Journal of Animal and Feed Sciences, 10, 2001, 91 – 101

The nutritive value of Polish-grown lupin cultivar seeds for ruminants

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(Received 20 March 2000; accepted 22 January 2001)

ABSTRACT

The chemical composition, amino acid profiles, protein and amino acid ruminal and intestinal digestion and nutritive value of lupin seeds produced from yellow *(Lupinus luteus* L.*)* cv. Popiel, white *(L. albus* L.*)* cv. Bac, Bardo, and narrow-leaved *(L. angustifolium* L.*)* cv. Emir, Mirela, Sur, species were estimated. The seeds contained (per kg of dry matter) 307-442 g crude protein, 0.7-8.05 g of alkaloid, 16.3-20.6 MJ, 1.04-1.42 UFV, 68-85 g PDI, 207-283 g PDIN, 136-146 g PDIE. The seed protein included an average of 0.6-0.8 g/16 g N of methionine and 4.6 of lysine. The coefficients of effective rumen degradability of seed protein ranged from 0.82 (average for yellow and white lupin) to 0.75 (for cv. Sur of narrow-leaved lupin). The rumen degradable protein comprised 61% easily soluble protein and 30-39% slowly degradable protein (7.9% h^{-1}). The intestinal digestion coefficient of rumen-undegraded protein averaged 0.94. Methionine and lysine tended to be less digestible in the postruminal part of the alimentary tract than other amino acids.

KEY WORDS: ruminant, lupin seed, protein, amino acid, nutritive value

INTRODUCTION

Despite their high protein content, the seeds of lupin species cultivated in Poland are used as feedstuffs mainly for monogastric animals (Pastuszewska, 1997). Lupin seeds can, nonetheless be a substitute for soyabean meal in ruminant feeding, as shown by experimental results obtained in Australia, France, and the UK (Hill, 1990; Harzic and Emile, 1996; Moss et al., 1996). These reviews describe the nutritive value of lupin cultivars that are not suitable for the climatic and agronomic conditions of Poland. Plant variety and cultivation environment influence the chemical composition of seeds and, consequently, the extent of ruminal and intestinal digestion and nutritive value for ruminants (Żebrowska et al., 1995). The 24 local cultivars of lupin species offer the possibility of being an important source of protein in ruminant feeding, but the preparation of a correctly balanced feed ration, especially for high-productive cattle, requires the qualitative and quantitative estimation of nutrient components digested in the alimentary tract (Chalupa et al., 1996).

The objective of this study was to investigate the nutritional value of the seeds of Polish-grown lupin cultivars for ruminants.

MATERIAL AND METHODS

Seeds of six cultivars representing three Polish-grown lupin species: yellow *(Lupinus luteus* L.*)* cv. Popiel, white *(L. albus* L.*)* cv. Bac, Bardo and narrow-leaved *(L. angustifolium* L.*)* cv. Emir, Mirela, Sur were investigated. Soyabean meal (SBM) was the reference feed for the rumen and intestinal digestibility of seeds.

Rumen and intestinal digestion

The rumen degradability of protein was determined by the polyester bag technique according to Michaelet-Doreau et al. (1987) and amino acids according to the method of Benchaar et al. (1994) in 3 bulls of 420±30 kg BW equipped with rumen cannulas. The intestinal digestibility of the rumen undegraded protein was determined using the mobile bag technique according to Peyraud et al. (1988) in 3 bulls of 400±30 kg BW with duodenal cannulas fitted about 10 cm after the abomasal pylorus. The animals were fed a daily ration at 8.00 and 16.00 h in equal meals of meadow hay and concentrate (60: 40 ratio on dry matter basis). The concentrate contained 14.5% crude protein and consisted of (%): ground barley, 50, ground wheat, 10, soyabean meal, 10, wheat bran, 28 and mineral mixture, 2. The bulls were fed at 600 g day^{-1} gain levels. Samples of lupin seeds and soyabean meal as a reference meal were ground to a particle size of 0.75 mm. The bags were prepared using woven polyester tissue with approximately 42 μm pore size.

Chemical analyses

The nutrient content of seeds was analyzed using standard methods (AOAC, 1990); the alkaloid content was determined according to Wiewiórowski and Skolik (1959). Amino acids were estimated using a Carlo-Erba t.3A29 analyzer after hydrolysis with 6N HCl (110°C, 20 h); sulphur-containing amino acids were assayed after oxidation with a mixture of hydrogen peroxide and formic acid. Gross energy was determined using an adiabatic calorimetric bomb.

Calculations

The coefficients of ruminal effective protein degradation and rumen protein degradability constants were calculated at a rumen outflow rate equal to 0.06 h^{-1} using the equation of Ørskov and McDonald (1979) and the coefficients of intestinal digestibility of rumen undegraded protein according to Kowalski et al. (1995). Amino acid ruminal disappearance and intestinal digestibility of rumen-undegraded protein were calculated in agreement with Benchaar et al. (1994). The changes in alkaloid content during incubation were described on the basis of total alkaloid content in raw seeds. The nutritive value of seeds was estimated according to the INRA (1989) feed evaluation system using Inwar software ver. 1.0 (1993).

RESULTS

Chemical analyses showed that the crude protein content of the lupin seeds ranged from 31 to 44% of DM, ether extract 5-9.5%, crude fibre 13-17%, alkaloids 0.074-0.805% and gross energy 16.0-20.5 MJ kg^{-1} DM (Table 1). The highest contents of crude protein and gross energy were found in the seeds of yellow lupin cv. Popiel. The seeds of white lupin were characterized by the highest level of ether extract. The seeds of all narrow-leaved lupin cultivars had the lowest level of crude protein and a high crude fibre content. The amino acid profiles of the investigated lupin seed protein had a higher content of the tyrosine, serine (+30), glutamic acid, arginine and phenylalanine (+8) than SBM, but the amount of lysine, histidine, valine and isoleucine was lower (-25%-units). Lupin seed protein contained half as much methionine as SBM.

The values of ruminal effective protein degradation coefficients (EPD) for yellow and white lupin reached an average value of 0.82 and were higher than in the protein of narrow-leaved lupin, which was characterized by a mean value of 0.77 (Table 2). For all lupin seeds, the protein content of the easily soluble fraction (a) was similar (over 60%) and was significantly higher than the 20% determined in SBM. The degradable fraction (b; content ranged from 30 to 39%) was degraded in the rumen more slowly in narrow-leaved lupin than in other lupin species, but for all lupin seeds the rate of b fraction degradation was about twice as high as in SBM.

The coefficient of post-ruminal digestibility of rumen-undegraded protein of the investigated seeds was approximately 0.94. The protein digestibility in the whole tract was 0.99 for all lupin seeds.

TABLE 1

Chemical composition of lupin seeds and soyabean meal

Ingredients	Seeds						SBM
	Popiel	Bac	Bardo	Mirela	Emir	Sur	
Dry matter, g kg^{-1}	879	886	874	891	878	894	888
Content, g kg^{-1}DM							
crude protein	442	364	365	360	354	308	476
ether extract	53	94	80	54	65	58	21
crude fibre	160	144	131	150	133	170	75
total ash	43	36	36	34	54	42	63
alkaloids	1.53	8.05	0.98	6.67	0.88	0.74	-
gross energy, MJ kg^{-1}DM	20.56	19.60	17.83	16.85	19.38	16.26	-
Amino acids profiles, g/16g N							
Asp	8.9	9.6	9.7	9.7	9.7	9.9	9.9
Thr	3.2	3.9	4.0	4.0	4.0	4.2	3.8
Ser	4.4	4.6	4.9	4.6	4.6	4.7	3.7
Glu	23.6	18.7	18.6	19.9	19.1	20.0	17.7
Pro	3.7	3.6	4.4	4.3	4.0	4.6	4.0
Gli	3.6	3.8	4.0	4.2	4.2	4.6	3.9
Ala	3.1	3.2	3.6	3.7	3.7	3.9	3.2
Val	3.2	3.5	3.7	3.4	3.5	3.8	4.5
Ile	3.3	3.7	3.9	3.5	3.6	3.7	4.3
Leu	7.2	6.8	7.3	6.8	6.8	6.9	7.7
Tyr	3.0	4.6	4.3	3.5	4.5	3.5	2.8
Phe	3.6	3.9	3.8	3.9	3.9	4.3	3.7
His	2.7	2.3	2.7	2.7	2.8	2.8	3.6
Arg	10.4	10.0	9.4	10.6	10.4	10.2	9.4
Lys	4.7	4.5	4.5	4.5	4.5	4.7	6.7
Cys	2.3	1.8	1.9	1.4	1.4	1.4	0.9
Met	0.6	0.8	0.8	0.7	0.8	0.8	1.5
TAA[1]	91.4	90.0	91.7	91.4	92.2	94.4	91.7

[1] TAA = content of amino acids N in the total N, %

The rumen degradability of arginine, glutamic acid was higher than for lysine, histamine, valine, isoleucine and methionine (Table 3). In the intestine, the lower digestion of rumen-undegraded protein was obtained for cystine, methionine, and arginine than for remaining amino acids. In the entire alimentary tract, the sulphur-containing amino acids and lysine were characterized by a lower digestibility than other amino acids.

The total alkaloid level after 2 h of rumen incubation of white and narrow-leaved seed samples decreased (91% compared with raw seeds) and did not change during the next period (Figure 1). In the samples of yellow lupin seeds after 4 h of incubation, the total alkaloid level increased by 18% and later decreased by 41%.

TABLE 2

Digestibility of lupin seeds protein

	Seeds						SBM
	Popiel	Bac	Bardo	Mirela	Emir	Sur	
Rumen							
EPD[1]	0.83	0.82	0.81	0.78	0.79	0.75	0.49
a[2]	60	62	62	60	62	60	21
b[2]	36	33	32	34	30	39	63
c[2]	8.9	9.0	9.1	7.8	8.0	6.7	4.6
Post-rumen tract							
dsi[3]	0.94	0.94		0.93			0.97
Total tract							
TD[4]	0.99	0.99		0.98			0.98

[1] EPD: effective degradation of protein estimated according to Ørskov and McDonald (1979) at outflow rate 0,06 h^{-1}

[2] a = the immediately rumen-soluble fraction of rumen degradability protein (%); b = the slowly rumen-soluble fraction of rumen degradability protein (%); c = rate of degradation fraction b (%b h^{-1})

[3] dsi: the coefficient of intestinal digestibility of rumen undegraded protein estimated according to Kowalski et al. (1994)

[4] TD: the coefficient of the protein digestibility in the total digestive tract estimated according to Benchaar et al., 1994)

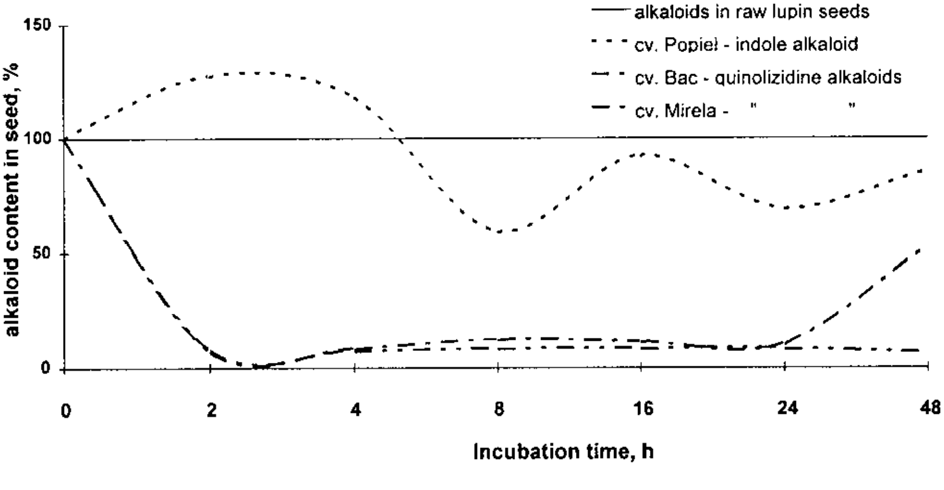

Figure 1. Alkaloid content in lupin seed during rumen incubation

TABLE 3

Lupin seed crude protein and amino acids degradability in the rumen, post-rumen and total digestibility

Ingredients	Popiel			Bac			Mirela			SBM		
	R_{16}[1]	dsi_{16}[2]	TD[3]	R_{16}	dsi_{16}	TD	R_{16}	dsi_{16}	TD	R_{16}	dsi_{16}	TD
Crude protein	0.91	0.87	0.99	0.86	0.91	0.99	0.78	0.92	0.98	0.55	0.98	0.99
Asp	0.91	0.86	0.99	0.88	0.89	0.99	0.84	0.92	0.99	0.51	0.99	0.99
Thr	0.90	0.91	0.99	0.88	0.90	0.99	0.82	0.93	0.99	0.44	0.99	0.99
Ser	0.91	0.89	0.99	0.86	0.88	0.98	0.79	0.94	0.98	0.55	0.98	0.99
Glu	0.94	0.96	0.99	0.87	0.96	0.99	0.85	0.96	0.99	0.57	0.99	1.00
Pro	0.93	0.92	0.99	0.88	0.91	0.99	0.79	0.97	0.99	0.60	0.98	0.99
Gli	0.91	0.90	0.99	0.90	0.92	0.99	0.79	0.95	0.99	0.52	0.96	0.98
Ala	0.89	0.93	0.99	0.87	0.94	0.99	0.81	0.95	0.99	0.38	0.98	0.99
Val	0.87	0.90	0.99	0.82	0.92	0.99	0.67	0.95	0.98	0.54	0.95	0.98
Ile	0.91	0.90	0.99	0.85	0.96	0.99	0.71	0.97	0.99	0.44	0.99	0.99
Leu	0.90	0.94	0.99	0.84	0.96	0.99	0.74	0.96	0.99	0.56	0.95	0.99
Tyr	0.88	0.92	0.99	0.92	0.96	1.00	0.75	0.98	1.00	0.39	0.95	0.97
Phe	0.89	0.84	0.98	0.85	0.94	0.99	0.74	0.94	0.98	0.42	0.98	0.99
His	0.89	0.92	0.99	0.67	0.97	0.98	0.50	0.99	1.00	0.57	0.98	0.99
Lys	0.86	0.89	0.98	0.77	0.93	0.98	0.65	0.93	0.97	0.56	0.98	0.99
Arg	0.94	0.64	0.98	0.91	0.86	0.98	0.85	0.97	0.99	0.67	0.94	0.98
Cys	0.95	0.64	0.98	0.90	0.82	0.98	0.66	0.89	0.96	0.57	0.91	0.96
Met	0.87	0.82	0.98	0.86	0.89	0.98	0.72	0.85	0.96	0.60	0.94	0.97
TAA	0.91	0.89	0.99	0.87	0.92	0.99	0.79	0.95	0.99	0.54	0.98	0.99

[1] the coefficient of the protein and AA rumen degradation during 16 h of incubation

[2] the coefficient of the protein and AA intestinal digestibility of undegraded protein in the rumen

[3] the coefficient of the total alimentary tract digestibility of protein and AA

The nutritive value of the investigated seeds is shown in Table 4. The highest energy content was found in white lupin seeds (cv. Bardo), the lowest in the seeds of narrow-leaved lupin, cv. Sur. The differences between the highest and lowest content in lupines of PDIA were 16%, PDIN 27% and PDIE 9%. The seeds of yellow lupin contained more DCP and PDIN than others, but the seeds of narrow-leaved lupin cv. Mirela were rich in PDIA and PDIE.

DISCUSSION

The presented chemical composition of lupin seeds is in line with data for Polish-grown lupin given by Święcicki (1993). The lupin seeds contain more protein than many other feeds available in our climatic region. The seeds of yellow lupin have about 20% more CP than other lupin species, but their protein contains less asparagine, threonine, proline, tyrosine, valine, alanine and methionine. Similarly to the observation reported for grain legumes by Dixon and Hosking (1992), the levels of essential amino acids, especially methionine and lysine, in the investigated lupin seeds are unsatisfactory in relation to SBM and animal requirements. In our experiment, the estimated gross energy level is lower than that given by Eggum et al. (1993) and Moss et al. (1997) for seeds of white lupin sub-species cultivated in Canada and the UK; but these seeds contained significantly more ether extract than Polish grown. The differences in species, varieties, and cultivation conditions are reflected in the chemical composition of lupin seed.

Our observations, as those of Murphy and McNiven (1994), indicate that lupin protein is more soluble and rumen-degradable than SBM. The literature data describing mainly white lupin shows a wide variability of the lupin protein effective rumen degradability coefficient, which is estimated to range from 0.60 to 0.95 (Valentine and Bartch, 1988; Kibelolaud et al., 1991). The differences can be caused by the lack of uniformity of animal feeding rations, the composition of which influences rumen digestibility processes (Nocek and Russel, 1987).

The rapid rate of protein degradation in the rumen is the consequence of the substantial content of the easily-soluble fraction of protein, but the results are inconsistent; more than 60% was noted in our observations, whereas Kibelolaud et al. (1991) found over 80% for white lupin seeds. For the same species of lupin, a significantly lower content of the easily soluble protein fraction was found by

TABLE 4

The nutritive value of seeds estimated according to INRA (1989) system, kg^{-1}DM

Seeds	Net energy units		Protein values, g			
	UFV[1]	UFL[2]	DCP[3]	PDIA[4]	PDIN[5]	PDIE[6]
Popiel	1.30	1.30	389	76	283	145
Bac	1.25	1.30	320	68	236	136
Bardo	1.38	1.42	320	71	238	139
Mirela	1.26	1.27	316	81	237	149
Emir	1.30	1.32	311	75	232	142
Sur	1.04	1.05	269	79	207	146

[1] UFL – the net energy value for milk production

[2] UFV– the net energy value for meat production

[3] DCP – digestible crude protein

[4] PDIA – protein truly digested in the small intestine originated from the rumen-undegraded dietary protein

[5] PDIN – the sum of PDIA and digested in the small intestine microbial protein synthesised from the rumen-degraded dietary protein when energy and others nutrients are not limiting factor

[6] PDIE – the sum of PDIA and digested in the small intestine microbial protein synthesised from the rumen-degraded dietary protein when the degraded N and others nutrients are not limiting factor

Moss et al. (1997), but the authors used a larger milling screen. This indicates that both the varieties of lupin and the methods of measurements affect the solubility parameter estimates (Madsen and Hvelplund, 1994).

In our study only about one-third of rumen degradable protein was slowly degraded; this fraction was more effectively degraded in the white and yellow lupin seeds than in narrow-leaved species. The presented differences in protein susceptibility to hydrolysis during digestion in the rumen can be a result of the differences in fractional protein composition among species indicated by Michniewicz et al. (1995). The *in vitro* experiment of Tai and Bush (1993) showed that the reason of the higher level of digestion of white lupin protein in comparison with the narrow-leaved species was the higher content of the readily rumen-digested globular protein fraction (<40 KD).

Similarly as shown by Benchaar et al. (1994), our observation points to the greater rumen degradability of arginine and glutamic acid than of lysine, histidine, valine, isoleucine and methionine. In the small intestine the essential amino acids disappear faster than non-essential AA for white lupin; the same results were reported by Schröder et al. (1997), who found this tendency for SBM and fish meal. Our study has not confirmed this tendency for other lupin seeds or SBM. Confirming the results of Benchaar et al. (1994) and O'Mara et al. (1997) our observations indicate selective intestinal release of individual AA from the rumen-undegraded protein. The rumen-undegraded protein was digested during intestinal passage, over 93%, but cystine, methionine, arginine and lysine tended to be less digestible than other AA. It seems that the rate of digestion of individual amino acids can be affected by the various amino acid compositions of the lupin protein fractions (Rubio et al., 1995).

The high digestibility of lupin CP and individual AA in the alimentary tract found in our experiment as well as by others (Benchaar et al., 1994; O'Mara et al., 1997; Schröder et al., 1997), suggests that lupin seeds can be a satisfactory source of protein in feeding ruminants. The main condition of satisfactory utilization of the high rumen degradability of lupin protein is the proper protein and energy balance of diets to stimulate high microbial protein synthesis in the rumen or to increase its efficiency.

Our results underscore the high alkaloid content in most Polish-grown lupin cultivars. The amount of alkaloid in seeds used for feeding animals has been highly reduced in many countries; e.g. in Australia it is estimated at 0.011% (Harris, 1990). Lupin alkaloids are recognized as antinutritional compounds mainly for monogastric animals. The *in vitro* experiments of Lanca et al. (1994) showed that a low concentration of lupin alkaloids was not toxic to rumen activity because the ruminant gastrointestinal microbes have the potential to detoxify harmful compounds (Smith, 1992). The microbial activity in the rumen fluid can be affected, however, by the concentration of alkaloids. The differences in the rumen solubility rate of alkaloids obtained in our experiment must be taken into consideration, especially when a significant amount of seed containing the quinolizidine alkaloids is used in feeding ruminants. The effect of alkaloids on ruminant health has not been studied sufficiently yet, so there is no conclusive answer to the question about their toxicity.

CONCLUSIONS

The seeds of Polish-grown lupin cultivars are a satisfactory protein source in ruminant feeding. Digestion is characterized by high susceptibility of protein to rumen degradation and to intestinal digestion of the rumen-undegraded fraction. Susceptibility differs among lupin species. Both degradation of individual amino acids in the rumen and intestinal digestibility also depend on the lupin species and kind of amino acid. Sulphur-containing amino acids and lysine are digested less than other AA in the post-rumen digestive tract.

The calculated nutritive values of Polish-grown lupin cultivar seeds depended on the species and cultivar and differed from the respective values published in Ruminant Nutrition Recommended Allowances and Feed Tables (INRA, 1989).

In formulating diets it is important to take into account the estimated differences between species and cultivars, especially when using lupin seeds in feeding high-productive cattle.

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STRESZCZENIE

Wartość pokarmowa nasion krajowych odmian łubinu w żywieniu zwierząt przeżuwających

Wartość pokarmową nasion łubinu żółtego odmiany Popiel, łubinu białego odm. Bac i Bardo oraz łubinu wąskolistnego odm. Mirela, Emir i Sur oznaczono wg systemu INRA (1988) na podstawie składu chemicznego, współczynników rozkładu białka w żwaczu oraz strawności jelitowej białka nie ulegającego rozkładowi w żwaczu. Określono podatność aminokwasów białka nasion badanych gatunków łubinu na trawienie żwaczowe i jelitowe. Nasiona zawierały (w kg suchej masy): 307-442 g białka ogólnego, 0,7-8,05 g alkaloidów, 16,3-20,6 MJ, 1,04-1,42 JPM, 68-85 g BTJ, 207-283 g BTJN i 136-143 g BTJE. Białko nasion zawierało średnio 0,6-0,8 g/16 g N metioniny i 4,6 g lizyny. Współczynnik efektywnego rozkładu białka w żwaczu łubinu żółtego i białego wynosił średnio 0,82, natomiast łubinu wąskolistnego był niższy (odm. Sur 0,75). Asparagina i kwas glutaminowy były szybciej rozkładane w żwaczu, natomiast lizyna, histamina, walina wolniej niż pozostałe AA. Białko łubinu rozkładane w żwaczu w 61% ulegało szybkiemu rozpuszczeniu, natomiast 30-39% stanowiła frakcja wolno rozkładana w żwaczu (7,9% $godz^{-1}$). Współczynnik strawności jelitowej białka ogólnego nie ulegającego rozkładowi w żwaczu dla wszystkich nasion wynosił średnio 0,94, słabiej niż pozostałe aminokwasy były trawione metionina, cystyna i lizyna.