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Rumen degradability of concentrate protein, amino acids and starch, and their digestibility in the small intestine of cows*

Teresa Żebrowska, Zofia Długołęcka, J.J. Pająk and W. Korczyński

The Kielanowski Institute of Animal Physiology and Nutrition, Polish Academy of Sciences 05-110 Jabłonna, Poland

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ABSTRACT

The *in situ* and mobile nylon bag methods were used to determine the effective degradability of dry matter, crude protein and starch in the rumen and the digestibility of undegraded protein and individual amino acids of various feeds in the small intestine of the cow. The tested feeds included rapeseed oilmeal obtained from six industrial oil mills, soyabean oilmeal, field peas (coloured flowered), peas, field beans, lupin, rye, triticale, wheat, barley, oats, and wheat, rye and barley bran. The chemical and amino acid composition of the rapeseed meals from different sources was similar, and effective protein degradability, calculated assuming $k = 0.05$, ranged from 62 to 70%. The effective protein degradability of oilmeals was lower than in the legume seeds and cereal grains. Among cereals, oats had the highest effective protein degradability (92%), the lowest was found in winter barley (75%). The disappearance of total N in the rumen from rapeseed meals was lower than of total amino acids; in the remaining feeds these values were similar. Glutamic acid and arginine were degraded to a greater extent than the remaining amino acids, regardless of the type of feed. Intestinal digestibilities of total N and amino acids of feeds that were less degradable in the rumen, were higher. Cereal starch was degraded in the rumen to a higher extent than starch in legume seeds.

KEY WORDS: rumen, concentrates, amino acid profile, protein, ruminal degradability, intestinal digestibility

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INTRODUCTION

In modern nutrition systems for ruminants, the amount of amino acids absorbed in the small intestine is taken as a measure of the amount of amino acids available for further metabolism. Amino acids absorbed in the intestine come from two main sources: bacterial protein synthesized in the rumen and rumen undegraded protein (RUP) of feeds, as well as from endogenous protein secreted into the lumen of the intestinal tract. The true digestibility of bacterial protein in the intestine is relatively stable and ranges between 80-85% (Vérité and Peyraud, 1989; Hvelplund and Masden, 1990), while true digestibility of RUP of various feeds can vary a great deal (Hvelplund, 1985; Van Straalen et al., 1993; Erasmus et al., 1994; Kusumanti et al., 1996). These differences depend to a considerable degree on the type of feed and the technology used in its production. Intestinal digestibility of RUP also depends on its degree of ruminal degradability (Hvelplund, 1992). The rate of protein degradation in the rumen and the intestinal digestibility of RUP are thus important indicators of the nutritional value of feed protein for ruminants.

The main components of concentrates and concentrate mixtures for ruminants in Poland are cereal grains and bran, rapeseed and soyabean oilmeals (for young animals), legume seeds, chiefly field bean, lupin, field peas. These feeds differ in their chemical composition, and the nutritional value of their protein may vary, depending on the species and variety, as well as production technology.

The aim of this study was to determine the extent and rate of ruminal degradation and intestinal digestibility of protein, individual amino acids and starch of domestic concentrates made with various species and varieties of cereal, legume seeds and by-products from different plants.

MATERIAL AND METHODS

Animals and nutrition

The experiment was conducted on 3 cows with body weights of about 500 kg with fistulas in the rumen and duodenum. They were fed meadow hay to appetite with 1.5 kg/day mineral-supplemented barley meal, twice daily at 8^{00} and 15^{00}. Water was available *ad libitum*.

Feeds

The following feeds were studied: spring and winter barley, spring and winter wheat, rye, triticale, oats, field pea (coloured flowered) cv. Miga and Gamit, peas, field bean cv. Dino and Nadwiślański, narrow-leafed yellow lupin cv. Juno and Wat; all of these feeds were produced by Experimental Station Poświętne (central Poland). Wheat, rye and barley brans were bought from mill Białołęka (near Warsaw), soyabean and rapeseed oilmeals were made by 6 oil mills from various regions of the country.

Dry matter, crude protein and starch degradability

The degradability of dry matter, protein and starch in the rumen was determined using the *in sacco* method (Mehrez and Ørskov, 1977). Feeds were ground in a Tecator mill with a sieve pore diameter of 2 mm, and 5 g samples of feeds were placed in 11 x 8 cm nylon bags (42 μm pore size). The nylon bags containing feeds were incubated in the rumen for 2, 4, 8, 16, 24 and 48 h. For the 2, 4 and 8 h incubation period, 6 bags of each feed were placed in the rumens of 3 cows, for the 24 and 48 h incubations, 15 bags of each feed were used, and for the 16 h incubation, 30 bags were inserted in order to obtain sufficient amounts of material to determine intestinal crude protein and amino acid digestibility by the mobile bag method.

After removal from the rumen, the bags were rinsed for 15 min in an automatic washing machine, dried in a draft drier at 60^{0}C for 24 h, then weighed and pooled samples were prepared separately for each cow, duration of incubation and feed. In order to determine the loss of contents due to washing, a „0" sample was prepared using 5 g of each feed in 7 bags, which were washed and dried in the same manner as samples after incubation.

Crude protein and amino acids disapperance form the mobile bags

Intestinal digestibility of protein undegraded in the rumen was determined according to Hvelplund et al. (1992) by the mobile bag method. The material collected after incubation in the rumen for 16 h was weighed (0.5 g) and placed in 3x4 cm nylon bags (pore size 42 m); 90 bags were prepared for each feed, 30 per cow. The bags were incubated in a pepsin solution (100 mg pepsin/L 0.004 M HCl) at a temp. of 39^{0}C for 2 h. Next, 5 bags per h were introduced through the cannula into the duodenum. The bags were removed from the faeces, washed in a washing machine, dried in a draft drier at 60^{0}C for 24 h, weighed, and pooled samples were prepared for analysis. The amino acid composition of the residue after incubation in the rumen and intestine was determined in samples pooled from all of the cows for each feed, on the basis of the total nitrogen content in the individual samples.

Chemical analyses

The basic chemical composition of feeds was determined by conventional methods, starch was assayed in cereals, peas and beans by an enzymatic method (AOAC, 1990). Dry matter and total N were determined in samples incubated in the rumen, and starch was also determined in the residue following incubation in the rumen of cereal and legume feeds. The amino acid composition of feeds, samples after incubation in the rumen and intestine were determined using a Beckman amino acid analyzer. Samples were hydrolyzed in 6N HCl at 110^0 for 22 h. Methionine and cystine were determined after preliminary oxidation of samples with performic acid. Tryptophan was not determined.

Calculations

The effective degradabilities of dry matter, crude protein and starch were computed using NAWAY (Rowet Research Institute) software that is based on the equation developed by McDonald (1981) using a constant outflow rate of $k = 0.05$. Degradability of crude protein and amino acids in the rumen was computed from the difference in the content of these components in feeds and samples after 16 h of incubation in the rumen, while digestibility in the small intestine was calculated as the difference between the content of these components in samples after incubation in the rumen and their content in the mobile bags after passing through the intestine.

RESULTS

Rapeseed and soyabean oilmeal

The chemical composition of samples from 6 oil mills was uniform (Table 1). The protein content in dry matter equaled 35.3-36.4%, crude fibre 11.7-15.1%, ether extract 2.7-4.4%. The amino acid composition of these samples was also very similar (Table 2).

The rate of degradation in the rumen of dry matter and crude protein in all samples of rapeseed oilmeal was similar, but the samples from oil mill Kruszwica had a tendency to progress more rapidly, while those from oil mill Gdynia more slowly, than the other samples. The effective dry matter degradability ranged from 58.1 to 63.9, of crude protein from 62.5 (Gdynia) to 70.1% (Kruszwica) (Table 5). The average effective degradability of dry matter of rapeseed oilmeals was 5 percentage units lower than that of protein.

TABLE 1

Chemical composition of feeds, %

Feeds	Dry matter	Ash	Crude protein	Ether extract	Fibre	N-free extractives	Starch
Rapeseed oilmeal							
A	87.8	7.7	35.6	3.1	11.7	41.9	
B	89.6	7.5	36.3	4.2	14.3	37.7	
C	89.8	7.3	35.5	3.7	13.1	40.3	
D	89.4	7.6	36.4	3.0	13.6	39.4	
E	85.4	7.8	35.6	3.8	14.8	38.1	
F	90.1	7.4	36.1	3.9	13.7	38.8	
Soyabean oilmeal	88.1	6.4	51.7	1.2	4.9	35.5	4.3
Wheat bran	89.2	5.3	16.1	4.6	10.9	63.1	25.7
Rye bran	87.9	4.6	14.9	3.1	6.0	71.4	31.3
Barley bran	87.5	4.6	12.8	3.9	11.1	67.5	40.8
Barley, spring Klimek	85.8	2.4	12.1	1.5	5.4	78.6	53.3
winter Gil	88.6	2.3	11.3	2.9	5.5	78.0	55.2
Rye, Dańkowskie Złote	84.9	1.8	12.5	1.9	1.9	81.9	59.6
Triticale, Presto	85.2	1.8	15.4	1.3	2.0	79.5	64.4
Wheat, spring Henika	86.2	1.9	13.8	1.7	2.2	80.4	61.9
winter Kamila	85.6	1.6	16.1	2.1	2.5	77.7	62.3
Oat	89.2	2.2	10.5	4.5	11.9	70.7	47.3
Field pea, Mige	85.8	3.6	27.7	1.1	5.9	61.7	36.2
Gomik	85.5	3.5	26.3	1.7	6.6	61.9	37.9
Pea, Kwestor	86.9	3.5	25.9	1.2	6.3	63.1	36.4
Field bean, Dino	88.1	3.7	29.9	0.6	7.1	58.7	30.5
Nadwiślański	86.6	4.0	30.4	1.1	8.7	55.8	35.1
Lupin, narrow leaved Emir	87.9	3.9	34.8	5.4	15.7	40.2	1.3
yellow Juno	86.4	5.4	42.7	5.6	15.6	30.7	1.3
white Wat	88.1	4.0	31.2	9.2	15.7	39.9	1.6

A – oil mill – Bielsko Biała
B – oil mill – Brzeg
C – oil mill – Gdynia
D – oil mill – Kruszwica
E – oil mill – Szamotuły
F – oil mill – Warszawa

TABLE 2

Amino acid (AA) profile (g AA/100 g AA) of rapeseed oilmeals and soyabean oilmeal

Amino acids	Rapeseed oilmeals[1]						Soyabean oilmeal
	A	B	C	D	E	F	
Asp	8.1	8.3	8.2	8.4	8.2	8.0	11.7
Thr	4.8	5.0	4.8	4.9	5.0	4.8	3.9
Ser	4.5	4.7	4.6	4.7	4.7	4.6	5.0
Glu	20.6	20.5	19.9	19.9	20.0	20.1	20.8
Pro	6.5	6.6	6.5	6.5	6.5	6.5	5.9
Gly	5.5	5.6	5.5	5.6	5.5	5.5	4.1
Ala	4.7	4.8	4.8	4.8	4.8	4.7	4.2
Val	6.0	6.0	6.0	6.1	6.0	5.8	4.9
Ile	4.2	4.2	4.2	4.1	4.2	4.1	4.2
Leu	7.4	7.4	7.4	7.5	7.5	7.5	7.4
Tyr	3.1	3.0	3.1	3.1	3.3	3.0	3.4
Phe	4.2	4.3	4.3	4.3	4.4	4.2	5.0
His	2.7	2.8	3.1	2.9	2.9	2.9	2.6
Lys	6.0	5.8	5.6	6.0	5.8	6.1	6.3
Arg	6.3	6.1	6.3	6.5	6.4	6.3	7.4
Cys	2.7	2.5	2.7	2.4	2.4	2.7	1.6
Met	2.2	2.2	2.3	2.1	2.2	2.2	1.5

[1] refer to Table 1

TABLE 3

Amino acid (AA) profile (g AA/100 g AA) of cereal grains and cereal brans

Amino acids	Barley		Rye Dańkowskie Złote	Triticale	Wheat		Oats	Bran		
	spring	winter			spring	winter		rye	barley	wheat
Asp	6.4	6.3	7.4	6.0	6.1	4.9	8.6	9.3	6.8	7.6
Thr	3.7	3.8	3.5	3.1	3.2	2.9	3.8	4.1	3.5	3.7
Ser	4.4	4.5	4.4	4.7	4.4	4.5	5.0	4.6	4.4	4.7
Glu	27.5	26.5	27.9	32.0	30.7	34.7	22.3	21.0	24.7	23.9
Pro	11.0	11.0	10.8	10.2	10.2	10.4	5.5	7.5	9.8	7.3
Gly	4.1	4.4	4.3	4.1	4.0	3.8	5.2	5.5	4.5	5.5
Ala	4.1	4.3	4.1	3.8	3.8	3.4	4.9	5.2	4.6	5.0
Val	5.5	5.5	5.0	4.7	5.0	4.4	5.7	5.5	5.5	5.3
Ile	3.5	3.5	3.4	3.3	3.5	3.5	3.8	3.6	3.6	3.5
Leu	7.0	7.0	6.3	6.4	6.6	6.6	7.6	6.6	7.1	6.7
Tyr	3.1	3.3	2.7	2.8	2.8	2.7	3.4	3.0	3.2	3.1
Phe	5.2	5.0	4.8	4.6	4.8	5.0	5.4	4.5	5.2	4.5
His	2.3	2.2	2.3	2.3	2.3	2.3	2.3	2.9	2.5	3.1
Lys	3.6	3.8	3.6	3.0	3.2	2.6	4.5	5.0	4.3	4.5
Arg	5.1	5.3	5.4	5.0	5.1	4.6	7.1	6.9	6.1	7.6
Cys	2.1	2.4	2.5	2.4	2.5	2.1	3.0	2.7	2.1	2.3
Met	1.5	1.5	1.7	1.6	1.7	1.3	1.7	1.8	1.7	1.7

TABLE 4

Amino acid (AA) profile (g AA/100 g AA) of peas, field beans and lupins

Amino acids	Field pea		Pea	Field bean		Lupin		
	Mige	Gomik	Kwestor	Dino	Nadwiślański	Emir	Juno	Wat
Asp	12.2	12.4	12.4	11.5	11.5	10.3	10.0	11.1
Thr	4.0	3.9	3.9	3.8	3.7	3.7	3.3	3.9
Ser	4.9	4.9	4.9	5.3	5.1	4.9	4.9	5.6
Glu	19.2	19.2	19.5	19.5	19.5	24.7	26.3	23.8
Pro	4.3	4.3	4.5	4.6	4.7	4.3	3.9	4.3
Gly	4.5	4.5	4.5	4.3	4.4	4.4	3.8	4.0
Ala	4.5	4.5	4.4	4.1	4.2	3.5	3.1	3.5
Val	5.1	5.1	5.2	4.9	5.0	4.3	3.8	4.2
Ile	4.0	4.0	4.3	4.1	4.2	3.9	3.8	3.9
Leu	7.1	7.2	7.7	7.9	7.9	7.1	7.7	7.6
Tyr	3.2	3.2	3.5	3.4	3.4	3.5	2.8	4.5
Phe	4.6	4.5	5.2	4.5	4.5	3.9	3.8	4.1
His	2.6	2.6	2.7	2.7	2.8	2.9	2.9	2.3
Lys	7.2	7.3	7.7	6.8	6.7	5.1	5.3	5.2
Arg	10.0	9.9	8.6	10.4	10.4	11.2	11.6	9.4
Cys	1.5	1.5	1.5	1.2	1.3	1.6	2.3	1.6
Met	0.9	0.9	0.9	0.7	0.7	0.7	0.6	0.7

The disappearance of crude protein during 16 h of incubation in the rumen averaged 73.3% and ranged from 66.4 to 79.3%, while that of total amino acids from 68.8 do 80.3% (Table 9). Among essential amino acids, 70.9-80.8% of Lys and 72.2-81.0% of Met disappeared during 16 h incubation in the rumen. A tendency was observed for His and Arg to undergo a higher degree of degradation than other essential amino acids, and for branched chain amino acids to be degraded more slowly.

No differences were observed in the amino acid composition among samples of rapeseed oilmeal before and after 16 h of incubation in the rumen, aside from a clearly lower share of glutamic acid and arginine than in feeds, and higher share of threonine in samples following incubation (Table 6).

The effective ruminal degradability of soyabean oilmeal dry matter was 11 percentage units higher than of crude protein. Crude protein was degraded in the rumen to a lesser extent than that of rapeseed meals (Table 5), while the intestinal digestibility of protein and particular amino acids that were not degraded in the rumen was considerably higher than of rapeseed oilmeal (Table 12).

Cereals

The chemical and amino acid composition of cereal grain and bran is given in Table 1 and 3. The effective degradability of the dry matter of the cereals ranged from 71.2 (oats) to 95.6 (rye). Degradation of bran dry matter was markedly

TABLE 5

Effective degradability of dry matter (DM), crude protein and starch in the rumen (k = 0.05) and intestinal digestibility of rumen undergraded protein estimated by mobile bags method

Feed		Effective degradability			Intestinal digestibility	
		DM	protein	starch	DM	protein
Rapeseed oilmeals						
A		62.7	68.2		42.7	71.4
B		61.2	65.2		46.5	78.6
C		58.1	62.5		49.9	78.6
D		63.9	70.1		34.2	66.5
E		60.9	65.0		40.6	72.2
F		62.6	68.5		38.8	69.5
Soyabean oilmeal		68.7	57.4		89.7	99.0
Cereals						
barley, spring		80.0	81.7	92.6	27.1	81.2
barley, winter		73.8	75.3	85.9	29.9	83.0
rye, Dańkowskie		95.6	87.9	97.8	34.7	69.0
triticale		90.3	74.2	95.7	42.78	8.4
wheat, spring		88.3	78.0	95.9	40.9	87.3
wheat, winter		84.4	77.8	96.0	36.3	86.0
oats		71.2	91.8	99.1	9.6	57.5
rye bran		75.5	83.7	97.2	17.3	44.7
barley bran		69.3	82.3	95.8	15.3	72.0
wheat bran		68.3	80.0	98.0	9.7	58.8
Legumes						
field pea,	Mige	78.3	84.0	74.8	63.8	94.3
	Gomik	77.7	82.7	76.2	54.2	86.1
pea,	Kwestor	73.8	82.3	72.3	70.9	96.7
faba bean,	Dino	67.8	82.5	59.6	51.9	86.1
	Nadwiślański	65.5	83.0	62.1	42.1	80.1
lupin,	Emir	69.9	83.0		24.9	75.8
	Juno	74.2	81.0		22.6	55.9
	Wat	72.2	85.0		26.9	52.4

[1] refer to Table 1

lower than of dry matter in the respective grain, but protein was degraded at a similar rate in both bran and grain. Among the studied cereals, the crude protein of oats and rye was characterized by the fastest rate of degradation. Winter barley grain starch was degraded to a lesser degree in the rumen than the starch of the remaining cereals and bran (Table 5).

The degradability of crude protein of cereal grain during 16 h of incubation ranged from 82.4 (winter barley) to 95.3% (oats) and was similar to the degradability of total amino acid content (Table 11).

TABLE 6

Amino acid (AA) profile of residue from rapeseed oilmeal, and soyabean oilmeal after 16 h incubation in the rumen, g AA/100 g AA

Amino acids	Rapeseed oilmeals[1]						Soyabean oilmeal
	A	B	C	D	E	F	
Asp	9.5	9.3	9.2	9.6	9.4	9.5	11.6
Thr	5.8	5.8	5.6	5.8	5.7	5.8	4.2
Ser	5.4	5.5	5.3	5.4	5.3	5.3	5.5
Glu	14.9	16.2	16.2	15.2	15.9	15.0	8.0
Pro	6.4	6.7	6.4	6.8	6.8	6.8	5.6
Gly	5.7	5.6	5.6	5.6	5.5	5.6	4.3
Ala	5.3	5.3	5.2	5.2	5.1	5.2	4.6
Val	6.6	6.4	6.4	6.7	6.6	6.7	5.1
Ile	4.8	4.6	4.8	4.8	4.8	4.8	4.6
Leu	8.0	8.0	8.1	7.9	8.0	7.8	8.4
Tyr	3.9	3.8	3.8	3.8	3.7	3.9	3.8
Phe	4.8	4.8	4.9	5.0	4.9	4.9	5.3
His	2.5	2.5	2.5	2.5	2.4	2.4	2.4
Lys	6.1	5.6	5.7	6.0	5.9	6.0	6.2
Arg	5.8	5.7	5.8	5.7	5.6	5.7	6.3
Cys	2.1	2.2	2.1	1.8	2.2	2.2	1.7
Met	2.1	2.1	2.1	2.2	2.1	2.1	1.7

[1] refer to Table 1

TABELA 7

Amino acid (AA) profile of residue from cereal grains and bran after 16 h incubation in the rumen, g AA/100 g AA

Amino acids	Barley		Rye Dańkowskie Złote	Triticale	Wheat		Oats	Bran		
	spring	winter			spring	winter		rye	barley	wheat
Asp	7.5	6.7	9.5	7.1	6.4	6.3	10.8	10.3	7.5	9.4
Thr	4.4	4.2	4.5	3.7	3.5	3.4	4.6	4.9	4.1	4.5
Ser	5.1	5.1	5.3	4.9	5.0	5.0	5.0	5.4	4.5	5.1
Glu	13.0	14.5	16.0	25.0	27.3	29.7	16.6	13.2	23.4	15.7
Pro	13.0	14.8	5.9	8.0	9.4	9.4	6.2	5.5	10.1	6.1
Gly	4.9	4.6	6.8	4.9	4.6	4.5	6.2	8.2	4.6	7.1
Ala	5.1	4.6	6.1	4.8	4.3	4.2	6.6	6.4	4.8	6.1
Val	6.5	6.2	6.3	5.6	5.3	5.1	6.2	6.1	5.6	6.0
Ile	4.6	4.4	4.1	4.1	3.9	4.1	4.3	4.3	4.1	3.9
Leu	8.6	8.7	8.0	7.5	7.4	4.3	8.4	7.9	7.7	7.8
Tyr	3.5	5.5	3.4	2.9	2.8	2.8	1.4	3.5	2.9	3.1
Phe	6.7	6.9	5.2	4.9	5.1	5.4	4.8	5.4	5.9	5.1
His	2.6	2.4	2.5	2.3	2.2	2.4	2.0	2.6	1.9	2.8
Lys	4.0	3.5	5.1	3.7	3.5	3.3	5.0	5.1	3.8	4.7
Arg	6.1	5.5	6.9	6.1	5.3	6.1	6.6	6.5	5.2	7.8
Cys	2.1	2.0	2.5	2.1	2.1	2.1	3.1	2.7	1.9	2.7
Met	2.2	1.9	2.0	1.9	2.0	1.9	2.2	2.2	1.7	2.3

TABLE 8

Amino acid (AA) profile of residue from legume seeds after 16 h incubation in the rumen, g AA/100 g AA

Amino acids	Field pea		Pea	Field bean		Lupin		
	Mige	Gomik	Kwestor	Dino	Nadwiślański	Emir	Juno	Wat
Asp	11.8	11.8	11.8	11.5	11.5	12.6	14.0	14.1
Thr	3.7	3.7	3.5	3.8	3.8	4.2	4.8	5.0
Ser	5.1	5.2	5.0	5.3	5.3	5.7	6.3	6.9
Glu	19.7	19.0	19.5	19.2	18.9	19.1	14.0	13.4
Pro	4.6	4.9	4.8	4.9	5.0	5.0	5.3	5.7
Gly	4.3	4.6	4.0	5.0	5.4	4.4	4.8	4.5
Ala	4.4	4.5	4.3	4.2	4.3	4.1	4.6	4.1
Val	5.1	5.2	5.1	5.0	5.0	5.4	6.3	6.9
Ile	4.5	4.6	4.6	4.5	4.5	4.8	5.1	4.8
Leu	8.4	8.4	8.6	8.4	8.3	7.8	8.2	7.9
Tyr	3.1	3.3	3.1	3.6	3.7	3.5	3.6	4.0
Phe	5.2	5.2	5.4	4.8	4.7	5.1	6.5	5.9
His	2.6	2.8	2.5	2.9	2.8	2.4	2.5	2.2
Lys	6.8	6.8	7.3	6.5	6.4	5.8	6.3	7.2
Arg	8.5	8.3	8.0	8.4	8.4	7.7	4.8	4.8
Cys	1.1	1.1	1.1	1.2	1.2	1.6	1.9	1.6
Met	1.0	0.8	1.1	0.9	1.0	0.9	0.8	0.9

TABLE 9

Degradability of crude protein and amino acids from rapeseed oilmeals and soyabean oilmeal during 16 h incubation in the rumen, %

Amino acids	Rapeseed oilmeals[1]							Soyabean oilmeal
	A	B	C	D	E	F	mean	
Crude protein	74.6	68.5	66.4	79.3	73.1	78.0	73.3	70.9
Amino acids								
Asp	73.3	65.9	67.9	78.2	73.5	75.5	72.4	71.4
Thr	73.2	64.9	67.5	77.5	73.1	75.0	71.9	68.5
Ser	73.1	64.5	67.4	78.1	73.4	76.4	72.2	68.9
Glu	84.6	76.2	77.1	85.4	81.3	85.2	81.5	74.3
Pro	78.6	69.7	72.1	80.1	75.5	78.2	75.5	72.2
Gly	77.7	69.6	71.4	80.6	76.7	79.2	75.7	69.4
Ala	75.0	67.1	69.0	79.4	75.0	77.7	73.9	68.2
Val	75.0	67.7	69.6	79.0	74.6	76.3	73.7	70.2
Ile	74.9	66.0	67.1	77.9	72.9	75.9	72.3	68.2
Leu	76.6	67.6	69.3	79.7	75.1	78.2	74.3	67.1
Tyr	72.0	62.8	66.5	77.1	72.5	73.4	70.7	67.5
Phe	74.1	65.8	67.2	78.1	73.5	76.5	72.5	69.4
His	79.1	72.5	77.7	84.2	80.1	82.3	79.3	72.6
Lys	77.9	70.9	71.8	80.8	76.3	79.3	76.0	71.7
Arg	79.4	72.2	74.0	82.9	79.1	81.4	78.2	75.4
Cys	82.2	74.3	77.7	85.9	78.9	83.5	80.4	68.9
Met	79.8	72.2	74.1	80.8	77.1	81.0	77.3	67.2
Mean	76.4	68.8	71.0	80.3	75.8	78.5	75.2	70.1

[1] refer to Table 1

TABELA 10

Degradability of crude protein and amino acids from legume seeds during 16 h incubation in the rumen, %

Amino acids	Field pea		Pea	Field bean		Lupin		
	Mige	Gomik	Kwestor	Dino	Nadwiślański	Emir	Juno	Wat
Crude protein	87.7	87.1	83.1	89.9	82.5	93.2	96.2	95.3
Amino acids								
Asp	89.6	89.5	85.7	87.6	88.0	95.8	97.6	97.1
Thr	89.8	89.5	86.3	87.6	88.0	96.1	97.5	97.2
Ser	88.8	88.5	84.5	87.3	87.7	95.9	97.8	97.2
Glu	88.9	89.1	85.0	87.8	88.4	97.3	99.1	98.7
Pro	88.3	87.4	83.8	86.6	87.1	95.9	97.6	97.0
Gly	89.8	88.8	86.5	85.5	85.2	96.5	97.8	97.5
Ala	89.5	89.2	85.3	87.2	87.7	96.0	97.5	97.3
Val	89.3	88.9	85.3	87.5	88.2	95.7	97.1	96.4
Ile	87.8	87.3	84.0	86.5	87.2	95.9	97.6	97.2
Leu	87.2	87.1	83.2	86.8	87.4	96.2	98.2	97.6
Tyr	89.5	88.8	86.6	86.9	87.1	96.5	97.8	98.0
Phe	87.7	87.5	84.7	86.8	87.6	95.6	97.1	96.7
His	88.8	88.3	86.3	87.2	88.1	97.1	98.5	97.8
Lys	89.7	89.8	85.7	88.0	88.7	96.1	97.9	96.9
Arg	90.8	90.9	86.0	89.9	90.3	97.6	99.3	98.8
Cys	92.1	92.4	88.9	88.3	89.2	96.6	98.6	97.6
Met	88.4	90.4	82.6	85.3	85.4	95.4	97.7	97.1
Mean	89.2	89.0	85.3	87.2	87.7	96.2	97.9	97.4

After 16 h of incubation in the rumen, the amino acid composition of cereal feeds differed from their initial composition, with the largest differences being noted in the contents of glutamic acid, proline and arginine. The intestinal digestibility of rumen undegraded oat and rye protein was lower than that of the remaining cereals. The digestibility of crude protein of rye bran and wheat bran was characteristically low, 44.7 and 58.8%, respectively. The digestibility of total amino acids was similar to that of crude protein in the respective cereal feeds, while lysine digestibility was 7, 10 and 5, and methionine 8, 18 and 10 percentage units higher than the digestibility of total N of rye, rye and oat bran, respectively (Table 13).

Legume seeds

The chemical and amino acid composition of different varieties of legume seeds was similar, only Juno lupin was characterized by a higher crude protein content than the remaining lupin varieties (Tables 1 and 4).

TABLE 11
Degradability of crude protein and amino acids from cereal grains and bran during 16 h incubation in the rumen, %

Amino acids	Barley		Rye Dańkowskie Złote	Triticale	Wheat		Oats	Bran		
	spring	winter			spring	winter		rye	barley	wheat
Crude protein	87.6	82.4	91.6	87.1	88.7	87.2	95.3	90.6	86.7	85.3
Amino acids										
Asp	86.7	84.5	91.5	87.6	85.1	85.5	95.0	90.9	87.0	88.1
Thr	86.6	83.3	91.6	87.4	84.5	86.6	95.3	90.0	86.6	88.6
Ser	86.8	83.3	92.2	88.9	83.9	87.6	96.1	90.3	87.8	89.9
Glu	94.6	81.6	96.2	91.8	87.3	90.3	97.1	94.8	88.9	93.8
Pro	86.5	80.2	96.4	91.7	87.0	89.7	95.5	93.9	88.0	92.0
Gly	86.5	84.5	89.7	87.2	84.2	86.4	95.2	87.7	88.1	87.6
Ala	85.7	83.9	90.5	86.6	83.7	85.8	94.7	89.9	87.4	88.1
Val	86.6	83.3	91.8	87.4	84.6	87.0	90.8	90.8	88.1	89.3
Ile	85.3	81.3	92.0	87.1	84.0	86.5	95.6	90.1	87.0	89.1
Leu	85.9	82.0	91.7	87.7	83.9	92.5	95.6	90.1	87.6	89.1
Tyr	87.5	84.4	91.9	89.2	85.8	88.5	98.5	90.3	89.2	90.6
Phe	85.1	80.0	93.0	88.7	84.8	87.6	96.5	90.2	86.6	89.1
His	87.1	84.7	92.7	88.7	86.2	87.8	96.6	92.7	90.9	91.1
Lys	87.7	86.0	90.9	86.7	84.3	85.5	95.6	91.5	89.5	90.2
Arg	86.2	84.5	91.5	87.0	85.0	85.1	96.3	92.3	90.1	90.3
Cys	88.9	87.4	93.5	90.6	88.0	88.5	95.9	91.8	89.6	89.3
Met	83.6	81.9	91.8	87.3	83.2	84.8	95.1	89.9	88.3	87.9
Mean	86.9	83.3	92.3	88.3	85.0	87.4	95.9	91.0	88.2	89.6

The ruminal degradability of dry matter and crude protein of all legume seeds was similar, although the degradation of field bean protein in the first 4 h of incubation was slower than of the lupins and peas. The effective degradability of dry matter ranged from 70 to 78%, crude protein from 81 to 85%. Effective degradability of starch in field beans and peas was lower than that of cereal starch (Table 5).

Incubation of feeds in the rumen for 16 h did not change the proportion of most amino acids in comparison with unincubated samples, with the exception of glutamic acid and arginine, which had a distinctly lower proportion in the samples after incubation (Table 8).

The degradability of crude protein and individual amino acids during 16 h incubation in the rumen equaled from over 85% in peas and field beans to over 90% in lupins (Table 10).

Intestinal digestibility of crude protein and the particular amino acids of peas and field beans ranged from 80 to 94%. Crude protein digestibility and that of

TABELA 12

Intestinal digestibility of rumen-undegraded protein and amino acids of rapeseed oilmeals and soyabean oilmeal, %

Amino acids	Rapeseed oilmeals[1]							Soyabean oilmeal
	A	B	C	D	E	F	mean	
Crude protein	71.4	78.6	78.6	66.5	72.2	69.5	72.8	99.0
Amino acids								
Asp	75.5	77.8	80.5	69.8	74.3	71.4	74.9	99.2
Thr	75.0	76.6	79.9	69.4	73.9	71.7	74.4	99.1
Ser	76.8	78.7	81.5	71.5	75.4	73.4	76.2	98.8
Glu	83.4	85.6	87.6	79.8	83.5	81.3	83.5	99.5
Pro	68.1	70.6	74.6	61.8	68.0	64.6	68.0	98.9
Gly	77.7	81.1	82.6	72.6	77.9	74.5	77.7	98.0
Ala	83.2	84.8	86.7	78.8	82.2	80.6	82.7	99.1
Val	76.9	77.7	81.3	71.2	75.6	73.4	76.0	99.1
Ile	79.9	80.3	84.0	74.1	78.6	76.6	78.9	99.3
Leu	83.8	85.1	87.3	79.4	82.8	81.0	83.2	99.3
Tyr	80.5	81.8	84.1	74.4	78.4	78.6	79.6	98.7
Phe	79.2	81.7	84.2	74.6	78.9	77.5	79.3	99.3
His	81.0	84.8	84.6	76.4	79.5	79.4	81.0	98.7
Lys	78.7	80.3	82.9	73.5	77.8	76.1	78.2	99.0
Arg	81.5	85.5	86.6	79.3	82.7	81.3	82.8	99.4
Cys	67.6	72.4	73.6	67.8	67.7	64.5	68.9	n.d.
Met	84.3	85.5	87.5	79.4	83.1	82.6	83.7	n.d.
Mean	78.4	80.6	82.9	73.7	77.1	75.8	78.2	99.0

[1] refer to Table 1
n.d. – not determined

amino acids of lupins was from 15 to 30 percentage units lower than in the remaining legume seeds (Table 14).

DISCUSSION

Rumen degradation

Proteins in the feeds used in the nutrition of ruminants, including those in feed concentrates, vary in their rate of degradation in the rumen resulting from the different chemical characteristics of the protein and the technology used to prepare the feeds. Protein that is undegraded in the rumen and digested in the intestine is a source of supplementary amino acids to ruminal microbial protein. The amount of amino acids available in feed concentrates is particularly important in the nutrition of highly productive animals to ensure coverage of

TABELA 13

Intestinal digestibility of rumen – undegraded protein and amino acids of cereal grains and bran, %

Amino acids	Barley		Rye Dańkowskie Złote	Triticale	Wheat		Oats	Bran		
	spring	winter			spring	winter		rye	barley	wheat
Crude protein	81.2	83.0	69.0	88.4	87.3	86.0	57.5	44.7	72.0	58.8
Amino acids										
Asp	74.3	74.4	71.3	84.4	84.9	83.6	59.6	49.0	68.3	55.1
Thr	80.1	82.0	70.8	85.8	87.5	86.0	57.4	47.6	72.5	54.3
Ser	80.6	82.8	72.5	87.8	89.3	88.9	57.2	48.5	74.6	54.3
Glu	82.7	94.7	83.1	95.1	96.0	95.9	69.5	60.8	89.1	71.3
Pro	91.0	92.8	74.7	92.1	93.7	93.2	49.7	46.6	85.0	59.5
Gly	74.4	76.8	60.1	81.8	81.3	78.6	46.8	36.3	64.7	41.5
Ala	76.1	76.9	72.0	85.8	85.9	83.7	58.7	50.0	69.3	54.3
Val	81.5	83.0	75.3	87.7	88.3	86.8	62.7	54.2	75.8	59.3
Ile	83.6	84.7	75.0	89.0	90.0	89.8	64.9	53.7	78.2	58.2
Leu	83.2	85.1	74.7	89.2	90.1	81.7	62.8	53.4	77.4	57.8
Tyr	82.8	84.3	69.0	86.8	87.8	87.6	26.5	40.6	88.4	43.9
Phe	83.5	85.9	73.4	88.2	89.6	90.2	65.7	51.6	83.0	55.9
His	85.5	85.8	75.6	89.6	89.8	89.7	56.2	50.0	77.1	64.9
Lys	79.0	80.4	75.9	86.7	87.3	86.0	63.5	54.4	72.6	57.9
Arg	86.2	84.3	79.2	90.1	89.4	90.1	63.7	55.7	76.4	69.3
Cys	76.5	79.2	57.2	79.5	80.9	81.3	58.1	25.8	64.4	40.0
Met	82.1	83.5	77.0	89.4	90.2	89.4	68.8	62.4	74.3	64.1
Mean	81.1	83.3	72.7	87.6	88.3	87.2	58.3	49.5	76.0	56.6

their essential amino acid requirements, particularly of lysine and methionine, the amino acids that most often limit the nutritional value of protein.

The main nutrients of cereal grain and bran were degraded to a considerable degree in the rumen in a short time, and their degradation rates differed only slightly depending on the species and variety. The effective degradability of cereal starch averaged 96% and was on average 15 percentage units higher than the effective degradability of protein. Among the studied cereals, the degradability of oat dry matter, protein and starch was highest, about 90%, during 2 h of incubation in the rumen, which confirms the results of Herrer-Saldan et al. (1990). They suggest that the rapid degradation of oat protein is caused by its large proportion of proteins susceptible to ruminal degradation. Oats also contain more easily soluble carbohydrates than other cereals. The rate of starch and protein degradation in barley was slower than in other cereals, and winter barley protein and starch degraded more slowly than those of the spring variety. Lehman et al. (1995) studied various barley varieties and showed considerable differences in degradability among them. It has been suggested (Givens et al.,

TABELA 14

Intestinal digestibility of rumen-undegraded protein and amino acids of legume seeds, %

Amino acids	Field pea		Pea	Field bean		Lupin		
	Mige	Gomik	Kwestor	Dino	Nadwiślański	Emir	Juno	Wat
Crude protein	94.0	86.0	97.0	86.0	80.0	76.0	56.0	52.0
Amino acids								
Asp	93.4	86.7	94.7	88.2	83.7	79.5	56.1	52.9
Thr	92.6	83.1	94.2	86.1	80.7	80.5	58.7	55.7
Ser	93.1	85.2	94.5	87.9	83.5	74.3	55.3	49.7
Glu	95.7	90.7	96.4	92.1	89.4	91.0	72.1	71.9
Pro	92.5	84.1	94.8	87.3	83.6	80.3	58.5	55.5
Gly	90.0	76.9	93.1	73.3	64.4	79.9	57.1	55.3
Ala	92.9	85.0	94.3	87.6	82.5	80.5	60.8	59.6
Val	92.6	85.9	94.2	87.7	83.3	76.6	53.4	48.9
Ile	93.4	86.9	94.3	89.6	85.0	82.9	60.2	61.6
Leu	93.9	88.4	94.7	90.9	86.9	84.7	62.3	62.3
Tyr	92.2	84.5	92.9	81.7	73.3	78.4	57.3	57.6
Phe	93.3	87.2	94.5	89.0	84.8	81.5	58.4	57.9
His	93.6	84.8	94.8	84.4	76.5	81.4	56.1	52.7
Lys	94.6	87.0	95.6	89.6	84.8	71.5	52.5	45.3
Arg	95.7	89.7	96.2	92.3	88.8	91.2	72.1	75.2
Cys	83.0	60.5	88.9	75.6	68.2	72.1	54.2	44.9
Met	91.9	78.4	94.6	83.1	79.3	81.0	70.0	73.2
Mean	92.6	83.8	94.3	94.3	81.1	80.4	59.7	57.6

1993) that barley characterized by lower ruminal degradability might be a better feed for ruminants since starch digested in the small intestine supplies more energy. Nocek and Tamminga (1991) showed a positive relationship between the quantity of starch escaping the rumen and entering the intestine and intestinal starch digestion. However, as the quantity of starch entering the intestine increased, starch digestion as a percent of that entering decreased.

The effective degradability of rapeseed oilmeal protein made in various oil mills ranged from 63 to 70%. These results are similar to those reported by Madsen and Hvelplund (1985), equaling 63-77%, Kendall et al. (1991), 63% and Dakowski et al. (1996) 70-75%. The source of the differences found both among the literature data as well as in this study can be the differences in the production technology of rapeseed oilmeal. It is known that excessive heating causes considerable reduction in protein degradation. In the studies of Lindberg et al. (1982), additional heating of oilmeal reduced effective protein degradability to 29%. The experiment by Dakowski et al. (1996) shows that heating meal to 130, 140 or 150^{0}C reduced the effective degradability of protein from about 70 to 57, 23 and 14%, respectively. It can be assumed that the differences in the effective degradability of rapeseed oilmeal from different production plants were probably caused by differences in the temperature used to toast the rapeseed.

The results of this study show that the effective degradability of legume seeds and cereal feeds protein (average 82%) is significantly higher ($P<0.01$) than of rapeseed and soyabean oilmeal (average 65.3%); the effective degradability of the dry matter of cereal feeds, mainly of grain, is higher than that of the remaining studied feeds.

The values of effective ruminal degradability of dry matter (72%) and protein (83%) of legume seeds are similar to the values given by Dixon and Hosking (1992). They point to the considerable differences in digestibility and degradability of the dry matter and protein of legume seeds depending on particle size and rumen outflow rate, which means that determining the effective degradability of dry matter and protein in these feeds *in sacco* is not very precise. In contrast with grains, protein degradability of legume seeds was higher than that of starch. The effective degradability of legume seeds starch was much lower than starch of cereal grain and averaged 74% for peas and 61% for field beans. We did not find any data in the literature on the rate of ruminal degradation of legume seeds starch.

The studied feeds differed considerably in the rate of protein degradation during 16 h of incubation in the rumen. During this time total N degradability of rapeseed and soyabean meals was 14% less than in peas and field beans, and 23% less than in lupin seeds. Among the cereals, total N of rye and rye bran was degraded to a similar degree as that of lupin, and was higher than of the remaining cereals.

The proportion of the particular amino acids in the protein of feeds and rumen undegraded protein during 16 h incubation was similar, with the exception of glutamic acid and arginine, of which there was less in the protein remaining after degradation than there was in the feed protein. The clearly higher loss of glutamic acid and arginine than of other amino acids had also been found by other authors (Erasmus et al., 1994; Susmel et al., 1994; Skiba et al., 1996; Südekum and Andree, 1997; Van Straalen et al., 1997). Branched-chain amino acids were degraded slightly more slowly. Differences in the amino acid composition between feed protein and the remainder following incubation in the rumen depend on the type of feed and on contamination of the residue in the bags with nitrogen from microorganisms. Susmel et al. (1989, 1994) demonstrated the lack or small effect of incubation in the rumen on the proportion of amino acids in high-protein feeds, while Van Straalen et al. (1997) showed that the share of individual amino acids in the protein of silage and sugar-beet pulp before and after incubation differed considerably, although no such differences were found for soyabean meal. The proportions of amino acids in samples after incubation in the rumen can change depending on contamination with bacterial protein. Erasmus et al. (1994) calculated on the basis of DAPA content that bacterial N constituted from 2.2 to 5.9% N of total amino acids of rumen undegraded protein from high-protein plant feeds. Taking this factor into account, they showed significant differences in the proportion of Leu, Phe, Lys and Cys in the protein of these feeds before and after incubation in the rumen. In the study of Van Straalen et al. (1997) microbial protein constituted from 0 to 36% of total nitrogen of amino acids not degraded in the rumen, with the highest values being found for bulk feeds with low protein contents. It can then be assumed that part of the protein found after degradation in the rumen is of microbial origin, but that the share of this protein after incubation of high protein feeds and its effect on the proportion of amino acids is small, which would be in agreement with the suggestions of Varviko and Lindberg (1985). They did show, however, that the results pertaining to the degradability of protein of such starch feeds as cereal grain, can be burdened by an error resulting from the higher contamination by microbial protein than in high-protein feeds.

The differences between ruminal degradability of total N and the total amino acids of all of the studied feeds were small. This is in agreement with the results of Weakly et al. (1983), Teller et al. (1985) and Rulquin and Vérité (1993), and confirms the suggestion of the latter authors that degradation of total N in the rumen can be used to estimate the amount of amino acids from the feed entering the small intestine. Analysis of the results of degradation of the particular amino acids in our experiment shows that the degradability of lysine and methionine of rapeseed meals, rye, oats and rye bran was higher than of total N, and that estimating the amounts of these amino acids passing into the intestine on the basis of degradation of total N in the rumen can give exaggerated results.

Intestinal digestibility of protein and amino acids

Intestinal digestibility of protein and amino acids comprise digestibility in the small and large intestines as the mobile bags were recovered from faeces. This is in agreement with the generally accepted method, since it has been shown (Hvelplund, 1985; Vanhatalo, 1995) that feed protein is only slightly digested in the large intestine and this does not have a significant effect on intestinal digestibility.

The decrease in total N and total amino acids in the intestine from rumen undegraded protein of the studied feeds was similar, with the exception of rapeseed oilmeal, Dino faba beans and Emir lupin, in which the decline in total amino acids was greater than in the degradability of total N. This may show that in these feeds, there are more non-protein nitrogenous compounds that do not undergo degradation in the rumen and are not digested in the intestine.

Intestinal digestibility of rumen undegraded rapeseed oilmeal protein averaged 72%, and of lysine and methionine, the amino acids considered limiting for cows, 78 and 84%, respectively. These values are similar to the data given by other authors (Hvelplund, 1985; De Boer, 1987; Dakowski et al., 1996). Rapeseed oilmeal protein is rich in methionine and with its low degradation rate in the rumen and high digestibility of methionine in the small intestine, can be a good source of this amino acid for ruminants. The intestinal digestibility of rumen undegraded protein and of lysine and methionine of soyabean meal was higher than in other feeds and equaled 99%, a value similar to that given by van Straalen et al. (1987). The intestinal degestibility of protein and amino acids of various varieties of field peas, field bean, barley and wheat was similar. Feeds for which rumen degradability of protein and amino acids was the highest (oats, rye, lupin) were characterized by a low, with the exception of rapeseed meal, Dino faba beans and Emir lupin, digestibility of these components in the intestine.

Assuming that total N and amino acids remaining after 16 h of incubation in the rumen enter to the duodenum, and that the disappearance from the mobile bag represents the amount absorbed in the small intestine, the amount of total N and essential and nonessential amino acids that was absorbed from the feed in the intestine was computed. The calculations show that 20 and 29% of total N, 20 and 30% essential amino acids (EAA) and 18 and 30% nonessential amino acids (NEAA) of rapeseed and soyabean meal, respectively, was absorbed. Of the legume seeds, from 3 (lupin) to 16% of total N (peas), 2-14% EAA and 2-12% NEAA was absorbed in the intestine. Among the cereal feeds, the most EAA (14%) and NEAA (13%) was absorbed in the small intestine from winter barley, the least from rye and oats, 6 and 2%, respectively. This shows that the protein of lupins, rye and oat grains are poor sources of amino acids for ruminants.

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STRESZCZENIE

Rozkład w żwaczu białka, aminokwasów i skrobi pasz treściwych oraz ich strawność w jelicie cienkim krów

Oznaczono efektywny rozkład suchej masy, białka ogólnego i skrobi w żwaczu (*in situ*) oraz strawność nierozłożonego w żwaczu białka i poszczególnych aminokwasów różnych pasz w jelicie cienkim (*mobile bags*) krów. Badaniom poddano poekstrakcyjną śrutę rzepakową wyprodukowaną w sześciu zakładach przemysłu tłuszczowego, poekstrakcyjną śrutę sojową, nasiona peluszki, grochu, bobiku, łubinu, ziarna żyta, pszenżyta, pszenicy, jęczmienia i owsa, otręby pszenne, żytnie i jęczmienne. Skład chemiczny i aminokwasowy poekstrakcyjnych śrut rzepakowych był podobny, a efektywny rozkład białka w żwaczu, obliczony przy k=0,05, wynosił od 62 do 70%. Efektywny rozkład białka śrut poekstrakcyjnych był mniejszy niż nasion roślin strączkowych i pasz zbożowych. Spośród zbóż efektywny rozkład białka był najwyższy dla owsa (92%), a najniższy dla jęczmienia ozimego (75%). Ubytek w żwaczu azotu ogólnego po 16 godzinnej inkubacji śrut rzepakowych był mniejszy niż sumy aminokwasów, podczas gdy wartości te u pozostałych pasz były podobne. Kwas glutaminowy i arginina ulegały degradacji w żwaczu w większym stopniu niż pozostałe aminokwasy, niezależnie od rodzaju paszy. Strawność w jelicie cienkim białka ogólnego i aminokwasów pasz o mniejszej degradacji w żwaczu była większa. Skrobia zbóż ulegała rozkładowi w żwaczu w większym stopniu niż skrobia nasion roślin strączkowych.