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Apparent ileal digestibility of amino acids and metabolisable energy value in grains for broilers

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Using ileal digestible amino acids in feed optimising will intensify feed protein utilizing and decrease nitrogen excretion to the environment. The study determined the apparent ileal digestibility (AID) coefficients of amino acids in barley, wheat, oats, triticale, maize, and dehulled oats in the diets of 180 Ross broiler chickens (aged 24–35 days). The birds were fed semi-purified diets that contained grain as the sole protein source and chromium-mordanted straw as an indigestible marker. The AID coefficients of the nutrients were assessed using the slaughter technique, and the apparent metabolisable energy (AME) was determined using total excreta collection. The ileal digestibility of the dry matter and organic matter were the highest in maize. The AME of maize was higher than that of other cereals. The ileal digestibility of crude protein was higher in wheat than that in barley, oats and dehulled oats. The AME of wheat was similar to that of barley and oats but lower than that of triticale and dehulled oats. The amino acid AID was highest in wheat (0.86) and triticale (0.85) and lowest in oats (0.79) and barley 0.77). The average amino acid AID was 0.81 in dehulled oats. The threonine AID was the same in all tested ingredients. The lysine, methionine, and cystine AID coefficients were 0.81, 0.79, and 0.71 respectively for barley; 0.86, 0.84, and 0.38 respectively for oats; 0.87, 0.86, and 0.53 respectively for dehulled oats; 0.84, 0.90, and 0.66 respectively for maize; 0.89, 0.88, and 0.77 respectively for triticale; and 0.87, 0.85, and 0.71 respectively for wheat. Results indicated that AME –values of domestic grains (barley, oats and wheat) are in the same level. Especially, low AME value of wheat needs further investigation.

Key words: poultry, apparent ileal digestibility, grain, amino acids

Introduction

Grains are the most important ingredients of and energy source in poultry diets. Depending on the age of the birds, poultry diets typically contain between 300 and 600 g kg^{-1} of grains. Wheat is the cereal most used in broiler diets in Europe. Maize is used especially in the USA and in South America. In northern Europe and Canada, barley is also used as an energy source in poultry feeds. Triticale is an intergenic hybrid of wheat (*Triticum* spp.)

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and rye (*Secale* spp.). It contains more protein and amino acids than wheat, and its metabolisable energy (ME) content is higher than that of barley and oats (Tuori et al. 1996). Because of their high fat content, hulled and dehulled oats are used in Nordic countries in diets for broilers, especially young broilers.

Most nutritive value variability in grains for poultry is caused by non-starch polysaccharides (NSP), especially those NSPs that are soluble (Hughes and Choct 1999). The ME of the grains is also affected by the amount of carbohydrates such as starch and sugars available in the grain. The location of protein in the grain also causes variation in protein and amino acid digestibility between different cereals (Wallis 1984).

Currently, feed formulation based on the ileal digestibility of amino acids is preferred. However, there are only a limited number of published studies of apparent ileal digestibility (AID) of amino acids in grains. Digestibility values determined using excreta are subject to error because of microbial protein synthesis and degradation in the lower digestive tract. Therefore, the apparent digestibility of amino acids should be measured in the ileum, where amino acids are also absorbed (Moughan and Donkoh 1991). The aim of the present experiment was to investigate the apparent ileal digestibility of amino acids in grains used in poultry diets to enable the future formulation of diets based on ileal digestible amino acids.

Material and methods

Experimental animals

A total of 180 one-day-old Ross broiler chickens were obtained from a hatchery to investigate apparent ileal digestibility of amino acids in grains used in poultry diets. Birds were raised in battery wire cages (47.5 × 56 × 40 cm). In the beginning, there were five birds per cage, and after ileal viscosity determination, four birds, 2 hens and 2 cocks. Equal numbers of both sexes per treatment were used for excreta and digesta collections and digesta viscosity determination. The birds received standard broiler starter diets (220 g kg^{-1} crude protein (CP)) from day 1 to day 23. Experimental diets were introduced on day 24 onwards. The broiler house temperature was maintained at +19°C during the experiment, and light was controlled according to the Ross broiler breeder instructions (20-h light cycle (5–10 lux) and 4-h dark cycle).

Diets

The domestic grains (oats, wheat, barley, and triticale) were harvested during 1998 at MTT Agrifood Research, Jokioinen (N 61°E 23°) Finland. Maize and dehulled oats were supplied by Rehuraisio Ltd., Raisio, Finland. Grains were roller-milled with a 4.0-mm sieve (Gehl Company, West Bend, Wisconsin, USA) before dietary incorporation. The semi-purified experimental diets were composed of minerals, vitamins, rapeseed oil, and either barley, wheat, oats, triticale, maize, or dehulled oats as the sole source of protein (Table 1). In all diets, 1.7 g of chromium-mordanted straw (0.2 g Cr kg^{-1} feed, Udèn et al. 1980) was used as an indigestible marker. The test ingredients were mixed in a batch mixer and cold-pelleted into 4-mm pellets (Amandus Kahl Laborpresse L175, Germany).

Experimental procedures

Six cages of five 24-day-old birds were randomly allocated to each of the six dietary treatments. Feed and water was provided *ad libitum*. The trial lasted 11 days. On the last day of the 3-day adaptation period, the viscosity of the contents of the ileum of one bird per cage was determined as described in Perttilä et al. (2001). Then, excreta was collected daily for 3 days from plates under the cages and stored frozen (–20°C) prior to analysis. Total excreta collection was followed by a further 3-day adaptation period, 24-h fasting, and 4-h free access to feed, after which the birds were humanely slaughtered for the collection of ileal digesta.

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Table 1. Dietary ingredients (g kg^{-1}) and chemical composition (g kg^{-1} DM, unless otherwise stated) of experimental diets.

Diet	Barley	Wheat	Oats	Triticale	Maize	Dehulled oats
Barley	940					
Wheat		940				
Oats			940			
Triticale				940		
Maize					940	
Dehulled oats						940
Rapeseed oil	20	20	20	20	20	20
Monocalcium phosphate	18	18	18	18	18	18
Limestone	14	14	14	14	14	14
Salt	4.0	4.0	4.0	4.0	4.0	4.0
Trace mineral premix[1]	2.0	2.0	2.0	2.0	2.0	2.0
Vitamin premix[2]	2.0	2.0	2.0	2.0	2.0	2.0
Cr-mordanted straw, g kg^{-1}	1.7	1.7	1.7	1.7	1.7	1.7
Dry matter, g kg^{-1}	898	897	898	874	866	876
Crude protein	127	135	121	119	89	139
Crude fat	49	51	97	51	72	92
Crude fibre	43	30	77	27	21	35
Ash	52	46	57	51	41	51
Gross energy, MJ kg^{-1} DM	18.4	18.5	19.5	19.5	18.8	19.5

[1] The trace mineral premix supplied the following per kg of diet: 0.95 g calcium, 43.8 mg iron, 7.6 mg copper, 75.4 mg magnesium, 97.6 mg zinc, 0.7 mg iodine, 0.3 mg selenium.

[2] The vitamin premix supplied the following per kg of diet: 2.1 mg calcium, 8.9 mg phosphorus, 5.6 mg retinol, 0.1 mg cholecalcipherol, 60.0 mg vitamin E, 54.0 mg tocopherol, 7.5 mg phylloquinone, 4.5 mg thiamin, 9.0 mg riboflavin, 6.0 mg pyridoxine, 0.05 mg cyanocobalamin, 0.45 mg biotin, 1.5 mg folic acid, 60.3 mg niacin, 22.5 mg pantothenic acid, 0.92 mg ethoxyquin.

Cages were divided into six blocks that each consisted of one cage from each of the six different treatments. Feeding and slaughter were started at the same time for each block. Birds were killed by stunning with carbon dioxide and subsequent cervical dislocation. This procedure was conducted as quickly as possible in order to minimise changes in digesta composition. The ileum was dissected from Meckel's diverticulum to the ileo-caeco-colic junction. Digesta was collected from the distal half of the ileum for digestibility and viscosity determinations. The digesta of birds within a cage was pooled before chemical analysis. Birds were weighed at the beginning and end of the trial and at the beginning and end of excreta collection. The feed intake of each cage was recorded during the collection period and the 4-h pre-slaughter feeding period. The experimental procedures were evaluated and approved by the Animal Care Committee of MTT Agrifood Research Finland.

Chemical analysis

The feed ingredients were sampled before preparation of the experimental diets, and samples of the diets offered were collected prior to feeding. The ileal digesta samples were freeze-dried, and the excreta samples were dried overnight at 60°C. Before analysis, all samples were passed through a hammer mill fitted with a 1-mm mesh. Nitrogen analysis of excreta was conducted using fresh samples according to the Kjeldahl method and of dried ileal digesta samples according to a Dumas-based method using a Leco FP 428 nitrogen analyser (Leco Corp., St Joseph, USA). Proximate analysis was performed according to standard AOAC procedures (methods 954.02 and 942.05, AOAC 1990), and crude fibre was analysed using the method of Hirsjärvi and Andersen (1954). Samples were hydrolysed with 4 M HCl before ether extract analysis. Starch was analysed using the method of

McCleary et al. (1994). Total and insoluble β-glucan content was determined enzymatically using a β-glucan kit (Cat. No. 1120, Megazyme International Ireland Ltd., Bray, Ireland). To determine the insoluble fraction, the soluble fraction of the sample was removed by washing twice with warm distilled water. The soluble fraction of β-glucans was then calculated as the difference between the total and the insoluble fractions. Amino acid content was determined using a Biochrom 20 Amino Acid Analyser (Pharmacia Biotech, Cambridge, England) according to official EU procedures (EC 1998). Methionine and cystine were determined after oxidisation with performic acid prior to acid hydrolysis. The gross energy of the feeds and dried excreta were determined with an IKA C 400 calorimeter (Janke & Kunkel GmbH, Staufen, Germany) using benzoic acid (BCS-CRM 190, Bureau of Analysed Samples Ltd, Newham Hall, England) as a calibration standard. Chromium was determined by atomic absorption spectrometry (Williams et al. 1962).

Data analysis

Apparent ileal and faecal (AED) digestibilities were calculated using Cr as an indigestible marker as follows:

Coefficient of apparent ileal or faecal digestibility = $[(N/Cr)_d - (N/Cr)_{ie}] / (N/Cr)_d$

where $(N/Cr)_d$ = dietary ratio of nutrient to Cr and $(N/Cr)_{ie}$ = ratio of nutrient to Cr in ileal digesta or excreta. Apparent ME values (AME) were calculated by subtracting the gross energy (GE) of excreta from GE intake and then dividing by total dry matter intake. The AME values of diets were corrected for zero nitrogen retention (AME_n) by assuming a value of 36.55 kJ g^{-1} of nitrogen lost or retained (Titus et al. 1959). Experimental data from AID measurements were subjected to analysis of variance using the GLM procedure of SAS (1990) and using the following statistical model (Snedecor and Cochran 1989): $y_{ijk} = \mu + b_i + d_j + e_{ijk}$, where y_{ijk} is the dependent variable, μ is the overall mean, b_i is the random block effect, d_j is the fixed diet effect, and e_{ijk} is the error term. Experimental data from AED measurements were subjected to analysis of variance using the GLM procedure of SAS (1990) and using the same model as for AID measurements, but without use of the random block effect in the model. Differences between diets were tested using the Tukey test. In all cases, residuals were plotted against fitted values to ensure the normality of the experimental data.

Results

The chemical composition of the grains is shown in Table 2. Dehulled oats and wheat had the highest CP content and maize the lowest. Barley, oats, and triticale had intermediate CP contents. The crude fat contents of oats and dehulled oats were clearly higher than those of other grains. In addition, oats had the highest crude fibre content. Methionine, leucine and alanine content of maize were clearly higher than those of the other cereals. In addition, lysine, leucine and aspartic acid content of wheat were lower than those of the other cereals.

The dry matter intake of maize-fed broilers was the lowest ($P < 0.05$) (Table 3). Their live weight was lowest at the end of the excreta collection period and on the slaughter day as well ($P < 0.05$). The live weight of broilers fed dehulled oats was highest both at the end of the excreta collection period and on the slaughter day ($P < 0.05$). However, their live weight did not differ from that of barley-fed and oats-fed broilers. The viscosity of ileal digesta of broilers fed dehulled oats was higher than that of broilers fed barley, wheat, oats, or maize ($P < 0.05$) (Table 3) but did not differ from that of triticale-fed broilers.

The AID of dry matter and of organic matter was higher in maize than in other cereals ($P < 0.05$), intermediate in triticale and dehulled oats, and lowest in barley, wheat and oats (Table 3). The AID of crude protein was higher in wheat than in barley, oats, and dehulled oats ($P < 0.05$).

The AED of dry matter and of organic matter was the lowest in oats and wheat, intermediate in

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Table 2. Chemical composition of test ingredients (g kg^{-1} DM, unless otherwise stated).

Feed	Barley	Wheat	Oats	Triticale	Maize	Dehulled oats
Dry matter, g kg^{-1}	881	890	891	869	857	876
Crude protein	132	142	131	119	92	159
Crude fat	30	31	80	24	55	82
Crude fibre	48	32	100	26	26	45
Ash	23	17	30	17	12	23
Starch	630	659	495	686	749	621
-glucans	41.9	7.8	40.3	7.9	nd	49.2
Soluble	35.7	6.0	39.8	5.7	nd	43.4
Insoluble	6.2	1.6	0.4	2.2	nd	5.8
Gross energy, MJ kg^{-1}	18.6	18.8	19.9	18.5	19.1	19.9
Amino acids, g $16g^{-1}$ N						
Arginine	5.5	5.0	6.8	5.5	4.9	6.8
Histidine	2.4	2.5	2.3	2.4	3.2	2.4
Isoleucine	3.5	3.5	3.7	3.4	3.7	3.7
Leucine	6.9	6.9	7.2	6.6	12.9	7.5
Lysine	3.8	2.8	4.1	3.6	3.0	4.0
Methionine	1.8	1.9	1.7	2.0	2.4	1.9
Phenylalanine	5.0	4.5	4.9	4.7	4.8	5.1
Threonine	3.9	3.3	3.8	3.7	4.2	3.6
Valine	5.9	5.9	6.0	5.8	6.1	6.0
Alanine	3.9	3.6	4.5	3.9	7.5	4.4
Aspartic acid	6.3	5.2	8.0	6.2	6.6	7.8
Cystine	2.5	2.5	3.3	2.5	2.9	3.3
Glutamic acid	21.2	30.3	17.1	24.4	15.8	18.5
Glycine	3.9	3.9	4.7	4.1	3.7	4.5
Proline	10.7	10.8	5.2	9.2	9.1	5.3
Serine	4.4	4.7	4.8	4.9	5.2	4.7
Tyrosine	3.4	3.2	3.6	3.0	4.3	3.7

nd = not determined

barley, triticale, and dehulled oats, and highest in maize ($P < 0.05$). However, the AED of dry matter and organic matter in wheat and barley did not differ from these values in triticale. The AED of crude fibre was either negative or close to zero in all cereals. The AED of crude fat was the highest in maize and oats and the lowest in dehulled oats.

The nitrogen retention of birds fed wheat was lower than that of birds fed oats and triticale ($P < 0.05$) (Table 3). Birds fed oats, triticale, barley, maize, or dehulled oats had the same nitrogen retention. Metabolisation of energy was the highest in birds fed maize ($P < 0.05$). In addition, the AME_n of maize was also the highest among the cereals ($P < 0.05$). AME_n of triticale was also higher than that of barley, wheat, and oats ($P < 0.05$). AME_n of wheat was the lowest, but it did not differ from that of barley and oats ($P > 0.05$).

The mean amino acid AID was the highest in wheat and triticale and the lowest in barley and oats (Table 4). Lysine AID was lower in barley than in triticale and wheat ($P < 0.05$), but it did not differ significantly from that in dehulled oats, oats, and maize. Methionine AID was the highest in maize ($P < 0.05$) but did not differ significantly from that in triticale and dehulled oats. Furthermore, cystine AID was the highest in wheat, triticale, maize, and barley ($P < 0.05$). Threonine AID was similar among all the grains.

Discussion

Great variation in the crude protein content of wheat, barley, oats, triticale, and maize has been observed in earlier experiments (Sibbald and Price 1976, Coates et al. 1977, Åman et al. 1985, Bach Knudsen et al. 1987, Rundgren 1988, Franke et al.

Table 3. Live weight and intake of broilers on slaughter day, ileal digesta viscosity, digestibility, and retention of nutrients.

Diet N	Barley 6	Wheat 6(5)[1]	Oats 6	Triticale 6	Maize 6	Dehulled oats 6	 SEM
Excreta collection period							
Live weight at beginning, g	1064^{b}	1011^{ab}	1000^{ab}	1008^{ab}	953^{a}	1052^{b}	47.5
Live weight at end, g	1194^{cd}	1081^{ab}	1148^{bd}	1104^{bc}	986^{a}	1215^{d}	167.5
Intake, g per day	127^{c}	106^{b}	117^{bc}	113^{bc}	71^{a}	117^{bc}	11.4
Ileal digesta collection day							
Live weight, g	1269^{cd}	1157^{bc}	1314^{d}	1147^{b}	999^{a}	1363^{d}	29.0[(1]
Intake, g	52^{bc}	58^{c}	62^{c}	44^{b}	27^{a}	56^{bc}	3.3
Ileal digesta viscosity, centipoises	14.5^{a}	19.0^{a}	17.6^{a}	143.8^{ab}	3.4^{a}	230.9^{b}	33.97
Apparent ileal digestibility of							
Dry matter	0.63^{ab}	0.57^{a}	0.58^{a}	0.71^{c}	0.81^{d}	0.70^{bc}	0.018
Organic matter	0.66^{ab}	0.60^{a}	0.62^{a}	0.74^{b}	0.84^{c}	0.74^{b}	0.019
Crude protein	0.74^{a}	0.85^{d}	0.77^{ab}	0.83^{cd}	0.81^{bcd}	0.79^{abc}	0.013
Ash	0.01^{ab}	0.00^{ab}	-0.11^{a}	0.12^{b}	0.05^{b}	0.00^{ab}	0.003
Apparent faecal digestibility of							
Dry matter	0.61^{abc}	0.57^{ab}	0.55^{a}	0.63^{bc}	0.79^{d}	0.65^{c}	0.016
Organic matter	0.65^{abc}	0.60^{ab}	0.59^{a}	0.66^{bc}	0.83^{d}	0.69^{c}	0.017
Crude fibre	-0.14^{b}	-0.16^{b}	-0.31^{a}	0.02^{c}	-0.14^{b}	-0.29^{a}	0.016
Crude fat	0.57^{a}	0.69^{bc}	0.76^{cd}	0.58^{ab}	0.88^{d}	0.47^{a}	0.027
Retention, proportion of intake							
Ash	-0.02^{ab}	-0.06^{a}	-0.06^{a}	0.07^{c}	-0.01^{ab}	0.01^{bc}	0.014
Nitrogen	0.33^{ab}	0.25^{a}	0.36^{b}	0.39^{b}	0.33^{ab}	0.33^{ab}	0.019
Energy	0.64^{ab}	0.61^{ab}	0.60^{a}	0.67^{b}	0.83^{c}	0.66^{ab}	0.016
Apparent metabolisable energy, MJ kg^{-1} DM	11.4^{ab}	11.1^{a}	11.4^{ab}	12.9^{c}	15.4^{d}	12.7^{bc}	0.31

[1] Values based on the mean of 5 observations; therefore, standard error of means (SEM) is 1.022 times that reported in the table for the live weight of broilers and 1.095 times that reported in the table for apparent faecal digestibility, retention, and apparent metabolisable energy value of nutrients.
Values in the same row with different superscript differ significantly ($P < 0.05$).
SEM = standard error of means

Table 4. Coefficient of apparent ileal digestibility of amino acids.

Diet N	Barley 6	Wheat 6	Oats 6	Triticale 6	Maize 6	Dehulled oats 6	 SEM
Arginine	0.80^{a}	0.87^{b}	0.91^{b}	0.87^{b}	0.88^{b}	0.90^{b}	0.014
Histidine	0.78^{a}	0.87^{b}	0.86^{b}	0.86^{b}	0.86^{b}	0.87^{b}	0.008
Isoleucine	0.80^{a}	0.89^{b}	0.88^{b}	0.88^{b}	0.85^{ab}	0.89^{b}	0.015
Leucine	0.81^{a}	0.91^{b}	0.88^{b}	0.89^{b}	0.92^{b}	0.88^{b}	0.011
Lysine	0.81^{a}	0.87^{b}	0.86^{ab}	0.89^{b}	0.84^{ab}	0.87^{ab}	0.014
Methionine	0.79^{a}	0.85^{bc}	0.84^{b}	0.88^{cd}	0.90^{d}	0.86^{bcd}	0.010
Phenylalanine	0.79^{a}	0.88^{b}	0.88^{b}	0.86^{b}	0.87^{b}	0.89^{b}	0.012
Threonine	0.71^{a}	0.78^{a}	0.72^{a}	0.78^{a}	0.73^{a}	0.75^{a}	0.021
Valine	0.81^{a}	0.89^{b}	0.86^{ab}	0.87^{b}	0.84^{ab}	0.85^{ab}	0.015
Alanine	0.76^{a}	0.84^{b}	0.81^{b}	0.84^{b}	0.91^{c}	0.82^{b}	0.012
Aspartic acid	0.76^{a}	0.82^{b}	0.82^{b}	0.83^{b}	0.84^{b}	0.83^{b}	0.014
Cystine	0.71^{c}	0.79^{c}	0.38^{a}	0.77^{c}	0.66^{bc}	0.53^{b}	0.032
Glutamic acid	0.86^{a}	0.95^{c}	0.91^{b}	0.94^{bc}	0.91^{b}	0.93^{bc}	0.008
Glycine	0.72^{abc}	0.82^{d}	0.66^{a}	0.80^{d}	0.75^{bcd}	0.69^{ab}	0.019
Proline	0.86^{b}	0.93^{c}	0.78^{a}	0.92^{c}	0.86^{b}	0.82^{ab}	0.011
Serine	0.76^{abc}	0.85^{c}	0.68^{a}	0.83^{c}	0.80^{bc}	0.71^{ab}	0.023
Tyrosine	0.68^{abc}	0.78^{d}	0.63^{a}	0.74^{bcd}	0.75^{cd}	0.66^{d}	0.019
Mean digestibility	0.77	0.86	0.79	0.85	0.83	0.81	

Values in the same row with different superscript differ significantly ($P < 0.05$).
SEM = standard error of means

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1999, Kosieradzka and Fabijanska 2001). In the present experiment, the protein contents of barley, wheat, oats, triticale, and maize were in the range observed in the earlier experiments. The crude protein content of dehulled oats in our investigation was similar to that of naked oats in previous experiments of Franke et al. (1999) and Kosieradzka and Fabijanska (2001). In addition, the amino acid composition of wheat in the present experiment confirmed previous results of McCracken and Quintin (2000) and Cave (1988). Most amino acid contents that we observed in maize were slightly higher than previous results of Parsons et al. (1998). Only aspartic acid and glutamic acid contents were slightly lower in the present experiment. However, Ravindran et al. (1999) observed similar amino acid contents in maize to those in the present experiment. The amino acid content of triticale in the present experiment was in agreement with the results of Flores et al. (1994), but the serine, alanine, leucine, and histidine contents were lower. In Rundgren (1988), the amino acid content of triticale was much lower than in the present experiment, although the crude protein content was similar.

Most nutritive value variability in grains for poultry is caused by non-starch polysaccharides, especially those NSPs that are soluble (Hughes and Choct 1999). An increase in ileal digesta viscosity has been noticed in many studies (e.g. Hughes and Choct 1999, Perttilä et al. 2001). The main viscosity-increasing part of barley consists of β-glucans. In barley, 75% of the endosperm's polysaccharides are β-glucans (MacGregor and Fincher 1993). Similarly, the β-glucan content of barley was among the highest in the present investigation. In addition, in wheat, pentosans, mainly arabinoxylans, have been shown to decrease the digestibility of nutrients and increase ileal digesta viscosity in broilers (Choct and Annison 1992).

In the present experiment, the amino acid AID was highest in wheat and triticale and lowest in barley. Unfortunately, there is very little literature data available for the ileal digestibility of amino acids in barley, oats, dehulled oats, or triticale. In contrast to our results, the apparent mean digestibility of amino acids was higher in wheat and barley than in maize in caecectomised cockerels (Green et al. 1987). Gruhn et al. (1989) also observed similar lysine, arginine, and histidine digestibilities in barley and oats in adult caecectomised cockerels and hens, and these values are inconsistent with our results. In their experiment, the digestibilities of methionine and cystine were higher in barley than in oats; in contrast, in our experiment, the digestibility of methionine was lower and that of cystine higher in barley than in oats. Soluble NSP, i.e. β-glucans, may have caused low amino acid digestibility in barley in the present experiment, as was also observed in the study of Perttilä et al. (2001) with differently preserved barley samples. The present experiment's amino acid AID in wheat and maize was consistent with the results of Ravindran et al. (1999), but that experiment's aspartic acid, lysine and threonine AID values were lower. In contrast, the AID of arginine, histidine, lysine, methionine, phenylalanine, threonine, and tyrosine in wheat were higher in Wallis et al. (1985) than in the present experiment. There seems to be large variation in the results obtained depending on the methods used, and one must take this into account when applying the values in diet formulation. An ileal digestibility assay should give reliable results because amino acids are absorbed in the small intestine, but there are still only a few published papers with digestibility values obtained using this kind of assay. However, there is some practical evidence that apparent ileal digestibility values are useful in practical feed formulation (Dalibard and Paillard 1995, Perttilä et al. 2002).

In the present experiment, the wheat AME_n value was low compared to the values in the previous results of Scott et al. (1998), but it was in the range of variation presented by the results of Wiseman (2000) and Hughes and Choct (1999). In addition, the AME_n value for dehulled oats confirmed the results of Franke et al. (1998) for oats containing 139 g of crude protein per kg of DM and 60 g of crude fat per kg of DM, although the crude fat content of the oats in the present study was higher (80 g kg^{-1} DM). Hughes and Choct (1999) have determined values from 10.5 to 12.4 MJ kg^{-1} DM for oats in earlier studies. Rundgren (1988) and

Hughes and Choct (1999) reported that the ME content of triticale used for growing broiler chickens varied from 12.3 to 15.3 MJ kg^{-1} DM and from 8.6 to 16.2 MJ kg^{-1} DM respectively. In addition, Hughes and Choct (1999) observed AME values ranging from 10.4 to 13.5 MJ kg^{-1} DM for barley and from 15.5. to 17.0 MJ kg^{-1} DM for maize. All these values were in the range of values observed in our study.

Generally, the ME value is most affected by the amount of available carbohydrates such as in the form of starch and sugars, the amount of which is highest in wheat and maize and lowest in oats. However, the higher crude fat content of oats and dehulled oats increases their ME value compared to that of other grains. In addition, the high proportion of hulls in oats, 20–40%, usually decreases the AME of this grain. Annison (1991) demonstrated a high negative correlation between the AME of wheat and its soluble NSP content. Unfortunately, the pentosan content of wheat was not analysed in the present experiment. However, the viscosity of ileal digesta was highest in broilers fed dehulled oats but it did not differ from that in triticale. Similarly, the digestibility of fat was low in dehulled oats and triticale. In contrast, the AME of triticale and dehulled oats was the highest of the values for domestic grains. In addition, Sibbald and Price (1976), did not find any correlation between the β-glucan content and the AME values of barley samples. The explanation was that the highest concentration of β-glucans was only 5.6%, which confirms our results for wheat and triticale. However, Svihus et al. (1997) concluded that fibre in barley and oats affects broiler chickens in different ways. This confirms our results, in which a high content of soluble β-glucans decreased the nutritive AME value and the digestibility of amino acids in barley but not in oats or in dehulled oats.

In conclusion, the digestibility of dry matter and organic matter was the highest in maize. The apparent metabolisable energy (AME) content of maize was higher than that of other cereals. The AME of wheat was similar to that of barley and oats but lower than that of triticale and dehulled oats. The values of amino acid AID were highest in wheat and triticale.

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SELOSTUS

Viljojen aminohappojen näennäinen ohutsuolisulavuus broilereilla

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Aminohappojen ohutsuolisulavuuteen perustuva valkuaisarvojärjestelmä tarkentaa siipikarjan rehusuunnittelua. Se vähentää valkuaisen yliruokintaa ja typpipäästöjä. Tutkimuksessa selvitettiin ohran, vehnän, kauran, ruisvehnän, maissin ja kuoritun kauran aminohappojen näennäinen ohutsuolisulavuus 180 Ross-broilereilla (ikä 24–35 päivää). Linnut ruokittiin puolipuhdistetuilla rehuilla, joissa vilja oli ainoa valkuaisen lähde. Ravintoaineiden näennäinen ohutsuolisulavuus määritettiin teurastustekniikalla ja näennäinen muuntokelpoinen energia kokonaiskeruulla.

Maissin kuiva-aineen ja orgaanisen aineen ohutsuolisulavuus oli korkein. Myös maissin näennäinen muuntokelpoinen energia-arvo oli korkein. Raakaproteiinin ohutsuolisulavuus oli korkeampi vehnässä kuin ohrassa, kaurassa ja kuoritussa kaurassa. Vehnän näennäinen muuntokelpoinen energia-arvo oli sama kuin ohran ja kauran, mutta alhaisempi kuin ruisvehnän ja kuoritun kauran. Vehnän ja ruisvehnän aminohappojen ohutsuolisulavuudet olivat korkeimmat ja kauran ja ohran alhaisimmat. Treoniinin aminohappojen ohutsuolisulavuus oli sama kaikissa viljoissa. Lysiinin, metioniin ja kystiinin näennäinen ohutsuolisulavuus oli 0,81, 0,79 ja 0,71 ohrassa, 0,86, 0,84 ja 0,38 kaurassa, 0,87, 0,86 ja 0,53 kuoritussa kaurassa, 0,84, 0,90 ja 0,66 maississa, 0,89, 0,88 ja 0,77 ruisvehnässä sekä 0,87, 0,85 ja 0,71 vehnässä. Kokeen tulokset osoittivat, että kotimaisten viljojen, ohran, kauran ja vehnän, muuntokelpoiset energia-arvot ovat samalla tasolla. Erityisesti vehnän matalan energia-arvon varmentaminen vaatii lisäselvityksiä.