

Recent Advances in Amino Acid Nutrition

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Ideal Amino Acid Profile for Growing Pigs

% of Lys, in SID	6 to 25 kg LW	25 to 60 kg LW	60 to 115 kg LW
Thr:Lys	65	67	68
Trp:Lys	22	20	19
Met+Cys:Lys	60	60	60
Val:Lys	70	>65	>65
Ile:Lys	53	53	53
Leu:Lys	100	100	100
His:Lys	32	32	32
Phe+Tyr:Lys	95	95	95

Ideal Amino Acid Profile for Lactating Sows

% of Lys, in SID	
Thr:Lys	>70
Trp:Lys	24
Met+Cys:Lys	60
Val:Lys	>85
Ile:Lys	55

SID: Standardized Ileal Digestible.
LW: Live Weight



Ideal Amino Acid Profile for Broilers

% of Lys, in TD	0-42 days of age
Met+Cys:Lys	75
Thr:Lys	65
Val:Lys	80
Arg:Lys	105
Ile:Lys	67
Trp:Lys	17
Leu:Lys	105
His:Lys	40
Phe+Tyr:Lys	105

Ideal Amino Acid Profile for Laying Hens

% of Lys, in TD	
Met+Cys:Lys	85
Thr:Lys	70
Val:Lys	90
Arg:Lys	110
Ile:Lys	80
Trp:Lys	24

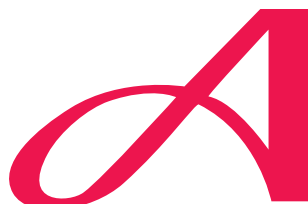
TD: True Digestible.

Recent Advances in Amino Acid Nutrition

Experimental findings are essential to the feed industry to design more efficient formulas and to face the challenges of economy, health and environment. Spurred on by the availability of new feed-use amino acids produced by Ajinomoto Eurolysine s.a.s., significant advances have been made in the field of animal nitrogen nutrition, leading to drastic changes of formulation practices. The Ideal Amino Acid Profiles recommended by AEL (see tables) are therefore based on experimental data, some of which are presented here. These profiles are used to make choices for optimal amino acid nutrition and to achieve better technical and economic performances.

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Piglet Feeds: Towards Amino Acid Precise Nutrition

Since 2009, a breakthrough in amino acid nutrition in piglets has been achieved with the availability of L-Valine. This has been made possible by Ajinomoto Eurolysine s.a.s., first company worldwide to produce L-Valine for feed use. Feed use amino acids allow the essential amino acid needs of piglets to be met with a high degree of precision, and the dietary crude protein content can be reduced safely. It becomes technically possible to formulate piglet diets in which seven amino acids are co-limiting for performance. The experimental program is therefore focused on refining with accuracy the piglet's response to the amino acids supply.

Tryptophan

Estimation of the tryptophan requirement in piglets by meta-analysis

A. Simongiovanni¹, E. Corrent¹, N. Le Floc^{h2,3} and J. van Milgen^{2,3}

¹ Ajinomoto Eurolysine s.a.s., 153 rue de Courcelles, F-75817 Paris cedex 17, France;

² INRA, UMR1079 Systèmes d'Elevage Nutrition Animale et Humaine, F-35590 Saint-Gilles, France;

³ Agrocampus Ouest, UMR1079 Systèmes d'Elevage Nutrition Animale et Humaine, F-35000 Rennes, France.

A meta-analysis was performed to estimate the SID Trp:Lys ratio that maximizes performance of weaned piglets between 7 and 25 kg of BW. A database comprising 130 experiments on the Trp requirement in piglets was established. The nutritional values of the diets were calculated from the composition of feed ingredients. Among all experiments, 37 experiments were selected to be used in the meta-analysis because they were designed to express the Trp

requirement relative to Lys (e.g. Lys was the second-limiting amino acid in the diet) while testing at least three levels of Trp. The linear-plateau (LP), curvilinear-plateau (CLP) and asymptotic (ASY) models were tested to estimate the SID Trp:Lys requirement using average daily gain (ADG), average daily feed intake (ADFI) and gain-to-feed ratio (G:F) as response criteria. A multiplicative trial effect was included in the models on the plateau value, assuming that the experimental conditions affected only this parameter and not the requirement or the shape of the response to Trp. Model choice appeared to have an important impact on the estimated requirement. Using

ADG and ADFI as response criteria, the SID Trp:Lys requirement was estimated at 17% with the LP model, at 22% with the CLP model and at 26% with the ASY model. Requirement estimates were slightly lower when G:F was used as response criterion. The Trp requirement was not affected by the composition of the diet (corn v. a mixture of cereals). The CLP model appeared to be the best-adapted model to describe the response curve of a population. This model predicted that increasing the SID Trp:Lys ratio from 17% to 22% resulted in an increase in ADG by 8%.

The first published work of meta-analysis about the Trp requirement in piglet. It confirms the ratio of 22% SID Trp:Lys to maximize piglet performance and to take advantage of the numerous biological functions of Tryptophan.

Animal. 2012. 6:4:594–602

Tryptophan

The effect of diet composition on tryptophan requirement of young piglets

A. J. M. Jansman¹, J. Th. M. van Diepen¹, and D. Melchior²

¹ Animal Sciences Group, Wageningen University and Research Centre, PO Box 65, 8200 AB Lelystad, the Netherlands;

² Ajinomoto Eurolysine s.a.s., 153, Rue de Courcelles, 75817 Paris, France.

The aim of the study was to evaluate the requirement for Trp in relation to diet composition in piglets in the period after weaning (BW range of 9 to 24 kg). Two Trp- deficient [relative to the Dutch (CVB, 1996) and NRC (NRC, 1998) requirement values for piglets of 10 to 20 kg of BW] basal diets were formulated: one based on corn and soybean meal and a second one based on wheat, barley, soybean meal, peas, and whey powder

[1.0 g/kg of apparent ileal digestible (AID) Lys; 1.4 g/kg of AID Trp; 1.5 g/kg of standardized ileal digestible (SID) Trp]. Both basal diets were supplemented with 0.3, 0.6, and 0.9 g of L-Trp per kg of diet to obtain diets with 1.7, 2.0, and 2.3 g of AID Trp per kg (1.8, 2.1, and 2.4 g of SID Trp per kg), respectively. Each of the 8 treatments was evaluated in 8 replicates (pens with 8 male or female piglets). Average daily feed intake, ADG, and G:F were measured as response criteria.

Over the 28-d experimental period, ADG and G:F were greater for the treatments on the wheat/barley diet compared with those on the corn/soybean meal and were increased by the level of Trp in the diet ($P < 0.05$).

Average daily feed intake was only increased by the level of Trp supplementation ($P < 0.05$). Increasing the Trp level increased ADFI for the corn/soybean meal diet up to 2.3 g of AID Trp per kg (2.4 g of SID Trp per kg) and up to 2.0 g of AID Trp per kg (2.1 g of SID Trp per kg) in the wheat/barley diet ($P < 0.05$). For both diet types supplementation of free L-Trp increased the G:F up to 1.7 g of AID Trp per kg (1.8 g of SID Trp per kg). Nonlinear regression analysis of the response curves for ADFI using an exponential model for estimating a requirement value for Trp (defined as the Trp level resulting in 95% of the maximum response) revealed a requirement estimate of 2.3 g of AID Trp per kg for the corn/soybean meal based diet and 2.1 g of AID Trp per kg for the wheat/barley-based diet, equivalent to 2.4 and 2.2 g of SID Trp per kg of diet, respectively. For ADG, a requirement estimate of 2.1 g of AID Trp per kg for both types of diets was derived, equivalent to 2.2 g of SID Trp per kg of diet. The Trp requirement for young piglets seems to be greater than indicated by some commonly used recommendations and does not seem largely dependent on diet ingredient composition.

Using digestible amino acid values and a net energy based system, this study shows that whatever are the ingredients used (wheat or corn based diets) the response to Trp and the Trp requirement are unchanged with a need of 22% SID Trp:Lys for piglets' growth.

Journal of Animal Science. 2010. 88:1017–1027

Tryptophan

Supplementary tryptophan downregulates the expression of genes induced by the gut microbiota in healthy weaned pigs susceptible to enterotoxigenic *Escherichia coli* F4

P. Trevisi¹, E. Corrent², S. Messori¹, S. Formica³, D. Priori¹, P. Bosi¹

¹ DIPROVAL, University of Bologna, 42123 Reggio Emilia, Italy;

² Ajinomoto Eurolysine s.a.s., 75017 Paris, France;

³ Interdepartmental Centre for Cancer Research 'G. Prodi', University of Bologna, 40123 Bologna, Italy.

Supplementary L-Tryptophan (L-Trp) limits the decrease of feed intake and growth in Enterotoxigenic *Escherichia coli* F4 (ETEC) susceptible pigs upon oral challenge with this pathogen. Susceptibility to ETEC is genetically controlled and related to the presence of receptors for the F4 fimbriae (F4R). We aimed to assess if dietary Trp affects genes involved in the intestinal barrier of healthy pigs carrying or not the F4R. Thirty-six littermate

weaning pigs were selected to have potentially eighteen ETEC-susceptible and eighteen ETEC-non-susceptible subjects, based on a Mucin 4 gene polymorphism. For 21 days they were fed a diet with 0.17 or 0.22 SID Trp:Lys ratio. Using the test of ETEC adhesion to the intestinal villi, the pigs were divided into F4R negative (no bacteria adhering, F4R-), F4R positive (F4R_p), and F4R mildly positive (F4R_{mp}). A preliminary test (GeneChips Porcine Genome Array) highlighted the differentially expressed genes in the jejunum of 3 F4R- and 3 F4R_p pigs. The expression of the most interesting genes was assessed on the whole sample.

In F4R_p pigs, Trp reduced the mRNA of four genes involved in the intestinal barrier and/or induced by several bacteria-associated molecular patterns, like lipopolysaccharide (LPS) (REG3G, Regenerating islet-derived 3 gamma; SFTPD, Surfactant pulmonary-associated protein D; CFB, Complement factor B; LBP, LPS-binding protein) ($P < 0.05$). In pigs fed the low-Trp diet, REG3G, SFTPD and LPB mRNA increased with F4R presence ($P < 0.05$). Interleukine-8 tended to be less expressed with the higher Trp level whatever the F4R presence ($P = 0.09$). No DNA from ETEC was detected in the jejunum contents. Trp favorably interacts to reduce the bacterial induction of some genes involved in the intestinal barrier in ETEC susceptible pigs, but the causative mechanism is yet to be established.

Tryptophan is well known for its numerous biological functions, particularly for its effects on feed intake and its strong implications in the immune response and health. These traits are confirmed by this new study using nutri-genomics technics.

Livestock Science. 2012. 147: 96–103

Valine

The standardized ileal digestible valine-to-lysine requirement ratio is at least seventy percent in postweaned piglets

R. Barea^{1,2}, L. Brossard^{1,2}, N. Le Floc'h^{1,2}, Y. Primot³, D. Melchior³, and J. van Milgen^{1,2}

¹ Institut National de la Recherche Agronomique (INRA), Unite Mixte de Recherche (UMR) 1079, F-35000 Rennes, France;

² Agrocampus Ouest, UMR1079, F-35000 Rennes, France;

³ Ajinomoto Eurolysine s.a.s., 75817 Paris Cedex 17, France.

To reduce the impact of animal production on the environment, the crude protein content of the diet can be reduced by limiting the excess supply of AA. Improving the balance between AA relative to the requirement of the animal implies that we need to have accurate knowledge of the requirement of individual AA. The purpose of this study was to determine the Val requirement in postweaned piglets (12 to 25 kg) because Val is considered to be

potentially limiting to performance after Lys, Met (and Cys), Thr, and Trp. The first experiment was carried out to identify a diet limiting in Lys supply. In this experiment, piglets were offered 1 of 3 diets: A low-CP diet containing low or adequate Lys concentrations [providing 1.0 and 1.2% standardized ileal digestible (SID) Lys, respectively] or a normal-CP diet with 1.2% SID Lys. Average daily gain of piglets receiving the diet containing 1.0% SID Lys was significantly less than that of piglets receiving diets containing 1.2% SID Lys at low or normal CP (486 vs. 522 g/d, respectively; $P < 0.01$).

In Exp. 2, four diets with 1.0% SID Lys were used in a 2×2 factorial design, in which diets contained 57 or 70% SID Val:Lys in combination with 50 or 60% SID Ile:Lys. Independent of the Ile supply, feed intake and daily BW gain were, respectively, 15 and 20% less in pig-

lets receiving diets providing 57% SID Val:Lys compared with piglets receiving 70% SID Val:Lys ($P < 0.001$). The Ile content of the diet did not affect feed intake or daily BW gain ($P > 0.10$). Experiment 3 was conducted to evaluate the response of piglets to an increasing Val supply provided by 2 sources of L-Val differing in the degree of purity. Increasing the Val supply from 58 to 66% SID Val:Lys resulted in a linear increase in both feed intake and daily gain by 24 and 30%, respectively ($P < 0.001$). No difference was observed between both sources of L-Valine ($P > 0.10$). Experiment 4 was a dose-response study using 5 concentrations of Val supply (ranging from 60 to 80% SID Val:Lys). The estimated SID Val:Lys requirements for maximizing ADFI, ADG, and G:F were, respectively, 74, 70, and 68% using a linear-plateau model, and 81, 75, and 72% using a curvilinear-plateau model. Plasma Val, plasma α -ketoisovaleric acid, Ile, and Leu concentrations after an overnight fast increased with increasing Val supply ($P < 0.001$). The results of these experiments indicated that the SID Val:Lys was at least 70%, which was slightly greater than the current NRC recommendation.

These four experiments were designed to determine a basis for the Valine recommendation in piglets, expressed in ratio to Lysine. Valine is the next limiting essential amino acid for piglet growth far before Isoleucine and a minimum of 70% SID Val:Lys was determined to support optimal growth.

Valine

Optimal ileal digestible valine-to-lysine ratio for the performance of piglets

S. Millet¹, J. De Boever¹, M. Aluwé¹, L. Segers², Y. Primot³, M. De Paepe¹, D. De Brabander¹

¹ Institute for Agricultural and Fisheries Research (ILVO), Animal Sciences Unit, Scheldeweg 68, 9090 Melle, Belgium;

² Orffa Belgium N.V., 2880 Bornem, Belgium;

³ Ajinomoto Eurolysine s.a.s., 75817 Paris Cedex 17, France.

The objective of this experiment was to evaluate the effect of increasing apparent ileal digestible (AID) valine/AID lysine ratios on the performance results of newly weaned piglets between 4 and 9 weeks of age. One hundred and eighty piglets (Piétrain boar x hybrid sow) were divided over 30 pens with 3 barrows and 3 sows. Each pen was randomly assigned to one out of 5 dietary treatments, leading to 6 replicates per treatment. One basal feed was formulated according to the ideal amino acid concept, with apparent ileal digestible lysine as the reference amino acid.

This additional Valine dose-response confirms the improvement of piglets' growth performance when animals are fed 70% SID Val:Lys between 8 and 25 kg corresponding to the value of 68% expressed in Apparent Ileal Digestibility value (AID).

Based on previous experiments, AID lysine content was slightly limiting performance (10.2g/kg). Dietary AID methionine+cystine, threonine, tryptophan, isoleucine, valine, and leucine contents expressed as percent of AID lysine were 65, 72, 23, 54, 60 and 107%, respectively. Then free valine was added to obtain 5 AID valine to AID lysine ratios: 60, 65, 70, 75 and 80%. Performance results were subject to simple and polynomial regression analysis. The requirements were estimated using broken line models with either a linear or a quadratic ascending function.

Dietary valine concentration had a clear impact on animal performance. Mainly feed intake and daily gain were affected. Requirement of AID valine expressed relative to AID lysine was 65% or 66% (for respectively average daily gain and average daily feed intake) using a broken line model with linear ascending function and 67% (average daily gain) or 68% (average daily feed intake) using a broken line model with quadratic ascending function. The results of the present experiment suggested even higher requirements in the first two weeks after weaning. Expressed as Standardised Ileal Digestible Val:Lys, the requirements range from 68% to 71%, depending on the model used.

EAAP – 61st Annual meeting, Heraklion. 2010. 16:82

Valine requirements of weaned piglets

E. Vinyeta¹, R. Gerritsen¹, M. Rovers², E. Corrent³

¹ Schothorst Feed Research B.V., Meerkoetenweg 26 P.O. Box 533, 8200 AM Lelystad, Pays-Bas;

² Orffa Additives B.V., Vierlinghstraat 51, 4251 LC Werkendam, Pays-Bas;

³ Ajinomoto Eurolysine s.a.s., 153 rue de Courcelles, 75817 Paris, France.

A dose response study was performed with weaned piglets to determine the relationship between the standardized ileal digestible (SID) dietary Valine:Lysine (Val:Lys) ratio and growth performance in 9-25 kg piglets. The experiment comprised a negative control (NC) diet with a limiting valine level (SID Val:Lys ratio of 61%), and four treatments: NC diet supplemented with L-Valine with higher SID Val:Lys ratios of 65%, 70%, 75% and 80 %.

The experiment was performed with 10 replicates (pens) per treatment, with 6 piglets per pen resulting in 60 piglets per treatment. A randomization process was used to allocate piglets to replicates based on weaning weight, sex and litter.

The experimental period was divided into two periods: a phase 1 period of one week (first week post-weaning) during which all piglets received the same commercial phase 1 diet and a subsequent phase 2 period lasting four weeks during which the pigs received the respective treatment diets.

The SID Val:Lys requirements for maximum growth performance were estimated at 66% using the linear-plateau model;

the estimate based on the curvilinear-plateau model was 74%. The requirements for minimum FCR could not be estimated due to a high residual variance.

When considering possible sources of variation and different interpretation of the models, a minimum of 70% SID Val:Lys was recommended.

In this dose-response study, piglets (from 9 to 25 kg) increased their average daily gain by 6% between 65 and 70% SID Val:Lys. Using different models, a minimum requirement of 70% SID Val:Lys is recommended.

Journées Recherche Porcine. 2011. 43:131-132

Valine

Providing a diet deficient in valine but with excess leucine results in a rapid decrease in feed intake and modifies the postprandial plasma amino acid and α -keto acid concentrations in pigs

M. Gloaguen^{1,2,3}, N. Le Floc^{1,2}, E. Corrent³, Y. Primot³, and J. van Milgen^{1,2}

¹ INRA, UMR1348 PEGASE, F-35590 Rennes, France;

² Agrocampus Ouest, UMR1348 PEGASE, F-35000 Rennes, France;

³ Ajinomoto Eurolysine s.a.s., F-75817 Paris Cedex 17, France.

Indispensable AA are involved in the control of feed intake. When a diet deficient in Val is offered to pigs, feed intake is typically reduced. This effect is aggravated when dietary Leu is supplied in excess of the requirement. If an unbalanced supply of branched-chain AA (BCAA) is harmful, an anorectic response may serve as a mechanism to prevent this situation. We verified this hypothesis by measuring the voluntary feed intake of a balanced

diet offered during the 30-min period 1 h after ingestion of a test meal deficient or not in Val (Val- and Val+) with an excess of Leu. Twelve and four 6-wk-old crossbred female pigs were used in Exp. 1 and 2, respectively.

Prior ingestion of the Val- test meal resulted in a 14% reduction in feed intake compared with that observed after ingestion of the Val+ test meal ($P = 0.06$) in Exp. 1, indicating that the signal to reduce feed intake occurred within 1 h. It is possible that the plasma concentration of the limiting AA serves as a signal for the dietary AA deficiency. We therefore determined the postprandial plasma concentrations of BCAA and their α -keto acids after ingestion of Val- and Val+ in 4 pigs in Exp. 2.

After ingestion of the Val- diet, plasma concentrations of Val and its keto acid were reduced compared with

values observed after ingestion of the Val+ diet. The peak concentration occurred earlier after ingestion of the Val- diet compared with that of the Val+ diet. Although the plasma concentration increased after the meal, it declined rapidly in pigs offered Val-, and the Val concentration 4 h after ingestion of the meal was even less than that observed in the fasted state. In conclusion, it appears that the pig is able to detect a deficient supply of Val within 1 h after ingestion. The plasma concentration of Val or its concentration relative to the other BCAA during the postprandial period may act as a signal indicating the AA deficiency.

A pig is able to detect within 1h after ingestion a diet which is unbalanced in amino acid pattern, particularly in Branched-Chain Amino Acids which have a singular common catabolism pathway. Knowing the mechanisms of the response of the animal contributes to refine nutritional requirements.

Journal of Animal Science. 2012.90:3135–3142

Isoleucine

Meta-analysis of the response of growing pigs to the isoleucine concentration in the diet

J. van Milgen^{1,2}, M. Gloaguen^{1,2,3}, N. Le Floc'h^{1,2}, L. Brossard^{1,2}, Y. Primot³ and E. Corrent³

¹ INRA, UMR1348 PEGASE, F-35590 Saint-Gilles, France;

² Agrocampus Ouest, UMR1348 PEGASE, F-35000 Rennes, France;

³ Ajinomoto Eurolysine s.a.s., 75817 Paris Cedex 17, France.

The efficiency of nitrogen utilization will be highest when the amino acid (AA) supply approaches the requirement of the animal. With the availability of different crystalline AA, it is theoretically possible to formulate low-protein diets for growing pigs in which seven AA are co-limiting for performance. In such a diet, the concentration of Lys, Met, Met+Cys, Thr, Trp and Val and a seventh AA would exactly match the requirement. To determine the extent to which low-protein diets can be used, it is important to have reliable information about the requirements for these AA. Isoleucine is often considered the seventh-limiting AA in diets for growing pigs; however, information about the Ile requirement is limited and sometimes conflicting.

The purpose of this study was to carry out a meta-analysis of the available literature information to determine the Ile requirement in growing pigs. A total of 46 Ile dose-response experiments were identified that used at least four concentrations of Ile in the diet. Because of differences in experimental design, both the Ile concentration and the response criteria were standardized. In 13 dose-response experiments, there was no indication of a response to an increasing Ile concentration. For the other 33 experiments, a response to the increasing Ile concentration was observed and the Ile requirement

estimates ranged from 53% to 114% of that of the National Research Council (1998).

An Ile concentration below the requirement resulted in important reductions in both feed intake and growth. A 10% reduction in the Ile concentration (below the requirement) resulted in a 15% reduction in feed intake and a 21% reduction in daily gain. The use of blood products in the diet was the main factor determining whether a response to the Ile concentration was observed or not. Blood meal and blood cells are protein sources with a very low Ile concentration, but with high or very high concentrations of Leu, Val, Phe and His. Some of these AA compete with Ile for catabolic pathways or transport across the blood-brain barrier, thereby potentially increasing the requirement for Ile. In diets without blood products, the Ile requirement appears to be lower than the currently recommended requirement. On the basis of the outcome of this study, we recommend a Ile:Lys requirement ratio of at least 50% on a standardized ileal digestible basis.

This exhaustive review of the literature data about Isoleucine studies in growing pig allows to explain the variability in the published results. The response to Isoleucine is subjected to blood cells use due to an unbalanced amino acid content. A clear recommendation for blood-free pigs diets of 50% SID Ile:Lys is given.

Animal. 2012. 6:10:1601–1608

Isoleucine

Estimation of the optimum ratio of standardized ileal digestible isoleucine to lysine for eight- to twenty-five-kilogram pigs in diets containing spray-dried blood cells or corn gluten feed as a protein source

M. K. Wiltafsky¹, J. Bartelt², C. Relandeau³, and F. X. Roth¹

¹ Lehrstuhl für Tierernährung, Technische Universität München, Department für Tierwissenschaften, Hochfeldweg 6, D-85350 Freising, Germany;

² Lohman Animal Health GmbH & Co. KG, Heinz-Lohmann-Straße 4, D-27472 Cuxhaven, Germany;

³ Ajinomoto Eurolysine s.a.s., 153 Rue de Courcelles, 75817 Paris Cedex 17, France.

Two growth assays and 1 N balance trial were conducted to determine the standardized ileal digestible (SID) Ile:Lys ratio in 8- to 25-kg pigs using spray-dried blood cells or corn gluten feed as a protein source. In Exp. 1, 48 individually penned pigs (initial BW = 7.7 kg) were used in a 6-point SID Ile titration study (analyzed SID Ile of 0.36, 0.43, 0.50, 0.57, 0.64, and 0.72%) by addition of graded levels of L-Ile. The basal diet contained 1.00% SID Lys, 18.4%

CP, and 13.6 MJ of ME/kg. Diets were based on wheat, barley, corn, and 7.5% spray-dried blood cells as a protein source. Dietary SID Leu and Val levels were 1.61 and 1.02%, respectively. For the 35-d period, ADG, ADFI, and G:F increased linearly ($P < 0.01$) and quadratically ($P < 0.04$) with increasing SID Ile:Lys. Estimates of optimal SID Ile:Lys ratios were 59% for ADG and ADFI. In Exp. 2, 24 N balances were conducted using the Exp. 1 diets (12 pigs; individually penned; average BW = 11.5 kg). Pigs were fed 3 times daily with an amount equal to 1.0 MJ of ME/kg of BW^{0.75}. Preparation and collection periods (7 d each) were repeated after rearranging the animals to treatments. Increasing the dietary SID Ile:Lys ratio increased N retention linearly ($P < 0.01$), and N utilization

The response to Isoleucine depends on the source of feedstuffs used in the experimental diet. This is in relation to the particular BCAA common catabolism. Under European piglet feed formulation (blood free diets), Isoleucine levels can be lowered.

linearly ($P < 0.01$) and quadratically ($P < 0.01$). An optimal SID Ile:Lys ratio of 54% was estimated for N retention. In Exp. 3, 48 individually penned pigs (initial BW = 8.0 kg) were fed grain-based diets in a 6-point SID Ile titration (analyzed SID Ile of 0.35, 0.41, 0.49, 0.56, 0.62, and 0.69%). Dietary SID Ile was increased by graded addition of L-Ile. The basal diet contained 0.97% SID Lys, 16.8% CP, and 13.6 MJ of ME/kg. In contrast to Exp. 1 and 2, spray-dried blood cells were excluded and corn gluten feed was used as a protein source. Dietary SID Leu and Val were set to 1.05 and 0.66%. For the 42-d period, ADG, ADFI, and G:F increased linearly ($P < 0.01$) and quadratically ($P < 0.01$) with increasing SID Ile:Lys. Estimated optimal SID Ile:Lys ratios were 54, 54, and 49 for ADG, ADFI, and G:F, respectively. These experiments suggest that the optimal SID Ile:Lys ratio depends on diet composition. In Exp. 1, AA imbalances because of increased Leu contents may have led to increased Ile nutritional needs. For ADG and ADFI, an optimum SID Ile:Lys ratio of 54% was estimated for 8- to 25-kg pigs in diets without Leu excess.

Journal of Animal Science. 2009. 87:2554–2564

Response of piglets to the standardized ileal digestible isoleucine, histidine and leucine supply in cereal–soybean meal-based diets

M. Gloaguen^{1,2,3}, N. Le Floc'h^{1,2}, Y. Primot³, E. Corrent³, and J. van Milgen^{1,2}

¹ INRA, UMR1348 PEGASE, F-35590 Saint-Gilles, France;

² Agrocampus Ouest, UMR1348 PEGASE, F-35000 Rennes, France;

³ Ajinomoto Eurolysine s.a.s., 75817 Paris Cedex 17, France.

Improving the amino acid (AA) profile of the diet by using L-Lys, L-Thr, DL-Met, L-Trp and L-Val helps to reduce the dietary CP content, thereby reducing nitrogen excretion while maintaining the performance of pigs. Valine is the fifth limiting AA in cereal–soybean meal-based diets. The extent to which the CP content in the diet can be reduced further without compromising performance depends on the requirement of the next limiting AA. In cereal–

soybean meal-based diets, Ile, His and Leu may be the limiting AAs after Val, although information on the requirements for these AAs is scarce.

Six experiments were conducted to determine the effect of supplementing a low-CP diet with L-Ile, L-His and L-Leu on the performance of pigs weighing 10 to 20 kg. Experiment 1 was designed to determine the most limiting AA with respect to performance among Ile, His and Leu. A diet 10% deficient in Ile, Leu and His relative to the National Research Council (NRC, 1998) requirement estimates tended to decrease daily feed intake and daily gain by 6% and 8%, respectively. A 10% deficiency in His alone had no effect, whereas a 10% deficiency in Ile or Leu slightly reduced daily

feed intake and gain. In the remaining experiments, the standardized ileal digestible (SID) Ile:Lys, His:Lys and Leu:Lys requirements were estimated. In Experiments 2, 3, 4, 5 and 6, 14 blocks of six pigs each were assigned to six levels of SID Ile:Lys (40%, 43%, 46%, 49%, 52% and 55%), His:Lys (20%, 24%, 28%, 32%, 36% and 40%), His:Lys (21%, 24%, 27%, 30%, 33% and 36%), Leu:Lys (70%, 78%, 86%, 94%, 102% and 110%) and Leu:Lys (80%, 90%, 100%, 110%, 120% and 130%), respectively.

Across experiments, the estimated SID Ile:Lys, His:Lys and Leu:Lys requirements for maximizing daily gain were 49%, 32% and 102%, respectively, using a curvilinear plateau model. When Ile, His and Leu levels were 10% below the requirement estimate, daily gain was reduced by 9%, 3% and 3%, respectively. The results of this study indicate that the Ile requirement estimate is lower than the current NRC requirement estimate, whereas the Leu and His requirements correspond to those proposed by the NRC.

A data set of six experiments allows to refine Isoleucine, Leucine and Histidine requirement of piglets. This seminal work gives room for the crude protein reduction in practical feeds without compromising technico-economic performance.

Animal. 2013. 7:6:901-908

Isoleucine and valine supplementation of a low-protein corn-wheat-soybean meal-based diets for piglets: Growth performance and nitrogen balance

M. M. Lordelo¹, A. M. Gaspar², L. Le Bellego³, and J. P. B. Freire¹

¹ Universidade Técnica de Lisboa, Instituto Superior de Agronomia, Departamento de Produção Agrícola e Animal, Tapada da Ajuda, 1340-017 Lisboa, Portugal;

² Indukern PT, Centro Empresarial Sintra Estoril II Rua Pé de Mouro Estrada de Albarraque 2710-335 SINTRA, Portugal;

³ Ajinomoto Eurolysine s.a.s., rue de Courcelles, 75817 Paris, France.

The effects of Ile and Val supplementation of a low-CP, corn-wheat-soybean meal-based piglet diet on growth performance, incidence of diarrhea, and N balance were studied using 60 Landrace × Duroc male piglets in a 4-wk experiment. The 60 individually caged piglets were divided into 5 dietary treatments, each consisting of 12 piglets. Diet 1 was a positive control diet (20% CP); diet 2 was a low-CP negative control diet (17% CP); diets 3, 4, and 5 were low-CP diets to which Ile, Val, or the combination of Ile and Val were added, respectively. All diets were supplemented with Lys, Met, Thr, and Trp to provide the required concentrations of these AA according to the 1998 NRC.

Average daily gain and ADFI were similar among pigs fed the positive control, Val-added, and the Val plus Ile added diets. On wk-2 and wk-4, fecal score was greater (softer feces) in piglets fed the 20% CP level compared with the remaining treatments ($P < 0.01$). Nitrogen intake was decreased ($P < 0.0001$) in pigs fed diets containing low levels of CP compared with pigs fed the 20% CP diet.

Fecal N excretion (g/d) was decreased ($P < 0.05$) in piglets fed low-CP diets at wk 1 and wk 4 of feeding, and in urine at wk 4 of feeding. Crude protein levels or AA supplementation had no effect on N retention efficiencies.

These results indicate that the supplementation of Val alone, or in combination with Ile, to a low-CP piglet diet with adequate levels of Lys, Met, Thr, and Trp is necessary to achieve maximum performance in pigs consuming corn-wheat-soybean meal-based diets.

Valine is the most limiting amino acid in a low crude protein diet for piglets. By controlling each essential amino acid and using L-Valine, it is possible to reduce the dietary crude protein content by 3 points without affecting growth performance.

Journal of Animal Science. 2008. 86:2936–2941

Fattening Pig Diets: Formulating with no Minimum Crude Protein

Recent advances in the determination of amino acid requirements of pigs and the increasing availability of feed-grade amino acids allow a drastic reduction of the dietary crude protein content and so the feed cost. These new diets markedly reduce nitrogen excretion without detrimental effects on nitrogen retention and performance. In a context of lower availability of food resources, formulating feeds on each essential amino acids and using a net energy system allow to create more efficient diets and to save feed costs. L-Tryptophan became a master piece ingredient in achieving these objectives for the fattening feeds.

Tryptophan

Tryptophan requirements of growing and finishing pigs, a dose response study

P. van Der Aar¹, P. Bikker¹, M. Rovers², E. Corrent³

¹ Schothorst Feed Research, PO Box 533, 8200 AM Lelystad, Pays-Bas;

² Orffa Additives BV, Vierlinghstraat 51, 4251 LC Werkendam, Pays-Bas;

³ Ajinomoto Eurolysine s.a.s., 153 rue de Courcelles, 75817 Paris Cedex 17, France.

A dose-response experiment was conducted to determine the standardized ileal digestible (SID) Trp:Lys requirement of growing (25-55 kg) and finishing pigs (55-110 kg). All 288 pigs (8 treatments x 6 replicates x 6 pigs) were reared between 25 and 110 kg and fed ad libitum. Pigs of treatments 1-4 received growing diets with an SID Trp:Lys ratio of 15, 18, 21 or 24% during 6 weeks and then they received a finishing diet with an SID Trp:Lys ratio of 20% until

slaughter at 110 kg. Pigs of treatments 5-8 received a growing diet with an SID Trp:Lys ratio of 20% during 5 weeks and then they received finishing diets with an SID Trp:Lys ratio of 15, 18, 21 or 24% until they had reached the weight of 110 kg.

During the both growing and finishing periods, the increase in SID Trp:Lys resulted in a significant ($P < 0.05$) improvement in feed intake (FI), average daily gain (ADG) and FCR. The lowest Trp diets fed in the growing or finishing periods resulted in longer fattening periods (+13 and +18 days, respectively) than the best treatments.

The linear-plateau and quadratic models were used to estimate the SID Trp:Lys requirement using FI, ADG and FCR as response criteria. On average on these criteria, the SID Trp:Lys requirements were estimated as 20% and 19% in the growing and finishing phase respectively, using the linear-plateau model. These values correspond to 96% of the maximum response obtained with the quadratic model and can be used as minimum SID Trp:Lys requirements for growing and finishing pigs.

In this work, the Trp requirement of fattening pigs is studied through a specific protocol ensuring a constant sublimiting Lys level all long the trial. Minimum requirements were assessed at 20% SID Trp:Lys for pigs between 25 to 55 kg live weight, and 19% SID Trp:Lys for pigs above 55 kg.

and 19% in the growing and finishing phase respectively, using the linear-plateau model. These values correspond to 96% of the maximum response obtained with the quadratic model and can be used as minimum SID Trp:Lys requirements for growing and finishing pigs.

Tryptophan

Study on optimum tryptophan to lysine ratio in low protein diets for female fattening pigs

K. Schedle¹, E. Corrent² and J. Bartelt³

¹ Institute of Animal Nutrition, Products and Nutrition Physiology, Department for agrobiotechnology, University of Natural Resources and Life Sciences, Vienna, Austria

² Ajinomoto Eurolysine S.A.S., 153 Rue de Courcelles, 75817 Paris Cedex 17, France ;

³ Lohman Animal Health GmbH & Co. KG, Heinz-Lohmann-Straße 4, D-27472 Cuxhaven, Germany.

Dietary crude protein (CP) reduction in combination with simultaneous supply of synthetic limiting amino acids (AA) significantly reduces environmental load with nitrogen and helps to save feed costs. When CP is reduced, each essential AA must be controlled. Among them Tryptophan (Trp) is described to limit performance of growing pigs. In this context, the objective of the present study was to determine the optimal Trp:Lys ratio in

modern crossbred fattening pigs by a dose-response study based on a low protein diet.

The study employed a total of 60 female Austrian crossbred [(Large White x German land race) x Piétrain] pigs and was conducted at the Austrian Pig Testing Facility (Streitdorf, Austria). Piglets were distributed equally to 4 dietary treatments among 12 pens (5 animals per pen, 3 pens per treatment) considering litter and initial body weight. Animals received a grower diet (13.7 MJ ME; 9.9 MJ NE/kg feed, 15.6% CP) from the start of the experiment up to a mean body weight (BW; mean of pen) of 62.3±0.9 kg. Subsequently, animals were fed a finisher diet (13.8 MJ ME;

10.1 MJ NE/kg feed, 13.2% CP). Diets were formulated to contain the relation of standardized ileal digestible (SID) Lys:Met+Cys:Thr:Val:Ile = 1:0.60:0.68:0.68: 0.55. Diets contain 9 g/kg SID Lys in grower and 7 g/kg SID Lys in finisher diet.

Feeding groups were supplemented with crystalline Trp until they reach the planned SID Trp:Lys ratios from 14, 17, 20, and 23% respectively. At the end of the feeding trial the animals were slaughtered, when individual body weight of animals reached 108.2±0.4 kg. Results: The average daily gain and the feed to gain ratio were improved by increasing SID Trp:Lys ratio up to 22% in early grower and grower diets as well as 19% in finisher diets. Daily feed intake was not affected by Trp level except the early grower period. The optimum SID Trp:Lys ratios of the present study reached higher values as recommended by the GfE 2006.

Controlling dietary Tryptophan is a key point to get the best growth and feed efficiency in pigs. The best performance in this trial were reached between 19 and 22% SID Trp:Lys depending on the weight categories.

Proceeding of the Society of Nutrition and Physiology. 2012. 21.

Tryptophan

Tryptophan requirement in growing pigs determined by meta-analysis

A. Simongiovanni¹, E. Corrent¹, N. Le Floc'h^{2,3} and J. van Milgen^{2,3}

¹ Ajinomoto Eurolysine s.a.s., 153 rue de Courcelles, F-75817 Paris cedex 17, France;

² INRA, UMR1348 PEGASE, F-35590 Saint-Gilles, France;

³ Agrocampus Ouest, UMR1348 PEGASE, F-35000 Rennes, France.

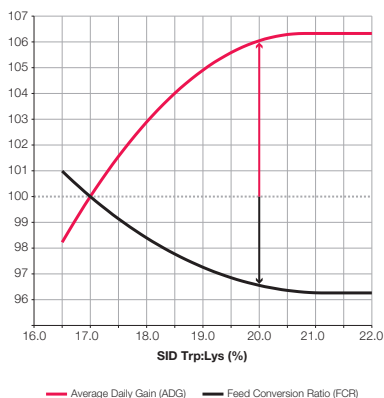
A meta-analysis was performed to estimate the tryptophan to lysine requirement ratio, on a standardized ileal digestible basis (SID Trp:Lys), that maximises average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G:F) of pigs between 25 and 120 kg body weight. A database of 87 trials was established. The nutrient composition of diets was recalculated from feed ingredients and information from INRA tables.

Among the trials, 13 were designed to express the requirement relative to Lys (i.e., Lys was the second limiting factor after Trp) while testing at least four levels of Trp, and these trials were considered in the meta-analysis. The curvilinear-plateau model was used to estimate the animal response to SID Trp:Lys. The estimated SID Trp:Lys requirements were 20.9, 19.9 and 21.0%, for ADG, ADFI and G:F, respectively, with an average value of 20.6%. The response between 17 and 21% SID Trp:Lys levels was estimated to be +6.7 and +3.6%, for ADG and G:F, respectively.

This meta-analysis performed about Trp requirement in fattening pigs depicts a response of 6.7% for gain and 3.6% for gain to feed when increasing Trp from a deficient level of 17% to 21% SID Trp:Lys. This work confirms a minimum requirement of 20% SID Trp:Lys for pigs above 25 kg live weight.

Journées Recherche Porcine. 2013. 45:163-164

Response of ADG and FCR (%)



Effect of dietary SID Trp:Lys on growing pigs' performance (> 25 kg live weight), based on the meta-analysis of Simongiovanni et al. and AEL Bulletin 37

Low protein diets

Utilisation of soybean meal in pig diets can be reduced through the formulation of low crude protein diets based on rapeseed meal and feed-use amino acids

N. Quiniou¹, Y. Primot², C. Peyronnet³, A. Quinsac⁴

¹ IFIP- Institut du Porc, Pôle Techniques d'Élevage, BP 35104, F-35651 Le Rheu cedex, France;

² Ajinomoto Eurolysine S.A.S., 153, rue de Courcelles, F-75817 Paris cedex 17, France ;

³ Onidol, 12 avenue George V, F-75008 Paris, France;

⁴ Cétiom, Rue Monge, Parc Industriel, F-33600 Pessac, France.

One hundred and forty-four (144) group-housed growing-finishing pigs were allocated to one of three experimental feeding strategies. Diets S were formulated with soybean meal and their dietary crude protein (CP) content averaged 15.9 and 15.0% during the growing and the finishing periods, respectively. In diets C, CP levels were reduced to 15.0 and 14.1%, respectively, and soybean meal was replaced partially or completely with rapeseed meal and balanced with L-Lysine, DL-Methionine, L-Threonine and L-Tryptophan. In diets CV, L-Valine was also incorporated (0.3 g/kg) allowing an additional reduction of CP content (14.5 and 13.2%, respectively). All diets were formulated on the same net energy basis (9.7 MJ NE/kg) and on minimum ratios between digestible lysine and other amino acids following the ideal protein profile.

Between 27 and 111 kg, no significant differences were observed between treatments on average daily gain, feed intake, feed conversion ratio or carcass gain. These results indicate that it is possible to replace soybean meal with rapeseed meal in association with available free amino acids for an extended time without impacting growth performance. They also show that an additional reduction of dietary CP content can be achieved using L-Valine without affecting growth performance, as long as diets are formulated on a NE basis and in keeping with the ideal protein concept. Reduced dietary CP obtained with C and CV feeding strategies was associated with a reduction of N output of 400 and 650 g /pig, respectively.

By using the ideal Amino Acid profile recommended by Ajinomoto Eurolysine s.a.s. it is possible to design efficient diets for fattening pigs containing only 14.5% to 13.0% crude protein. It is demonstrated that diets without soybean meal are efficient by taking advantage of the full range of free amino acids available and alternative feedstuffs such as rapeseed meal.

EAAP – 62nd Annual meeting, Stavanger. 2011. 17:351.

Low protein diets

Amino acid incorporation into pig feeds reduces the environmental impacts of pig production

F. Garcia-Launay^{1,2}, H. van Der Werf^{2,3}, T. Tuyet Hanh Nguyen^{2,3},
L. Le Tutour⁴, J.Y. Dourmad^{1,2}

¹ INRA, UMR1348 Physiologie, Environnement et Génétique des Animaux et Systèmes d'Élevage, 35590 Saint-Gilles, France ;

² Agrocampus Ouest, 35000 Rennes, France ;

³ INRA, UMR1069 Sol, Agro et Hydrosystème Spatialisation, F-35000 Rennes, France

⁴ Ajinomoto Eurolysine s.a.s., 153 rue de Courcelles, F-75817 Paris, France.

Feed-use amino acids (AA) allow reducing, at constant performance, the protein content of pig feeds and nitrogen excretion by the animals. The aim was to assess the environmental impact of one kg of live pig produced in a conventional farm in Brittany by Life Cycle Assessment (LCA) according to several scenarios of AA incorporation. Two modalities of effluent management (slurry or solid manure) and two hypotheses of protein sources (soybean only, or soybean, rapeseed and peas) were considered. In three scenarios, feeds were least cost formulated: no AA (NoAA-Min€), AA incorporation and fixed protein content at CORPEN level (AACORP-Min€), and AA with free protein content (AA-Min€).

In AA-MinCP, feeds were formulated to minimize protein content. Fattening pigs were fed either with only one feed (1P), two feeds (2P) or according to multi-phase feeding (MP).

The protein content of pig feeds decreased with the amino acid incorporation, down to 123 g/kg in MP-AA-MinCP. At the same time, the incorporation of soybean meal into feeds decreased down to 70 kg/t in MP-AA-MinCP. With slurry management, AA-Min€ reduced the impacts on climate change, acidification and eutrophication by at least 26%, 22% and 14% respectively. With solid manure management, AA-Min€ reduced the impacts on climate change, acidification and eutrophication by at least 20%, 20% and 12% respectively. The impacts on terrestrial ecotoxicity, cumulated energy demand and land occupation were barely sensitive to the studied scenarios. Amino acid incorporation in least cost formulated feeds substantially reduced the feeding cost and environmental impacts of pig production.

Journées Recherche Porcine. 2013. 45:123-128.

Using feed use amino acids and implementing low protein diets is already known as one of the Best Available Technics to reduce the impact of pig production on the environment. In this work, the effect of low protein diets and amino acids incorporation on environment is assessed by Life Cycle Assessment. It is showed that the environmental impact of pig production can be further reduced through feeding practices and the use of the Ajinomoto Eurolysine Amino Acid profile.

Optimizing the Amino Acid Nutrition in Broiler Feeds

Fine tuning the amino acid supply in a broiler diet by taking advantage of the complete range of feed-use amino acids available is the first step in designing an efficient broiler feed, targeting optimized quantitative and qualitative performance. Beside, environmental issues and the ban of the use of antimicrobial growth promoters lead the nutritionist to find new solutions which amino acids are part of.

Lysine

Study of lysine requirement in finishing broilers: Effect on performance

M. Lessire¹, J.M. Hallouis¹, T. Bordeau¹, Y. Primot², E. Corrent²,
P. Fraysse², S. Tesseraud¹, C. Berri¹

¹ INRA, UR 83 Recherches Avicoles, F-37380 Nouzilly, France ;

² Ajinomoto Eurolysine s.a.s., 153 rue de Courcelles, F-75817 Paris Cedex 1, France.

Results of this trial were introduced in order to re-evaluate amino acids requirement in poultry during the finisher period. A total of 4,600 one-day-old male Ross PM3 chicks were bred together from 0 to 21 days and received a common standard diet. At 21 days old, birds were weighed and 3,456 chickens were randomly distributed into 96 floor pens (3m²). The experimental design was composed of 12 diets with 8 pens per diets and 36 birds per

pen. 4 digestible lysine levels were tested (7.0; 8.5; 10.0 and 11.5g/kg) and this, for 3 essential amino acid profile based on 90%, 100% and 110% of the ideal protein introduced by Mack et al, 1999. Diets were formulated in order to be iso-energetic. On the opposite, the crude protein content varied from 13 to 24% according to digestible lysine and others essential amino acids concentrations. Performances and meat quality were measured at 36 days old. When digestible lysine concentration increased body weight gain was improved and feed intake decreased. For the body weight criteria, the digestible lysine requirements were evaluated at 9.7 g/kg or 10.7 g/kg according to the amino acid profile. Increasing digestible lysine concentration permitted to have a better feed conversion ratio with a requirement estimated at 12.7 g/kg. Minimized abdominal fat was obtained with a 13.7g/kg of digestible lysine meanwhile

The genetic improvement in broiler continuously challenges the knowledge of the nutritional requirement of these animals. Knowing the optimum values to reach the genetic potential is a prerequisite of designing a diet. Making the choice on the dietary Lysine level associated with usual amino acid profile allows to reach the best performance.

it was necessary to have a 12,6 g/kg digestible lysine concentration to optimize the breast meat criteria. This trial shows that using the ideal AA profile described by Mack et al (1999) allows to maximize weight gain and FCR.

Journées de la Recherche Avicole. 2013. 749-752

Lysine

Study of lysine requirement in finishing broilers: Implication for breast meat quality traits

C. Berri¹, J.M. Hallouis¹, T. Bordeau¹, Y. Primot², E. Corrent², S. Tesseraud¹, M. Lessire¹

¹ INRA, UR 83 Recherches Avicoles, F-37380 Nouzilly, France ;

² Ajinomoto Eurolysine s.a.s., 153 rue de Courcelles, F-75817 Paris Cedex 1, France.

Current opportunities for poultry meat industry concern more cuts and processed products. In the same time, new questions appear on the technological quality of meat, in particular its storage and processing abilities. In chickens, these characteristics are strongly influenced by the ultimate pH of the meat, which depends on muscle glycogen content. First observations suggest the possibility to modulate these characteristics by varying the

protein supply of animal feed. To better define the impact of amino acid supply on breast meat quality, we performed measurements of pH, color and drip loss in a trial whose initial objective was to estimate the amino acid requirements of broilers during the finishing period.

The experimental design included 12 diets varying in the level of digestible lysine (0.70, 0.85, 1.0 and 1.15%) and of essential amino acids (90, 100% and 110% of ideal protein described by Mack et al. 1999) during the finishing period (21-36 days).

Breast meat yield increased (from 17.3 to 20.2%) and abdominal fat percentage decreased (from 3.2 to 2.2%) with gradually increasing levels of lysine supply and thus with total protein content of feed.

Effects of amino acids to lysine ratio were observed on the breast meat ultimate pH. Thus, the lowest values of ultimate pH (≈ 5.8 on average) were obtained in the case of a high supply of amino acids relative to lysine (110%). The highest pH values (≈ 6.0 on average) corresponded to the lowest amino acid to lysine ratio (90%). These pH variations had a significant impact on the color and water retention of meat, with the most acid meats having the highest luminance L^* and drip loss during storage ($L^* = 50.6$ and drip loss = 2.7% in average). These results highlight the importance of integrating meat quality criteria in addition to standard production criteria when defining dietary requirements of broilers.

Lysine has confirmed its effects on broiler performance and new criteria predicting the meat quality can be optimized by using higher Lysine levels in broiler diets.

Journées de la Recherche Avicole. 2013. 440-444

Threonine

Threonine requirement of broiler chickens during subclinical intestinal *Clostridium* infection

L. Star¹, M. Rovers², E. Corrent³, and J. D. van der Klis¹

¹ Schothorst Feed Research, PO Box 533, 8200 AM Lelystad, the Netherlands;

² Orffa Additives B.V., Vierlinghstraat 51, 4251 LC Werkendam, the Netherlands;

³ Ajinomoto Eurolysine s.a.s., 153 rue de Courcelles, 75817 Paris Cedex 17, France.

The aim of this study was to determine the threonine requirement of broilers during a subclinical *Clostridium* infection. Three experiments were performed: Experiments 1 and 2 to investigate the dose response of threonine supplementation during infection and experiment 3 to validate the threonine requirement during infection. In each experiment, 1-d-old Ross 308 male broilers were used. An infection model was used with inoculation

of *Eimeria maxima* and *Clostridium perfringens* at d 9 and 14 of age, respectively. Control birds were inoculated with saline and liver broth at d 9 and 14 of age, respectively.

From d 9 of age, infected birds were fed diets differing in the standardized digestible threonine-to-lysine ratio (realized ratios experiment 1: 0.55, 0.58, 0.63, 0.69, and 0.72; realized ratios experiment 2: 0.64, 0.65, 0.67, 0.69, and 0.72; and realized ratios experiment 3: 0.63 and 0.67). Uninfected birds were fed diets with a realized Thr:Lys ratio of 0.63 in experiments 1 and 2 and of 0.63 or 0.67 in experiment 3. The incidence of lesions, lesion severity, and mortality rate of infected birds was not affected by the Thr:Lys ratio.

Experiments 1 and 2 showed that the decrease in BW gain and feed intake was less severe in infected birds fed a diet with a Thr:Lys ratio of 0.69 and 0.67, respectively (not significant). Validation of the Thr:Lys

ratio in experiment 3 showed that the BW gain and feed intake were higher for infected birds with a Thr:Lys ratio of 0.67 compared with infected birds with a Thr:Lys ratio of 0.63. This resulted in an increased BW gain and feed intake of 129 and 148 g, respectively, with a higher Thr:Lys ratio over a production period of 37 d. This indicates that a higher Thr:Lys ratio in infected birds improved production performance during infection with *C. perfringens*, although intestinal damage (incidence and lesion severity) was not affected.

Due to its high concentration in mucin, Threonine is involved in maintaining gut integrity in broilers and pigs. In this study, increasing dietary Thr content in broiler feeds allows to reduce the impact of intestinal infection on growth performance. This strategy associated with dietary crude protein reduction alleviates health risks for animals.

Poultry Science. 2012. 91:643–652

Valine

Impact of an increasing true digestible (TD) valine to lysine ratio in a protein reduced diet on the performance of broiler chicks.

Magdalena Lipp¹, R. Leitgeb¹, J. Bartelt², E. Corrent³ and K. Schedle¹

¹ Institute of Animal Nutrition, Products and Nutrition Physiology, Department for agrobiotechnology, University of Natural Resources and Life Sciences, Vienna, Austria

² Lohman Animal Health GmbH & Co. KG, Heinz-Lohmann-Straße 4, D-27472 Cuxhaven, Germany;

³ Ajinomoto Eurolysine s.a.s., 153 Rue de Courcelles, 75817 Paris Cedex 17, France.

The following study determines the impact of an increasing TD Val to TD Lys ratio in a protein-reduced diet on the growth performance of broiler chicks. 345 eight day old chickens (Ross 308; 121±0.9 g) were randomly assigned to 24 pens and 5 dietary treatments. The trial was divided into a grower- (until live day 21), and a finisher period (live day 36). Grower diets (13.0 MJ AMEN; 18.5% CP) were based on wheat (42.9%), corn (35.3%),

corn gluten meal (11.6%), and soybean meal with hulls (3.1%), while finisher diets (13.1 MJ AMEN; 15.7% CP) based on wheat (66.9%), corn (9.9%), soybean full fat (11.2%), vegetable oil (3.6%) and corn gluten meal (3.0%). Lys content was adjusted to become the second limiting amino acid (grower: 10 g TD Lys/kg, finisher: 8 g TD Lys/kg).

The ratio of TD Val:Lys in the diets ranged between 68%, over 73%, 78%, 83% to 88%. The chicks were fed and watered *ad libitum*. Performance parameter were analysed by ANOVA (P<0.05). Additionally, different statistical models were used to determine the optimal ratios between TD Val and Lys for average daily gain, daily feed intake and feed to gain.

The applied regression models to determine the optimal digestible valine to lysine ratio showed similar values for the parameter ADG and daily Feed Intake. For the parameter F:G a meaningful regression analysis was impossible with. However differences of the optimal ratio between the applied models were detected (broken line: 74.6%, quadratic model: 84.0%, linear regression: 78.0%).

Proceeding of the Society of Nutrition and Physiology. 2013. 22, and AEL's trial report 12AT02.

A significant response to Valine is observed when broilers are fed different levels of this essential amino acid.

It is therefore necessary to control Valine when dietary crude protein is reduced in broiler feeds. A ratio of 79% TD Val:Lys was determined in average in this study, confirming the usual recommendation of 80% TD Val:Lys obtained in previous works.

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AJINOMOTO EUROLYSINE S.A.S.

153, rue de Courcelles
75817 Paris Cedex 17 – France
Phone: + 33 1 44 40 12 12