The Amino Acid Composition of Protein Feedstuffs Before and After Ruminal Incubation and After Subsequent Passage Through the Intestines of Dairy Cows[1]

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ABSTRACT: The amino (AA) profile of eight feedstuffs (two samples of fishmeal, soybean meal [SBM], formaldehyde-treated SBM, sopralin, cottonseed meal [CSM], rapeseed meal [RSM], corn distillers grains [CDG], and corn gluten feed [CGF]) was determined before and after ruminal incubation for 8 and 12 h in three lactating Friesian cows using nylon bags. The profile of AA disappearing during intestinal passage was also measured by inserting the bags into the duodenum through T-piece cannulas after ruminal incubation and recovering them in the feces. The AA profile changed for all feedstuffs, except sopralin, following ruminal incubation. Changes were greater for the more degradable feedstuffs. The profile of AA disappearing during intestinal passage was generally similar to the profile after ruminal incubation, but some differences were found with feedstuffs that had low (< 84%) intestinal disappearance of AA (RSM, CDG, CGF). For the other feedstuffs, intestinal disappearance of AA was greater than 93%. The two fishmeal samples had the highest concentrations of methionine and lysine in their residues after ruminal incubation, whereas CDG and CGF had low lysine concentrations. Residues of these latter two and RSM were quite high in methionine concentration, whereas residues of SBM, sopralin, and CSM had the lowest concentrations. Corn distillers grains had 13% of its AA remaining after ruminal incubation followed by intestinal passage. These results show that feedstuffs vary in the proportion of their AA that escape ruminal degradation, in the profile of those AA, and in their intestinal digestibility. These factors should be considered in protein evaluation systems and in assessment of the protein quality of feedstuffs.

Key Words: Amino Acids, Ruminants, Degradation, Digestion

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Introduction

Milk and meat production of ruminants can be limited by protein supply. There is evidence that lysine and methionine are the first two amino acids (**AA**) limiting milk protein production (Schwab et al., 1976; Casper and Schingoethe, 1989; Rulquin et al., 1993), and histidine and phenylalanine have often been cited as the next limiting AA (Yang et al., 1986; Seymour et al., 1990).

Ruminant protein feeding systems (e.g., Jarrige 1989; NRC, 1989; AFRC, 1993) are constrained by limited knowledge of the AA absorbed from the small intestine. The AA profile of the absorbed fraction of bypass protein can be different from that of the original feed (Erasmus et al., 1994), making prediction of absorbed AA difficult. More information is needed on the AA content of bypass protein and on the intestinal digestibility of bypass AA. Most protein systems assume a constant digestibility for bypass AA (e.g., Jarrige, 1989; NRC, 1989), but Hvelplund (1984) using a mobile nylon bag technique (Hvelplund, 1985) found that it ranged from 59 to 70%. The objective of this experiment was to determine the AA profile of a number of protein feedstuffs, of their bypass protein fraction, and of the AA that disappear from the intestines.

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Table 1. Chemical analysis (% of DM) of the experimental feedstuffs

Feedstuff	Crude protein	Crude fiber	Oil	Ash
Fishmeal 1	79	—	9.7	10.9
Fishmeal 2	68.6	—	12.2	14.6
Soybean meal	54.5	4.6	1.7	7.3
Sopralin	51.1	3.5	2.3	9.1
Cottonseed meal	40.4	15.6	1.1	6.7
Rapeseed meal	36.3	9.5	3.0	8
Corn distillers grains	26.5	8.1	10.5	4.9
Corn gluten feed	21.7	8.1	3.9	6.1

Materials and Methods

Animals, Feedstuffs, and Treatments. Three multiparous Friesian cows fitted with ruminal cannulas and T-shaped cannulas in the proximal duodenum were used in this experiment. They were tied in individual stalls and milked in their stalls. At the start of the experiment, they were 48, 95, and 96 d postpartum. For the experimental period (10 d), their average milk yield was 15 kg/d. They were given ad libitum access to grass silage (dry matter 254 g/kg, pH 3.58, crude protein 131 g/kg of DM, in vitro DM digestibility .68) and were fed 7 kg/d of supplement in two equal feeds at 0830 and 1430. The main ingredients in the supplement were unmolassed beet pulp, corn gluten feed, barley, soybean meal, and molasses; the chemical composition (g/kg) was as follows: DM 876, CP 187, oil 18, crude fiber 71, and ash 75. Average silage DM intake for the experimental period was 8.9 kg/d.

Eight feedstuffs with moderate or high levels of CP (Table 1) were examined. They were ground to pass through a .5-mm screen (Cyclotec 1093 mill, Tecator, Höganäs, Sweden). They were subjected to the following treatments: 1) 8-h ruminal incubation, 2) 12-h ruminal incubation, 3) 8-h ruminal incubation followed by intestinal passage (insertion into the duodenum through T-piece cannulas and subsequent recovery in the feces), and 4) 12-h ruminal incubation followed by intestinal passage. The 8- and 12-h ruminal incubation periods were chosen to ensure that feed CP disappearance approximated that occurring in animals with high rumen outflow rates (i.e., .08/h). Subsequent examination of CP disappearance of 32 concentrate feeds over ruminal incubation periods ranging from 2 to 48 h (measured using similar techniques) indicated that a 12-h incubation gave the best agreement with effective CP degradability at a rumen outflow rate of .08 (O'Mara, 1993; B. Young and J. J. Murphy, personal communication). For this reason, some of the data were presented only for the 12-h ruminal incubation period.

Experimental Procedure. Nylon bags (Nybolt PA 40/30, Hall Pyke Sales, Dublin, Ireland) approximately 3.5 × 5 cm in size and with a pore size of 40 μm, were manufactured as described by De Boer et al. (1987). They were weighed and filled with approximately 1 g of feedstuff (36 bags per feedstuff). These small bags were incubated in the rumen of the cows in larger polyester mesh bags (approximately 20 × 40 cm), which were attached by a drawstring to the cannula and kept immersed in the rumen by an attached weight (De Boer et al., 1987). Incubation began at 0830, just after the first supplement feed, with 12 small bags of each feed being incubated in the rumen of each cow. Eight hours later, just after the second supplement feed, the polyester mesh bags were withdrawn from the rumen. Six small bags of each feedstuff were removed from each polyester mesh bag, which was then returned to the rumen. Three of the six bags removed were immediately inserted through the duodenal cannula into the small intestine of the cow from whose rumen they had been removed, at the rate of one every 4 to 5 min. Vanhatalo et al. (1995) showed that acid-pepsin treatment of ruminally incubated bags prior to insertion into the duodenum is not necessary. The other three bags removed from the rumen were immediately machine washed in cold water for 25 min.

The polyester mesh bags were taken out of the rumen again 4 h later (i.e., after 12 h of ruminal incubation), and the remaining six bags of each feedstuff were removed. Three were again machine washed immediately. The other three were stored (unwashed) at 4°C overnight and were inserted into the small intestine as described above, just after feeding of the supplement the following morning. This was to ensure that all bags were inserted into the duodenum just after a supplement feed in case this caused any variation in rate of flow of intestinal contents.

Bags inserted into the duodenum were recovered in the feces and machine washed. All washed bags were stored at –20°C until further analysis.

Analytical Methods. Dry matter of feedstuffs was determined by drying at 103°C for 4 h (Statutory Instruments, 1984). Their CP concentration (N × 6.25) was determined using a Kjelfoss instrument (Foss Electric, Hollgard, Denmark). Incubated bags were dried at 40°C for 48 h in an oven with forced air circulation, and weight was recorded. Contents of the bags were composited by treatment and cow for each feedstuff. Amino acid content of these composited samples was determined by ion-exchange chromatography (model 6300 analyzer, Beckman Instruments, Fullerton, CA) using the method of Mason et al. (1980). Methionine and cysteine were determined as methsulfone and cysteic acid, respectively, on preoxidized samples. There was not enough sample remaining after intestinal passage of some feedstuffs to determine AA in oxidized and unoxidized samples. In such cases, AA were determined on an oxidized sample.

Statistical Analysis. Within each feedstuff, the AA profile of the original feedstuff, of the residues after 8 and 12 h of ruminal incubation, and of the intestinally degraded AA following 8 or 12 h of ruminal incubation were compared using the ANOVA procedure of SAS (1985). Differences among feedstuffs in the AA profiles after 12 h of ruminal incubation were compared using the ANOVA procedure of SAS (1985). Values were calculated for the percentage disappearance of lysine, methionine, histidine, phenylalanine, and total AA in the rumen after 12 h of ruminal incubation, in the total tract, and in the intestines (for what reached there). The amount of each AA that disappeared in the intestines following 12 h of ruminal incubation was also calculated. These results were compared among feedstuffs using the ANOVA procedure of SAS (1985). Data were analyzed as a completely randomized design, using cow as the experimental unit.

Results and Discussion

Proximate Analysis of the Feedstuffs. The proximate analysis of the feedstuffs is given in Table 1. Both fishmeals were manufactured at the same plant (Killybegs Fishmeal, Killybegs, Ireland). Fishmeal 1 was a very high quality fishmeal with high protein and low ash and oil levels. Fishmeal 2 had lower protein and higher ash and oil than Fishmeal 1, which indicates a different raw material mix. The soybean meal and sopralin were similar in composition, but the sopralin was slightly lower in CP content (54.5 vs 51.1% of DM). The cottonseed meal was very low in oil (1.1% of DM), indicating chemical extraction, and it was a high fiber, low CP sample in comparison with some other tabulated values (NRC, 1989). The sample of rapeseed meal was similar in composition to the values for extracted rapeseed meal tabulated by NRC (1989), although its CP content of 36.3% of DM was low. Corn distillers grains were very similar in composition to that tabulated by NRC (1989), but the corn gluten feed sample was substantially lower in CP content (21.7% of DM) than tabulated by NRC (1989) for corn gluten feed (25.6% of DM).

Percentage of Amino Acid Nitrogen in Total Nitrogen. Tables 2 to 5 give the percentage of AA nitrogen (**AAN**) in total N for each feedstuff. It varied from 69.3% for corn gluten feed to 83.6% for Fishmeal 2. It was lower for Fishmeal 1 (72.9% of total N) than for Fishmeal 2 and resulted in both fishmeal samples having the same amount of AAN per kilogram of DM (9.2%). The AAN as a percentage of total N in Fishmeal 2 is higher than that calculated from the data of Ganev et al. (1979) for fishmeal (70.1%), but it is lower than that calculated from the data of Crooker et al. (1987), which was 101%. The fishmeal sample of Crooker et al. (1987) was unusual in that it contained a very high level of glycine. Glycine was 29.8% of total amino acids compared with 7 and 7.8% for Fishmeals 1 and 2 in this experiment, 11% in the sample of Ganev et al. (1979), 9.8% in the sample of

Table 2. The amino acid (AA) profile (g AA/100 g AA) of original feedstuffs (O), profile of residue remaining after 8 h (R-8) or 12 h (R-12) of ruminal incubation, and profile of intestinally digested amino acids following 8 h (I-8) or 12 h (I-12) of ruminal incubation for Fishmeal 1 and Fishmeal 2

Amino acid	Fishmeal 1						Fishmeal 2					
	O	R-8	R-12	I-8[a]	I-12	SEM	O	R-8	R-12	I-8	I-12	SEM
Cysteine	.9	1.1	1.1	1.1	1.1	.08	.9	1.2	1.1	1.2	1.1	.11
Aspartic acid	9.6[b]	10.1[c]	10.1[c]	10.1[c]	10.0[c]	.05	9.7	10.2	10.3	10.3	10.4	.13
Methionine	3.4	3.8	3.8	4.1	3.8	.27	3.2	4.0	3.6	4.0	3.6	.33
Threonine	4.7	5.0	5.0	5.0	5.0	.06	4.6	4.8	4.8	4.9	4.9	.11
Serine	4.4	4.4	4.3	4.7	4.2	.11	4.5	4.5	4.4	4.4	4.3	.12
Glutamic acid	14.4	14.3	14.4	14.2	14.4	.08	13.9	14.0	14.1	14.1	14.2	.17
Glycine	7.0[b]	4.5[c]	4.5[c]	4.5[c]	4.5[c]	.05	7.8[b]	6.0[c]	5.9[c]	5.4[d]	5.3[d]	.11
Alanine	7.2[b]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	.05	6.7[b]	6.1[c]	6.1[c]	6.0[c]	6.1[c]	.10
Valine	5.9[b]	6.2[c]	6.3[c]	6.3[c]	6.3[c]	.05	5.6[b]	5.9[c]	6.0[cd]	6.0[cd]	6.1[d]	.06
Isoleucine	4.6[b]	5.3[c]	5.3[c]	5.3[c]	5.3[c]	.04	4.6[b]	5.0[c]	5.1[c]	5.2[c]	5.3[c]	.10
Leucine	8.3[b]	8.9[c]	8.9[c]	8.9[c]	8.9[c]	.07	8.0	8.3	8.4	8.5	8.6	.11
Tyrosine	3.3[b]	3.9[c]	4.0[c]	4.1[c]	4.1[c]	.12	3.4[b]	4.1[c]	4.1[c]	4.1[c]	4.1[c]	.07
Phenylalanine	4.0[b]	4.5[c]	4.5[c]	4.4[c]	4.5[c]	.06	4.4	4.7	4.6	4.7	4.6	.09
Histidine	2.4	2.6	2.7	2.9	2.7	.13	3.0	2.7	2.9	2.7	2.9	.15
Lysine	8.2[b]	8.7[cd]	8.5[b]	8.8[d]	8.6[cd]	.08	8.1	8.0	8.2	8.2	8.3	.16
Arginine	6.9	6.2	6.2	5.7	6.2	.20	6.3	6.0	6.1	6.0	6.0	.22
Proline	4.8	4.2	4.0	3.6	3.9	.23	5.4[b]	4.5[c]	4.4[c]	4.3[c]	4.2[c]	.15
N, % of DM	12.64						10.98					
AA N, % of total N	73						84					

[a]Value for one cow.
[bcd]For each feedstuff, means in the same row with no common superscript differ ($P < .05$).

Table 3. The amino acid (AA) profile (g AA/100 g AA) of original feedstuffs (O), profile of residue remaining after 8 h (R-8) or 12 h (R-12) of ruminal incubation, and profile of intestinally digested amino acids following 8 h (I-8) or 12 h (I-12) of ruminal incubation for soybean meal and sopralin

	Soybean meal						Sopralin					
Amino acid	O	R-8	R-12	I-8	I-12[a]	SEM	O	R-8	R-12	I-8[a]	I-12	SEM
Cysteine	1.3	1.6	1.6	1.6	1.6	.15	1.4	1.6	1.5	1.6	1.5[a]	.13
Aspartic acid	11.8	11.7	11.7	11.7	11.8	.12	12.0	11.7	11.9	11.6	11.9	.17
Methionine	1.5	2.0	1.8	2.0	1.8	.18	1.6	2.0	1.8	1.9	1.8	.14
Threonine	4.1[b]	4.5[c]	4.5[c]	4.5[c]	4.5[c]	.04	4.1	4.0	4.1	4.0	4.1	.08
Serine	5.2	5.4	5.4	5.4	5.4	.05	5.2	5.1	5.3	5.0	5.2	.08
Glutamic acid	19.1[b]	16.9[c]	16.8[c]	17.1[c]	16.9[c]	.18	19.6	19.0	19.2	18.9	19.2	.31
Glycine	4.4[b]	4.6[c]	4.7[c]	4.6[c]	4.7[c]	.05	4.4	4.3	4.4	4.3	4.4	.08
Alanine	4.4	4.6	5.0	4.6	5.0	.25	4.5	4.4	4.5	4.4	4.5	.10
Valine	5.1[b]	5.9[c]	5.8[c]	5.9[c]	5.8[c]	.04	5.1	5.4	5.2	5.4	5.2	.06
Isoleucine	4.8[b]	5.2[c]	5.2[c]	5.3[c]	5.2[c]	.03	4.8	4.9	4.9	5.0	4.9	.09
Leucine	8.0[b]	8.7[cd]	8.6[c]	8.8[d]	8.6[c]	.07	8.0	8.2	8.1	8.1	8.1	.09
Tyrosine	4.0[b]	4.3[cd]	4.3[c]	4.4[d]	4.3[c]	.02	3.6	4.0	3.9	4.0	3.9	.10
Phenylalanine	5.3[b]	5.6[cd]	5.4[b]	5.6[c]	5.4[bd]	.05	5.2	5.4	5.3	5.4	5.3	.11
Histidine	2.6	2.6	2.5	2.6	2.5	.05	2.7	2.5	2.5	2.6	2.5	.06
Lysine	6.3[b]	4.6[c]	5.4[d]	4.6[c]	5.3[d]	.15	5.7	5.0	5.1	4.9	5.1	.15
Arginine	7.6[b]	6.4[cd]	6.2[cd]	6.5[c]	6.1[d]	.10	7.2	6.8	6.8	7.0	6.9	.08
Proline	4.7	5.5	5.1	4.9	5.0	.40	4.9	5.7	5.5	5.9	5.5	.37
N, % of DM	8.72						8.18					
AA N, % of total N	76						73					

[a]Means based on values of two cows.
[b,c,d]For each feedstuff, means in the same row with no common superscript differ ($P < .05$).

Susmel et al. (1989), and 6.2 to 10.1% in three samples of Wainman and Dewey (1988).

For the soybean meal and sopralin samples, values for AAN as a percentage of total N were similar (76 and 73%, respectively). These values were similar to values of 76% and a range of 72.2 to 78% calculated for soybean meal or sopralin from the data of Ganev et al. (1979) and Varvikko et al. (1983), respectively. They were somewhat lower than values calculated from the data of Crooker et al. (1986) for a range of soybean products (83 to 89%). For rapeseed meal, AAN as a percentage of total N was 80%. This is

Table 4. The amino acid (AA) profile (g AA/100 g AA) of original feedstuffs (O), profile of residue remaining after 8 h (R-8) or 12 h (R-12) of ruminal incubation, and profile of intestinally digested amino acids following 8 h (I-8) or 12 h (I-12) of ruminal incubation for rapeseed meal and cottonseed meal

	Rapeseed meal						Cottonseed meal					
Amino acid	O	R-8	R-12	I-8	I-12	SEM	O	R-8	R-12	I-8	I-12	SEM
Cysteine	2.4	2.1	2.1	2.1	1.9	.11	1.6	1.2	1.5	1.2	1.5	.23
Aspartic acid	8.0[a]	8.5[b]	8.6[b]	8.6[b]	8.6[b]	.08	10.1[a]	10.5[b]	10.2[a]	10.6[b]	10.3[a]	.07
Methionine	2.4	2.8	2.6	3.1	2.9	.14	1.8	1.9	2.1	1.8	2.1	.25
Threonine	5.0[a]	5.6[b]	5.7[b]	5.2[a]	5.2[a]	.09	3.6[a]	3.9[b]	3.9[bc]	3.9[bc]	3.8[c]	.04
Serine	4.7[ac]	5.0[ab]	5.2[b]	4.7[c]	4.8[ac]	.09	4.7[a]	5.2[b]	5.0[cd]	5.1[bd]	4.9[ac]	.07
Glutamic acid	19.2[a]	15.7[b]	15.5[b]	16.8[c]	16.8[c]	.22	21.7[a]	20.6[b]	19.8[c]	20.8[b]	20.1[c]	.16
Glycine	5.7	5.5	5.6	5.5	5.5	.11	4.9[ab]	5.1[b]	4.9[b]	5.0[b]	4.8[a]	.06
Alanine	4.9	5.1	5.1	5.4	5.4	.11	4.5[a]	4.9[b]	4.7[c]	4.9[b]	4.7[c]	.05
Valine	5.9[a]	6.8[b]	6.8[bc]	6.6[bc]	6.5[c]	.10	5.1[a]	5.4[b]	5.4[b]	5.4[b]	5.4[b]	.03
Isoleucine	4.4[a]	5.0[b]	5.0[b]	4.9[b]	5.0[b]	.05	3.4[a]	3.8[b]	3.9[b]	3.8[b]	3.9[b]	.03
Leucine	7.8[a]	8.2[a]	8.2[a]	8.6[b]	8.8[b]	.12	6.6[a]	7.1[b]	7.2[b]	7.1[b]	7.3[b]	.07
Tyrosine	3.4[a]	4.4[b]	4.4[b]	4.1[c]	4.1[c]	.05	3.4[a]	3.5[ab]	3.7[b]	3.5[ab]	3.5[ab]	.06
Phenylalanine	4.5[a]	4.8[b]	4.9[bc]	4.9[bc]	5.0[c]	.06	5.7[a]	5.9[ab]	6.1[b]	5.9[ab]	6.1[b]	.09
Histidine	3.0[a]	2.6[b]	2.6[b]	2.6[b]	2.7[b]	.06	2.8	2.7	2.9	2.7	2.8	.05
Lysine	5.9[a]	5.0[b]	5.4[a]	4.5[c]	4.9[b]	.15	4.4	3.9	4.3	3.8	4.2	.15
Arginine	6.2	5.9	5.5	6.5	6.0	.30	11.5[a]	9.9[b]	9.9[b]	10.2[b]	10.2[b]	.22
Proline	6.9[a]	7.0[a]	6.8[a]	6.0[b]	5.8[b]	.15	4.3	4.3	4.5	4.2	4.4	.1
N, % of DM	5.81						6.46					
AA N, % of total N	80						76					

[a,b,c]For each feedstuff, means in the same row with no common superscript differ ($P < .05$).

Table 5. The amino acid (AA) profile (g AA/100 g AA) of original feedstuffs (O), profile of residue remaining after 8 h (R-8) or 12 h (R-12) of ruminal incubation, and profile of intestinally digested amino acids following 8 h (I-8) or 12 h (I-12) of ruminal incubation for corn gluten feed and corn distillers grains with solubles

	Corn gluten feed						Corn distillers grains					
Amino acid	O	R-8	R-12	I-8	I-12[a]	SEM	O	R-8	R-12	I-8	I-12	SEM
Cysteine	2.2[bcd]	2.0[bd]	2.3[bc]	1.9[d]	2.7[c]	.12	1.7	1.8	1.6	1.7	1.6	.07
Aspartic acid	7.2	7.2	7.1	7.1	6.8	.14	6.8[b]	6.4[c]	6.6[c]	6.2[d]	6.4[c]	.06
Methionine	2.1[b]	2.5[b]	3.0[c]	2.5[b]	3.8[d]	.14	2.2	2.6	2.4	2.6	2.4	.11
Threonine	4.2[bc]	4.5[b]	4.5[b]	4.0[cd]	3.7[d]	.09	3.7	3.6	3.6	3.4	3.4	.07
Serine	5.0	5.2	5.0	5.1	4.8	.16	4.7	4.6	4.8	4.6	4.8	.05
Glutamic acid	18.5[bd]	17.8[cd]	17.6[c]	18.8[b]	19.0[b]	.25	20.2	20.2	20.9	20.6	21.4	.35
Glycine	5.4[b]	4.9[c]	4.7[cd]	4.4[d]	3.7[e]	.12	3.8[b]	3.4[c]	3.4[c]	3.2[d]	3.2[d]	.06
Alanine	8.0[b]	7.3[cd]	7.0[c]	7.5[bde]	7.2[ce]	.13	8.4	8.4	8.7	8.5	8.8	.17
Valine	5.7	5.8	5.6	5.7	5.3	.09	5.5[be]	5.5[b]	5.3[ce]	5.3[c]	5.1[d]	.04
Isoleucine	3.7	3.9	3.9	4.0	3.9	.06	4.1[bc]	4.2[c]	4.0[bd]	4.2[c]	4.0[bd]	.04
Leucine	10.2[b]	11.6[c]	11.9[cd]	12.1[de]	12.6[e]	.15	13.5[b]	14.0[cd]	13.8[bd]	14.2[c]	14.1[cd]	.12
Tyrosine	3.4[b]	4.2[c]	4.3[c]	4.2[c]	4.1[c]	.11	4.3[b]	4.6[c]	4.5[c]	4.8[d]	4.6[c]	.05
Phenylalanine	4.4[b]	5.2[c]	5.3[c]	5.3[c]	5.1[c]	.13	5.5	5.5	5.4	5.5	5.5	.11
Histidine	3.1[b]	2.6[c]	2.6[c]	2.6[c]	2.5[c]	.05	2.3	2.1	2.3	2.1	2.3	.11
Lysine	3.3[b]	2.2[ce]	2.6[c]	1.7[d]	1.8[de]	.15	1.7[b]	1.3[c]	1.2[c]	1.0[d]	1.1[cd]	.06
Arginine	4.6[b]	4.1[cd]	4.0[c]	4.3[bd]	4.5[b]	.09	3.1	2.7	2.6	2.9	2.7	.12
Proline	9.2	8.8	8.6	8.8	8.7	.66	8.6	9.1	9.0	9.2	8.6	.29
N, % of DM	3.47						4.24					
AA N, % of total N	69						72					

[a]Value for one cow.
[b,c,d,e]For each feedstuff, means in the same row with no common superscript differ ($P < .05$).

similar to values calculated from the data of Varvikko et al. (1983) for three samples of rapeseed meal or formaldehyde-treated rapeseed meal (81 to 82%) and similar to the value of 86% derived from the data of Varvikko (1986). For the two corn byproducts, corn gluten feed and corn distillers grains, AAN as a percentage of total N was similar (69 and 72%, respectively). These results show that a constant value should not be used for AAN as a percentage of total N in feedstuffs.

Amino Acid Profiles of the Feedstuffs and Their Residues After Ruminal Incubation. The amino acid profiles of the feedstuffs and their residues after the treatments are given in Tables 2 to 5. With sopralin, there were no significant differences in the profile before and after ruminal incubation for 8 or 12 h, indicating that all amino acids were protected to a similar extent by the formaldehyde treatment. Varvikko et al. (1983) and Crooker et al. (1986) reported similar findings with sopralin. However, with all the other feedstuffs, there were differences ($P < 0.05$) in the amino acid profiles after ruminal incubation compared with the original feedstuffs. The extent of the differences varied among feedstuffs and was least with the most undegradable samples: sopralin (as mentioned above), the fishmeals, and corn distillers grains. With these feedstuffs, any changes were generally small in magnitude. Exceptions to this would be the fall in the glycine proportion of the fishmeal samples (especially Fishmeal 1) and the fall in the lysine proportion of the corn distillers grains sample after ruminal incubation. Ganev et al. (1979), Crooker et al. (1987), and Erasmus et al. (1994) also reported glycine to be more degradable than average in fishmeal samples, and Stern et al. (1983) reported lysine to be the most ruminally degradable amino acid in corn gluten meal. With the other more degradable feedstuffs, the differences in amino acid profile before and after ruminal incubation were more substantial. Thus, this study confirms previous reports (Crooker et al., 1986; Crooker et al., 1987; Erasmus et al., 1994; Cozzi et al., 1995) that the amino acid profile of the feedstuffs cannot be used to predict the profile of the undegraded residues.

In general, the degradability of individual amino acids was feed dependent, but some patterns were observed. Lysine seems to be one of the more degradable of the important amino acids. It decreased, or tended to decrease, as a proportion of total amino acids after ruminal incubation with all feedstuffs except the fishmeals. Erasmus et al. (1994) reported a similar finding with nine of 12 feedstuffs. Methionine was reported by Tamminga (1979) to be one of the amino acids most resistant to ruminal degradation, and it increased, or tended to increase, as a proportion of total amino acids after ruminal incubation with all feedstuffs in this study. Similar observations were found for phenylalanine. Erasmus et al. (1994) reported a similar finding for phenylalanine with all their 12 feedstuffs except soybean meal. Glutamic acid was one of the most relatively degradable amino acids in the feedstuffs in which substantial

Table 6. Disappearance (%) of lysine, methionine, histidine, phenylalanine, and total amino acids (AA) in the rumen (after 12 h of ruminal incubation), the total tract, and disappearance (%) in the intestines of what reaches there

Item	Fish 1	Fish 2	SBM[a]	SOP	RSM	CSM	CDG	CGF[b]	SEM
Lysine									
% Rumen disap	28.8[c]	28.7[c]	67.6[ef]	30.2[c]	71.1[f]	60.3[e]	40.0[d]	82.5[g]	3.17
% Intestinal disap	97.9[f]	98.2[f]	93.6[ef]	95.8[ef]	71.3[d]	91.9[e]	75.6[d]	49.6[c]	2.18
% Total disap	98.6[e]	98.7[e]	98.1[e]	97.1[e]	91.8[d]	97.1[e]	85.4[c]	91.8[d]	.92
Methionine									
% Rumen disap	22.5[c]	21.4[c]	53.1[e]	12.0[d]	65.0[f]	54.3[e]	9.1[d]	67.7[f]	2.32
% Intestinal disap	97.3[ef]	95.2[de]	100[f]	96.9[ef]	85.7[c]	92.9[d]	84.9[c]	86.5[c]	1.31
% Total disap	97.9[cdef]	96.2[def]	100[c]	97.4[cdef]	95.0[def]	96.8[cdf]	86.3[g]	95.2[f]	1.11
Histidine									
% Rumen disap	23.1[cd]	32.6[c]	63.5[eg]	28.9[cd]	72.7[fg]	58.2[e]	18.6[d]	81.3[f]	3.69
% Intestinal disap	97.7[f]	97.1[f]	93.3[ef]	95.9[ef]	81.9[d]	92.5[e]	85.1[d]	72.6[c]	1.65
% Total disap	98.2[f]	98.1[f]	97.7[ef]	97.2[ef]	95.1[de]	97.1[ef]	87.9[c]	95.1[def]	.88
Phenylalanine									
% Rumen disap	23.4[c]	25.6[c]	60.9[de]	19.4[c]	65.9[ef]	56.6[de]	16.9[c]	72.6[f]	3.54
% Intestinal disap	96.9[ef]	96.7[ef]	100[f]	95.6[ef]	80.9[d]	94.7[e]	84.9[d]	73.5[c]	1.65
% Total disap	97.7[fg]	97.6[fg]	100[g]	96.5[ef]	93.6[d]	97.8[fg]	87.4[c]	93.0[de]	1.04
Total AA									
% Rumen disap	31.0[d]	29.5[d]	62.2[e]	21.3[cd]	68.8[ef]	59.7[e]	16.6[c]	77.6[f]	3.57
% Intestinal disap	97.2[e]	96.0[e]	95.5[e]	95.7[e]	78.8[c]	94.1[e]	83.9[d]	75.6[c]	1.78
% Total disap	98.1[e]	97.2[e]	98[e]	96.7[e]	93.5[d]	97.8[e]	86.6[c]	94.6[de]	.98

[a]Values for two cows for percentage of intestinal and total tract disappearance.
[b]Values for one cow for percentage of intestinal and total tract disappearance.
[c,d,e,f,g]Means in the same row with no common superscript differ ($P < .05$). Fish 1 = fishmeal 1, Fish 2 = fishmeal 2, SBM = soybean meal, SOP = sopralin, RSM = rapeseed meal, CSM = cottonseed meal, CDG = corn distillers grains, CGF = corn gluten feed.

degradation occurred (i.e., soybean meal, rapeseed meal, cottonseed meal, and corn gluten feed). Isoleucine and leucine were more relatively resistant than average to ruminal degradation in these feedstuffs, as has been previously reported (Susmel et al., 1989; Erasmus et al., 1994). Arginine was one of the more relatively degradable amino acids and was lower in proportion in all the feedstuff residues than in the original feedstuffs. However, several of the decreases were small and not significant. Changes in the proportions of other amino acids were feed dependent.

Differences Between Amino Acid Profiles After 8 and 12 Hours of Ruminal Incubation. There were some significant differences between the AA profiles after 8 or 12 h of ruminal incubation but most of these were small in magnitude (Tables 2 to 5). Exceptions of note were the higher methionine proportion in corn gluten feed after 12 h of ruminal incubation compared with 8 h, which was due to the resistance of methionine to ruminal degradation noted above, and the higher lysine proportion in soybean meal after 12 h of ruminal incubation compared with 8 h, which was also reported by Cozzi et al. (1995). Thus, it seems that once a certain amount of soybean lysine is degraded, the remainder is more resistant to ruminal degradation. However, in general, there was little difference in the amino acid profile of feedstuffs after 8 or 12 h of ruminal incubation.

Bacterial Contamination of the Residues. The lower lysine proportions in the corn byproduct residues after ruminal incubation compared with the original feedstuff (Table 5) provided evidence that the extent of bacterial contamination of these residues was small. Storm (1982) found the average lysine concentration of bacterial AA to be 8.5% in a review of 29 published values. If there was any significant bacterial contamination of low lysine products such as the corn byproducts, the apparent ruminal disappearance of lysine (Table 6) would be an underestimate. But apparent ruminal disappearance of lysine is very high in corn gluten feed (82.5%), and in corn distillers grains, it is much higher than the average disappearance of amino acids (40 vs 16.6%). These results suggest that there was little bacterial contamination of these products.

Erasmus et al. (1994) examined 12 feedstuffs and reported an average bacterial contamination of 3.9% (range .9 to 8.6%) after 16 h of ruminal incubation. This was lower than the range of 8 to 26% reported by Crooker et al. (1987). Crooker et al. (1987) washed their bags under tap water to remove adhering ruminal contents, whereas Erasmus et al. (1994) washed their bags in a washing machine for 10 min. This difference in washing procedure was identified by Erasmus et al. (1994) as a possible reason for the lower level of contamination found in their residues. In this experiment, bags were washed for an even longer period (25 min) in a washing machine. The evidence from the lysine concentrations of the ruminally incubated residues and the vigorous washing

Table 7. Amino acid (AA) profile (g AA/100 g AA) of feedstuff residues after 12 h of ruminal incubation

Amino acid	Fish 1	Fish 2	SBM	SOP	RSM	CSM	CDG	CGF	SEM
Cysteine	1.1^{ab}	1.1^{a}	1.6^{c}	1.5^{bc}	2.1^{d}	1.5^{bc}	1.6^{c}	2.3^{d}	.13
Aspartic acid	10.1^{d}	10.3^{d}	11.7^{e}	11.9^{e}	8.6^{c}	10.2^{d}	6.5^{a}	7.1^{b}	.10
Methionine	3.8^{e}	3.6^{e}	1.8^{a}	1.8^{a}	2.6^{cd}	2.1^{ab}	2.4^{bc}	3.0^{d}	.17
Threonine	5.0^{e}	4.8^{e}	4.5^{d}	4.1^{c}	5.7^{f}	3.9^{b}	3.5^{a}	4.5^{d}	.07
Serine	4.3^{a}	4.4^{a}	5.4^{e}	5.3^{e}	5.2^{de}	5.0^{c}	4.8^{b}	5.0^{cd}	.07
Glutamic acid	14.4^{a}	14.1^{a}	16.8^{c}	19.2^{e}	15.5^{b}	19.8^{e}	20.9^{f}	17.6^{d}	.22
Glycine	4.5^{bc}	5.9^{f}	4.7^{c}	4.4^{b}	5.6^{e}	4.9^{d}	3.4^{a}	4.7^{c}	.06
Alanine	6.4^{d}	6.1^{d}	5.0^{bc}	4.5^{a}	5.1^{c}	4.7^{ab}	8.7^{e}	7.0^{f}	.10
Valine	6.3^{f}	6.0^{e}	5.8^{d}	5.2^{a}	6.8^{g}	5.4^{bc}	5.3^{ab}	5.6^{c}	.05
Isoleucine	5.3^{d}	5.1^{cd}	5.2^{d}	4.9^{b}	5.0^{bc}	3.9^{a}	4.0^{a}	3.9^{a}	.05
Leucine	8.9^{e}	8.4^{cd}	8.6^{d}	8.1^{b}	8.2^{bc}	7.2^{a}	13.8^{f}	11.9^{g}	.07
Tyrosine	4.0^{b}	4.1^{b}	4.3^{c}	3.9^{b}	4.4^{cd}	3.7^{a}	4.5^{d}	4.3^{c}	.05
Phenylalanine	4.5^{a}	4.6^{a}	5.4^{c}	5.3^{c}	4.9^{b}	6.1^{d}	5.4^{c}	5.3^{c}	.08
Histidine	2.7^{def}	2.9^{ef}	2.5^{bc}	2.5^{bc}	2.6^{cde}	2.9^{f}	2.3^{ab}	2.6^{cd}	.08
Lysine	8.5^{e}	8.2^{e}	5.4^{d}	5.1^{d}	5.4^{d}	4.3^{c}	1.2^{a}	2.6^{b}	.12
Arginine	6.2^{d}	6.1^{d}	6.2^{d}	6.8^{e}	5.5^{c}	9.9^{f}	2.6^{a}	4.0^{b}	.13
Proline	4.0^{a}	4.4^{a}	5.1^{b}	5.5^{b}	6.8^{c}	4.5^{a}	9.0^{d}	8.6^{d}	.18

[a,b,c,d,e,f,g]Comparable means in the same row with no common superscript differ ($P < .05$). Fish 1 = fishmeal 1, Fish 2 = fishmeal 2, SBM = soybean meal, SOP = sopralin, RSM = rapeseed meal, CSM = cottonseed meal, CDG = corn distillers grains, CGF = corn gluten feed.

procedure suggests that the results reported here can be interpreted without fear of significant distortion due to bacterial contamination.

Profile of the Amino Acids Disappearing During Intestinal Passage. There were few differences between the amino acid profiles of absorbed amino acids (i.e., what disappeared during intestinal passage) and the amino acid profiles after ruminal incubation (Tables 2 to 5). This is in agreement with the results of Erasmus et al. (1994). It is not surprising, because for all the feedstuffs, except rapeseed meal, corn gluten feed, and corn distillers grains, approximately 95% or more of the amino acids entering the small intestine disappeared during intestinal passage (Table 6). With rapeseed meal, threonine, serine, tyrosine, lysine, and proline, proportions were lower in the intestinally digested residues than in the residues after ruminal incubation, but the opposite occurred with glutamic acid and leucine (Table 4). With corn gluten feed, glycine and lysine proportions were lower in the intestinally digested residues than in the residues after ruminal incubation, but the opposite occurred with glutamic acid and arginine (Table 5). With corn distillers grains, glycine proportion was lower in the intestinally digested residues than in the residues after ruminal incubation, and the same occurred, or tended to occur, with valine and lysine (Table 5). In general, differences were small in magnitude and followed no definite pattern, except that with all three feedstuffs, lysine made up a lower proportion in the intestinally digested residues than in the residues after ruminal incubation. These data show that the profile of amino acids after ruminal incubation could be used to predict the profile of absorbed amino acids for feedstuffs with high intestinal digestibility, and in general, for feedstuffs with poorer intestinal digestibility. However, with the latter feedstuffs, lysine seems to have poorer than average digestibility, and some other feed-dependent adjustments may need to be made.

Comparison Between Feedstuffs of Their Direct Amino Acid Contribution to Ruminants. Feedstuffs can contribute to the amino acid requirements of ruminants directly by absorption of bypass amino acids or indirectly by use in microbial protein synthesis. This article deals with their direct contribution only. Table 7 shows the amino acid profiles of each of the feedstuff residues after 12 h of ruminal incubation. Such comparisons are useful for comparing the value of a certain amount of bypass protein from one feedstuff with the value for the same amount from another feedstuff. Fishmeal residues had the highest concentrations of lysine and methionine, with the corn byproduct residues having very low lysine concentrations. The two fishmeal samples had lower concentrations of phenylalanine than the other feedstuffs. Histidine concentrations showed some variation between the feedstuff residues, but the differences were small in magnitude. There were also differences among the residues in all of the other amino acids, but it is the concentrations of lysine and methionine that have the greatest effect on the value of a given quantity of bypass protein, because these are often considered to be first limiting for milk protein production (Schwab et al., 1976; Casper and Schingoethe, 1989; Fraser et al., 1991; Munneke et al., 1991; Rulquin et al., 1993).

The intestinal digestibility of bypass amino acids is also a factor in determining the value of bypass protein. Table 6 compares the site and extent of disappearance of lysine, methionine, histidine, phenylalanine, and total amino acids for the feedstuffs. The high intestinal disappearance of total

Table 8. The amount of amino acids (g/kg DM of original feedstuff) that disappeared in the intestines following 12 h of ruminal incubation

Amino acid	Fish 1	Fish 2	SBM[a]	SOP	RSM	CSM	CDG	CGF[b]	SEM
Cysteine	4.8^{f}	4.6^{f}	2.5^{e}	4.9^{f}	1.5^{d}	1.8^{d}	2.6^{e}	$.8^{c}$	.16
Aspartic acid	44.2^{f}	44.4^{f}	19.9^{e}	39.1^{f}	7^{cd}	13.3^{de}	10.9^{cd}	2^{c}	2.57
Methionine	16.8^{i}	15.3^{h}	3.1^{e}	5.8^{g}	2.3^{d}	2.6^{de}	4.1^{f}	1.2^{c}	.24
Threonine	21.9^{g}	20.9^{g}	7.6^{e}	13.4^{f}	4.3^{cd}	5^{cde}	5.8^{de}	1.1^{c}	1.07
Serine	18.6^{f}	18.5^{f}	8.7^{e}	17.1^{f}	3.9^{cd}	6.3^{de}	8.2^{e}	1.5^{c}	1.2
Glutamic acid	63.3^{e}	60.8^{e}	28.7^{d}	63^{e}	13.7^{c}	26^{d}	36.3^{d}	5.9^{c}	4.19
Glycine	19.7^{f}	22.8^{g}	7^{d}	14.2^{e}	4.5^{cd}	6.2^{d}	5.4^{d}	1^{c}	1.06
Alanine	28^{f}	26^{f}	8.4^{d}	14.8^{e}	4.4^{c}	6.1^{cd}	15^{e}	2.2^{c}	1.3
Valine	27.5^{g}	26.2^{g}	9.6^{e}	17^{f}	5.3^{cd}	7^{de}	8.7^{e}	1.6^{c}	1.19
Isoleucine	23.2^{h}	22.5^{h}	8.9^{f}	15.8^{g}	4.1^{cd}	5^{de}	6.8^{ef}	1.2^{c}	.97
Leucine	42.6^{h}	36.6^{g}	14.5^{e}	26.4^{f}	7.1^{cd}	9.4^{cde}	24^{f}	3.9^{c}	1.97
Tyrosine	17.8^{g}	17.5^{g}	7.5^{e}	12.8^{f}	3.4^{cd}	4.6^{d}	7.9^{e}	1.2^{c}	.75
Phenylalanine	19.6^{e}	19.8^{e}	9.4^{d}	17.3^{e}	4.1^{c}	7.9^{d}	9.3^{d}	1.6^{c}	1.01
Histidine	12^{f}	12.3^{f}	4.1^{d}	8^{e}	2.2^{c}	3.7^{d}	3.9^{d}	$.7^{c}$	.52
Lysine	37.6^{g}	35.7^{g}	8.6^{e}	16.6^{f}	4^{cd}	5.5^{de}	1.9^{c}	$.5^{c}$	1.24
Arginine	27.3^{f}	25.8^{ef}	10.6^{d}	22.4^{e}	4.9^{c}	13.3^{d}	4.6^{c}	1.4^{c}	1.59
Proline	17.3^{ef}	17.8^{f}	8.8^{d}	17.8^{f}	4.7^{c}	5.7^{cd}	14.5^{e}	2.6^{c}	1.12
Total	439^{g}	427^{g}	168^{e}	326^{f}	81^{cd}	129^{de}	170^{e}	31^{c}	20.6

[a]Values for two cows.
[b]Values for one cow.
[cdefghi]Means in the same row with no common superscript differ ($P < .05$). Fish 1 = fishmeal 1, Fish 2 = fishmeal 2, SBM = soybean meal, SOP = sopralin, RSM = rapeseed meal, CSM = cottonseed meal, CDG = corn distillers grains, CGF = corn gluten feed.

amino acids in most feedstuffs has been referred to above. It was somewhat lower for rapeseed meal, corn distillers grains, and corn gluten feed. Disappearances of lysine, methionine, phenylalanine, and histidine were, in general, quite similar to the disappearance of total amino acids for all feedstuffs. However, the observation that lysine disappearance was lower than total amino acid disappearance in rapeseed meal, corn distillers grains, and corn gluten feed has already been made. The low intestinal digestibility of rapeseed meal and corn gluten feed is of little consequence because of the small percentage of their amino acids that are available for postruminal digestion (Table 6), but it could have implications for rumen-protected rapeseed meal. With corn distillers grains, the low disappearance in the intestines results in low overall disappearance, but the proportion of its amino acids that actually disappear in the intestines is very large because of the very low ruminal disappearance. This demonstrates that the level of bypass amino acids in the feedstuffs is at least as important as the amino acid profiles of the feed residues and their intestinal digestibility when considering the direct amino acid contribution of feedstuffs.

Table 8 combines all of the factors affecting direct amino acid contribution of feedstuffs and shows the amount of each amino acid that disappeared in the intestines following 12 h of ruminal incubation. The fishmeal samples had the highest disappearance of total amino acids (439 and 427 g for Fishmeals 1 and 2, respectively), with sopralin being the next highest (326 g). Corn distillers grains had the same postruminal disappearance of amino acids as soybean meal (170 and 168 g, respectively). Only 31 g of amino acids disappeared postruminally per kilogram of DM of corn gluten feed. Even though postruminal disappearance of most individual amino acids followed the same general trend, there were many exceptions. Lysine disappearance was far higher with the fishmeal samples than with any of the other feedstuffs, and it was extremely low with both of the corn byproducts. Methionine disappearance was substantially higher with the fishmeal samples than with the other feedstuffs. Corn distillers grains had a higher methionine disappearance than any of the other feedstuffs except sopralin.

In summary, these results show variation among feedstuffs in the percentage of total N that is amino acid N, in the proportion and profile of amino acids remaining after ruminal incubation, in the profile of amino acids disappearing during intestinal passage, and in the extent of amino acid disappearance during intestinal passage. Variations such as these should be considered when the protein quality of feedstuffs is assessed, and as amino acid requirements become better established, the resultant new knowledge should be incorporated into protein feeding and diet formulation systems.

Implications

These results show that the amino acid profile of bypass protein is different from that of the original feedstuff protein. The profile of amino acids absorbed from the intestines is similar to that of the bypass protein, but again is different from that of the original feedstuff protein and should be considered in protein evaluation systems. There is considerable variation in the amount of total and individual amino acids that feedstuffs will supply to the intestines for absorption, and this should be considered when evaluating their protein quality.

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