys/FUgp	5.7	5.3	5.7	5.3	5.7	5.1	5.7	5.3	5.8	5.2
g calcium/kg	7.5	7.5	7.1	8.0	7.1	7.3	7.1	7.1	7.1	7.3
g phosphorus/kg	6.4	6.5	5.9	6.0	5.9	6.1	5.1	5.0	5.9	6.1
g dig. phosphorus g/FUgp	3.6	3.6	3.3	3.3	3.3	3.,	3.3	3.3	3.3	3.3
Zinc, mg/kg[1]	2500	2740	100	140	100	138	100	166	100	267
Copper, mg/kg[1]	140	115	140	125	140	125	140	122	140	114

[1] For zinc and copper: E = amount added, AN = analysed content incl. natural content.

Phase 2: 9-15 kg. Average nutrient content (3 batches, 3 samples from each).
E = Expected, AN = Analysed, Eurofins Steins Laboratory A/S.
Digestible amino acid per FUgp is based on analysed amino acid values and the digestibility coefficient included in the feed formulation.

Group: 9-15 kg	**1 + 2**		**3**		**4**		**5**	
	E	AN	E	AN	E	AN	E	AN
Feed units/kg	1.14	1.17	1.14	1.17	1.14	1.16	1.14	1.17
g crude protein/kg	188.9	187.2	174.3	176.0	175.9	176.1	150.5	151.4
g dig. crude protein/FUgp	144.8	140.5	133.5	131.6	134.7	132.6	115.3	113.2
g lysine/kg	13.4	13.3	13.2	13.5	13.4	13.1	12.9	13.0
g dig. lysine/FUgp	10.6	10.3	10.5	10.6	10.5	10.5	10.5	10.3
g threonine/kg	8.5	8.4	8.4	8.5	8.6	8.4	8.3	7.9
g dig. threonine/FUgp	6.5	6.3	6.5	6.4	6.5	6.3	6.5	6.1
g methionine/kg	4.2	4.0	4.4	4.2	4.3	4.0	4.7	4.4
g dig. methionine/FUgp	3.4	3.2	3.6	3.4	3.5	3.2	3.8	3.5
g valine/kg	9.1	9.3	8.6	8.7	8.5	8.7	8.5	8.4
g dig. valine/FUgp	6.9	6.9	6.5	6.4	6.4	6.5	6.5	6.3
g histidine/kg	4.5	4.3	4.0	3.9	4.1	4.0	3.9	3.6
g dig. histidine/FUgp	3.4	3.2	3.0	2.9	3.1	3.0	3.0	2.7
g phenylalanine/kg	9.2	9.1	8.1	8.4	8.3	8.3	7.4	7.3
g dig. phenylalanine/FUgp	7.1	7.0	6.3	6.3	6.4	6.3	5.7	5.5
g isoleucine/kg	7.5	7.3	6.7	6.7	6.7	6.6	6.5	6.2
g dig. isoleucine/FUgp	5.8	5.4	5.1	5.0	5.1	4.9	5.0	4.7
g leucine/kg	13.9	13.6	12.5	12.6	12.5	12.3	12.3	11.9
g dig. leucine/FUgp	10.7	10.2	9.8	9.4	9.4	9.3	9.5	9.0
g met-cys/kg	7.5	7.0	7.5	7.1	7.5	6.8	7.5	6.8
g dig. met-cys/FUgp	5.8	5.3	5.8	5.3	5.8	5.2	5.9	5.2
g calcium/kg	6.9	8.0	6.9	7.7	6.9	7.8	6.9	7.8
g phosphorus/kg	5.8	6.1	5.8	6.1	5.9	6.1	5.9	6.2
g dig. phospforus g/FUgp	3.3	3.4	3.3	3.4	3.3	3.4	3.3	3.4
Zinc, mg/kg[1]	100	139	100	138	100	132	100	130
Copper, mg/kg[1]	140	93	140	96	140	88	140	71

[1] For zinc and copper: E = amount added, AN = analysed content incl. natural content.

Phase 3: 15-30 kg. Average nutrient content (3 batches, 3 samples from each).
E = Expected, AN = Analysed, Eurofins Steins Laboratory A/S.
Digestible amino acid per FUgp is based on analysed amino acid values and the digestibility coefficient included in the feed formulation.

Group, 15-30 kg	1 + 2		3 + 4 + 5	
	E	AN	E	AN
Feed units/kg	1.11	1.13	1.11	1.13
g crude protein/kg	190.9	190.6	190.6	190.0
g dig. crude protein/FUgp	150.5	147.5	150.3	147.3
g lysine/kg	13.0	13.2	13.4	12.8
g dig. lysine/FUgp	10.6	10.6	11.0	10.3
g threonine/kg	8.3	8.0	8.6	8.1
g dig. threonine/FUgp	6.5	6.2	6.8	6.3
g methionine/kg	4.1	4.0	4.2	3.8
g dig. methionine/FUgp	3.4	3.3	3.5	3.2
g valine/kg	8.8	9.0	8.9	9.1
g dig. valine/FUgp	6.8	6.9	6.9	7.0
g histidine/kg	4.6	4.3	4.6	4.4
g dig. histidine/FUgp	3.7	3.3	3.6	3.4
g phenylalanine/kg	9.0	6.6	8.9	8.7
g dig. phenylalanine/FUgp	7.2	6.8	7.1	6.9
g isoleucine/kg	7.3	6.9	7.2	7.0
g dig. isoleucine/FUgp	5.8	5.4	5.7	5.4
g leucine/kg	13.4	12.7	13.3	12.8
g dig. leucine/FUgp	10.6	9.9	10.5	10.0
g met-cys/kg	7.5	7.0	7.5	6.9
g dig. met-cys/FUgp	6.0	5.5	6.0	5.4
g calcium/kg	8.4	8.8	8.4	8.6
g phosphorus/kg	5.2	5.4	5.2	5.4
g dig. phosphorus g/FUgp	3.0	3.1	3.0	3.1
Zinc, mg/kg[1]	100	144	100	135
Cobber, mg/kg[1]	80	74	80	65

[1] For zinc and copper: E = amount added, AN = analysed content incl. natural content.

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