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Effects of pelleting and expanding of vegetable feeds on *in situ* protein and starch digestion in dairy cows*

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ABSTRACT

In situ digestion of protein and starch in barley, oats, wheat, wheat bran, maize, sorghum, peas, and soyabeans was evaluated in dairy cows after milling (untreated), pelleting (ca. 81°C) and expander processing at two different temperatures (110 or 130°C). Effective degradation of crude protein (EPD) and starch (ESD) in the rumen, as well as total tract indigested protein (IP) and starch (IS) fractions, were determined by *in situ* methods. Pelleting significantly decreased EPD of wheat and wheat bran by 14 and 10 percentage units, respectively, and increased ESD in maize by 10 percentage units. Expander treatment efficiently protected protein from rumen degradation in all feeds evaluated, except maize. The ESD of maize, sorghum, peas and oats increased with 31, 18, 22 and 5 percentage units, respectively, after expander treatment at 130°C. The IP fraction of sorghum and peas increased after expander treatment. In maize, sorghum and peas the IS fraction decreased by heat treatment. It is concluded that protein and starch digestion of vegetable feeds in dairy cows can be modified by different heat treatment.

KEY WORDS: expander, nylon bags, pelleting, rumen degradation, starch, total tract digestion

INTRODUCTION

The protein supply in ruminants depends on delivery of microbial protein and rumen undegraded feed protein (RUP) to the duodenum and their subsequent intestinal

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digestibility. Furthermore, it has been suggested that a shift of starch digestion from the rumen to the intestine would affect milk production positively, although reported results are inconclusive (Nocek and Tamminga, 1991; Clark et al., 1992; Reynolds et al., 1997). High intake of rumen degradable starch may increase the risk for rumen acidosis, loss of appetite, laminitis and other health problems (Nocek, 1997).

Pelleting of feeds is increasingly used to improve hygienical quality, and compound feeds in Norway are at present heated to a minimum of 81°C to ensure killing of *Salmonella.* Pelleting of concentrates may increase the RUP fraction and decrease the rumen undegraded starch (RUS) fraction due to the heat involved (Tait and Beames, 1988). However, the knowledge of the effects of pelleting on intestinal digestibility of RUP and RUS fractions are still scarce.

Treatment with the annular gap expander (Pipa and Frank, 1989), widely used by the compound feed industry, has increased the RUP of barley measured *in vivo* (Prestløkken and Harstad, 2001), and of barley, oats, wheat, rye, peas, soyabean meal, rapeseed meal and sunflower meal measured *in situ* (Lund et al., 1999; Prestløkken, 1999a). The risk of reduced intestinal digestibility of protein due to expander treatment seems to be slight in practice (Prestløkken, 1999a). However, expander treatment has shown increased rumen degradation of starch in grains like barley and oats measured *in vivo* (Harstad et al., 1996; Prestløkken and Harstad, 2001). Only few results are available on the impact of expander treatment on intestinal digestibility of the RUS fraction. The effect seems, however, to be small for barley (Prestløkken and Harstad, 2001) and legume seeds (Goelema et al., 1999) measured *in vivo* and *in situ,* respectively. The aim of this study was to expand the database on the effects of pelleting and expander treatment of some common vegetable feed on their protein and starch degradation in the rumen and intestine of dairy cows.

MATERIAL AND METHODS

Feeds

The experimental feeds were barley, oats, wheat, wheat bran, maize, sorghum, peas and soyabeans. Felleskjøpet Øst Vest (Kambo, Norway), delivered the cereal grains. The peas were obtained from Lantmännen (Stockholm, Sweden), and the soyabeans were obtained from Denofa AS (Fredrikstad, Norway). Feed processing was carried out at the Center for Feed Technology (Ås, Norway). All feeds were milled in a hammer mill (Münch, HM 21.115, Wuppertal, Germany) to pass a 3 mm screen (Table 1) representing treatment 1 (control, untreated). In treatments 2, 3 and 4, the control feeds were preconditioned in a mixer before further treatment (Table 1). In treatment 2 the feeds were pelleted in a pellet press (Münch RPM 350.100, Wuppertal, Germany) with 8 mm die, and a planned maximum temperature of

TABLE 1

Planned and achieved parameters during feed processing

Treatment No.[1]		Barley	Oats	Wheat	Wheat bran	Mai-ze	Sorg-hum	Peas	Soya-beans
Planned processing				Planned treatment temperatures, ˚C					
none	1	none	none	none	none	none	none	none	none
pelleting (P)	2	81	81	81	81	81	81	81	81
expanding + P	3	110	110	110	110	110	110	110	110
expanding + P	4	130	130	130	130	130	130	130	130
Parameters				Achieved parameters during processing					
temperature	2	60	82	71	50	60	51	60	81
at mixer, (t_1), ^oC	3	82	80	82	83	77	85	60	95
	4	86	70	76	80	80	85	60	80
temperature in pellet, (t_3), ^oC	2	82	76	81	81	81	81	84	83
temperature at	3	110	106	111	109	110	100	112	90
expander (t_2), ^oC	4	128	121	130	133	130	108	130	98
feeding rate,	2	750	600	600	800	800	600	800	600
kg/h	3	700	800	800	800	800	800	800	800
	4	700	800	800	800	800	800	800	600
added water (w)	2	2.5 (w)	0	0	2 (w)	0	0	0	0
or fat (f),	3	-	0	0	2 (w)	0	0	4 (f)	0
%	4	-	0	0	2 (w)	0	0	4 (f)	0
pressure at con,	2	0	0	0	0	0	0	0	0
bar	3	10	11	11	10	11	11	7	2
	4	13	29	20	14	12	16	9	11

81^{o}C. In treatments 3 and 4 the feeds were subjected to a two step procedure; first treatment in an annular gap expander (Amandus Kahl, OE 15 1, Reinbek, Germany) at 110 (treatment 3) or 130^{o}C (treatment 4), and thereafter pelleted. To obtain the planned temperatures, small amounts of water was added during pelleting of barley and during pelleting and expander treatments of wheat bran, whereas 4% of fat was added during expander processing of peas. A thermo-couple measured the temperature in the mixer-conditioner (t_1) and at the con of the expander (t_2), while temperatures in fresh pellets (t_3) were measured by a laser beam pistol (Raytek, ST3LXG). Batches of approximately 10 kg were manually collected after pelleting of each feed and spread on the floor in 1-3 cm thin layers for quick cooling. Thereafter, representative samples of 2 kg of all the feeds from treatment 2, 3 and 4 were milled using a 1.6 mm screen. The control feeds (treatment 1, already milled at 3 mm screen) were sieved, and particles larger than 1.0 mm were milled through a 1.6 mm screen, and then remixed with the particles under 1.0 mm.

The planned and achieved processing temperatures are shown in Table 1. The achieved processing temperatures were as planned for barley, wheat, wheat bran, maize and peas, but slightly lower for oats. The temperatures obtained during expander treatment of sorghum were 10 to 20°C lower than planned. For soyabeans, the achieved temperatures during expansion were lower than 100°C due to oil extraction, which reduced pressure and temperature.

In situ measurements

Experimental animals were non-lactating cows of the Norwegian Cattle breed fitted with permanent ruminal and duodenal cannulae. They were kept in a metabolism unit authorised by the Norwegian Animal Research Authority. Animals were fed at maintenance energy level of a standardized diet consisting of 4 kg grass hay and 1.8 kg concentrate mixture/d. The grass hay contained 65 g crude protein (CP)/kg DM and 667 g neutral detergent fibre (NDF)/kg DM, while the concentrate mixture contained 194 g CP/kg DM and 280 g NDF/kg DM. Rations were offered in equal meals at 6.00 and 15.00 h. The *in situ* procedures applied were as described in detail by Prestløkken (1999a), with the exception that the pore size of the nylon bags used to measure total tract digestibility was 15 μm instead of 11 μm. Approximately 2 g of feed was filled into artificial fibre bags with a pore size of 36 μm. The bags were incubated in the rumen of three cows for 0, 4, 8, 16, 24, and 48 h. After removal from the rumen, the bags were immediately rinsed in cold tap water, washed for 10 min three times and spun in a domestic washing machine. The zero-hour bags were washed in the washing machine only. The bags were dried at 45ºC for 48 h, and then weighed, whereupon the residues of replicates were pooled within incubation time and animal. The residues were stored at room temperature in air- tight glass jars before determination of N and starch. In the mobile bag experiment to determine total tract digestion, compound samples of residues after 16 h rumen incubation from the three animals, were used in two animals. Duplicates of 1 g of residues for each feed and animal, were placed in polyester bags. All bags were heat sealed and preincubated in a solution of 1 M HCl (pH 2.4) for 1 h, and in a solution of 1 M HCl (pH 2.4) and pepsin at 38ºC for 2 h. The bags were introduced into the intestine *via* the duodenal cannula, recovered from faeces, and washed in cold tap water in a sieve bucket for 2 h before drying at 45ºC for 48 h. The bags were weight and pooled within animal. The residues were stored at room temperature in air-tight plastic tubes before determination of N and starch.

Chemical analyses

Feed contents of dry matter (DM) and ash were determined using standard protocols (AOAC, 2002). Crude fat (acid hydrolysis and extraction with petroleum

ether) was determined according to 71/393/EEC (OJ, 1971), using 4 M HCl instead of 3 M HCl. Acid detergent fibre (ADF) and neutral detergent fibre (NDF) of feeds were determined according to Van Soest et al. (1991), but without washing with acetone. Nitrogen in feeds and residues after rumen and intestinal incubation was determined by the Combustion method (AOAC, 2002). Starch content in feeds and residues was determined as described by McCleary et al. (1994).

Calculations and statistical analyses

Feed content of CP was calculated as N x 6.25, except for wheat where N x 5.7 was used (Hoseney, 1994). Effective rumen degradation of protein (EPD) was estimated according to Ørskov and McDonald (1979), using the PROC NLIN procedure in the Statistical Analysis System (SAS, 1990), assuming a rumen outflow rate (k) of 8% h^{-1}. For maize and sorghum, an incubation time of 48 h was to short to estimate reliable protein degradation parameters, and their EPD was therefore calculated according to Kristensen et al. (1982). Effective rumen degradation of starch (ESD) was calculated as described by Goelema et al. (1998), where 10 % of the soluble starch fraction (a) was assumed to be undegraded in the rumen, and a rumen outflow rate (k) of 6% h^{-1} was used. Soyabeans contained less than 4% starch (Table 2), and the starch digestion was therefore not studied.

Total tract indigestible residues of protein (IP) and starch (IS) were determined as the fraction left in the nylon bags after intestinal incubation of residues after 16 h rumen incubation expressed in percentage of feed content.

A one-way general linear model and analysis of variance (GLM procedure) in the Statistical Analysis System (SAS, 1990) was used to test the effect of treatment on EPD, ESD, IP and IS within feeds, with treatment as main effect and animal as random effect. Least-square means and P-diff statement were used to separate means. Differences between means were considered significant at $P<0.05$, unless stated otherwise.

TABLE 2

Chemical composition of untreated experimental feeds, g kg^{-1} DM

Feeds	DM	Ash	Crude protein	Starch	NDF	ADF	Crude fat
Barley	895	25	120	527	266	73	44
Oats	902	29	114	512	257	116	67
Wheat	893	19	120[1]	666	162	40	45
Wheat bran	915	72	162	262	426	131	72
Maize	889	14	93	696	104	27	63
Sorghum	885	19	96	710	129	50	38
Peas	876	33	215	421	146	66	22
Soyabeans	903	55	395	18	173	95	238

[1] protein content: N x 5.7

RESULTS

The chemical composition of the feeds shown in Table 2 was within normal ranges (NRC, 1989, 2001).

Rumen degradation and total tract digestion of protein

The EPD values of the untreated feeds ranked from high to low as follows: oats, soyabeans, wheat bran, peas, wheat, barley, maize and sorghum (Table 3). Pelleting decreased EPD in all feeds numerically, but significantly ($P<0.05$) only for wheat and wheat bran. For wheat, pelleting decreased the EPD value with as much as 14 percentage units. All feeds except maize showed significantly decreased EPD as a result of expander treatment, irrespective of temperature. The EPD of barley, oats, wheat, and wheat bran was significantly lower after expander treatment than after pelleting. Except for oats, there were no significant differences in EPD between low and high temperature during expander processing. The expander treatment had the most pronounced effect in oats where EPD was lowered from 78 to 38% at 121°C.

As shown in Table 3, the IP fraction of untreated feeds was lowest for peas (1%) and highest for sorghum (23%). The other untreated feeds had IP values between 3 (soyabeans) and 9% (maize). Pelleting decreased IP numerically in all cereal grains, and significantly ($P<0.05$) for barley and oats. In most feeds, expanding at the high temperature increased numerically IP compared to pelleting and expanding at the low temperature. In sorghum, IP was 10 percentage units higher after expanding at the high temperature compared to untreated.

Rumen degradation and total tract digestion of starch

Effective rumen degradation of starch (ESD) in untreated feeds varied from 88.6 to 43.6% (Table 4), and ranged from high to low at the sequence: wheat bran, oats, wheat, barley, sorghum, peas and maize. Pelleting increased numerically ESD in feeds with low ESD as untreated, i.e. maize, sorghum and peas, although statistically significant ($P<0.05$) only for maize. Expander treatment of the latter feeds increased markedly and significantly ($P<0.05$) ESD compared to untreated, but significant effect of different expander temperature was shown only for maize. For the other feeds, the effects of treatments on ESD were relatively small and inconsistent.

The untreated feeds with the lowest ESD (maize, sorghum and peas) had the highest IS fraction (Table 4). Treatment reduced the IS of these feeds numerically, but significantly ($P<0.05$) only for peas. Otherwise, IS was ≤ 0.5 %, implying that total tract starch digestibility of the cereals was close to 100%, independent of treatment.

TABLE 3

Effective rumen degradation of protein (EPD) and indigestible protein (IP) fraction in untreated and treated cereals, peas and soyabeans

Feed	Treatment No.[1]	Achieved temp. ºC	EPD %	IP %
Barley	1	none	48.9[a]	5.3[a]
	2	82	44.9[a]	3.0[b]
	3	110	26.2[b]	3.7[b]
	4	128	29.8[b]	4.9[a]
SEM[2]			1.56	0.2
Oats	1	none	77.9[a]	4.4[a]
	2	76	68.9[a]	3.1[b]
	3	106	57.6[b]	3.5[ab]
	4	121	37.6[c]	5.0[a]
SEM			1.81	0.3
Wheat	1	none	64.6[a]	3.5
	2	81	50.8[b]	3.1
	3	111	37.9[c]	2.4
	4	130	39.2[c]	2.9
SEM			1.89	0.3
Wheat bran	1	none	75.2[a]	6.0
	2	81	65.3[b]	6.0
	3	109	54.8[c]	5.7
	4	133	52.5[c]	4.7
SEM			2.69	0.3
Maize	1	none	31.9	8.6
	2	81	28.7	5.0
	3	110	30.1	5.9
	4	130	31.3	7.4
SEM			1.97	1.7
Sorghum	1	none	25.7[a]	23.0[a]
	2	81	21.6[ab]	15.9[a]
	3	100	17.4[b]	25.4[ab]
	4	108	19.2[b]	33.2[b]
SEM			1.53	3.2
Peas	1	none	73.5[a]	1.0[a]
	2	84	65.6[ab]	1.9[a]
	3	112	63.1[b]	1.6[a]
	4	130	59.2[b]	4.7[b]
SEM			2.62	0.4
Soyabeans	1	none	75.5[a]	2.9
	2	83	66.6[ab]	3.9
	3	90	56.9[bc]	4.7
	4	98	48.4[c]	3.8
SEM			3.31	0.7

[a,b,c] EPD and IP values within feed bearing different letters differ significantly ($P<0.05$)

[1] see Table 1

[2] standard error of a mean

TABLE 4

Effective rumen degradation of starch (ESD) and indigestible starch (IS) fraction in untreated and treated cereals and peas

Feed	Treatment No.[1]	Achieved temp.ºC	ESD %	IS %
Barley	1	none	83.0	0.1[a]
	2	82	82.2	0.0[c]
	3	110	78.1	0.0[c]
	4	128	78.4	0.1[b]
SEM[2]			1.91	0.01
Oats	1	none	87.6[ab]	0.1[a]
	2	76	85.3[a]	0.1[ab]
	3	106	89.7[bc]	0.1[b]
	4	121	92.2[c]	0.1[ab]
SEM			1.30	0.01
Wheat	1	none	86.4	0.1[ab]
	2	81	79.4	0.3[a]
	3	111	74.8	0.0[b]
	4	130	77.4	0.0[b]
SEM			2.29	0.06
Wheat bran	1	none	88.6[a]	0.5[a]
	2	81	83.9[b]	0.2[b]
	3	109	88.6[a]	0.1[b]
	4	133	89.5[a]	0.1[b]
SEM			0.59	0.05
Maize	1	none	43.6[a]	7.3
	2	81	54.1[b]	2.4
	3	110	66.1[c]	1.9
	4	130	75.0[d]	0.8
SEM			1.78	1.64
Sorghum	1	none	57.8[a]	8.0[a]
	2	81	61.9[a]	1.3[b]
	3	100	79.4[b]	3.1[b]
	4	108	75.7[b]	4.6[ab]
SEM			4.05	1.32
Peas	1	none	55.6[a]	9.0[a]
	2	84	64.8[ab]	5.4[b]
	3	112	76.6[b]	2.6[c]
	4	130	77.1[b]	6.4[b]
SEM			4.50	0.61

[a. b. c]: ESD and IS values within feed bearing different letters differ significantly ($P<0.05$)

[1] see Table 1

[2] standard error of a mean

DISCUSSION

The *in situ* methods used for determination of degradation in rumen and digestion in the intestine of feed protein and starch have their limitations, but they are consistent in ranking feeds (Ponchet et al., 1995; Goelema, 1999; Nozière and Michalet-Doreau, 2000), which is of great importance in interpreting of the results of this study. The *in situ* method tends, however, to underestimate the extent of degradation of slowly degradable starch sources (Ponchet et al., 1995; Goelema, 1999). The *in situ* method for determining starch digestion in the intestine is based on the disappearance of material from nylon bags. Thus, this method ignores the possibility of limits on glucose absorption in the small intestine, which was presumed by Ørskov (1986) but rejected by Huntington (1997). Norberg and Harstad (2001) concluded that the mobile nylon bag technique is not suitable to determine values for total tract digestion of starch, but can be used to rank feedstuffs and measure effects of treatments on IS.

Rumen degradation and total tract digestion of protein in untreated feeds

In the present study, especially untreated barley and oats, but also wheat, had EPD values lower than in earlier studies from both our and other laboratories (Żebrowska et al., 1997; Prestløkken, 1999a). However, the ranking with highest EPD for oats followed by wheat, barley, maize and sorghum is in agreement with others (Herrera-Saldana et al., 1990; Żebrowska et al., 1997). Likewise, an EPD of 74% for peas is comparable with results obtained by others (Van Straalen and Tamminga, 1990; Goelema, 1999). The different EPD values among the feeds studied may partly be related to different proportional contents of rapidly and slowly degradable protein. Oats and peas contain high levels (>80%) of highly soluble and degradable albumins and globulins (Van Straalen and Tamminga, 1990; Hoseney, 1994),which contribute to their high EPD values. On the contrary, the high contents of insoluble prolamins and glutelins in wheat, barley, maize and sorghum (Hoseney, 1994) may explain their lower EPD values. The low EPD of untreated sorghum could be explained by the content of condensed tannins (Cheeke, 1998), since a complex formation by protein and tannins reduces rumen degradation of the protein (Streeter et al., 1993). The EPD of 75.5% for raw soyabeans was similar to values found by Faldet et al. (1991). The large IP fractions in maize and sorghum, shown herein, are in agreement with results obtained by Streeter et al. (1993) and Lund et al. (1999). High content of condensed tannins may explain the high IP fraction in sorghum (Streeter et al.,1993).

Effect of treatment on rumen degradation and total tract digestion of protein

All feeds except maize showed a decreased EPD following treatment. Goelema et al. (1999) found that rumen protein degradation increases after pelleting, which

is in contrast to the present results. The effect of pelleting on EPD depends on the conditions applied, particularly input of heat and moisture (Voragen et al., 1995). The relatively high heat input may at least partly explain the lowered EPD after pelleting in the present study.

Information about the effect of pelleting on IP is scarce. The studies by Prestløkken (1999b) showed no effect of pelleting on IP in barley and oats. In the present study a minor, but still significant lowering effect of pelleting on the IP of barley and oats was found. Thus, it seems that pelleting of some feeds may make the rumen escape protein fraction more available for digestion in the intestine.

The present results, indicating that oats need a higher temperature during expander treatment than barley, wheat and wheat bran to achieve lower rate of protein degradation, support findings by McNiven et al. (1994) and Prestløkken (1999a,b). Thus, the highest protection of the protein fraction against rumen degradation in oats may require a temperature higher than 120°C during expander processing. Untreated maize and sorghum are characterized by low extent of rumen degradation of the protein fraction, indicating only a minor potential for further lowering of protein degradation by treatment. However, the expander treatment appeared to promote a slight reduction of the EPD of sorghum.

The lowering effect of expander treatment on the EPD of peas, but not significant ($P>0.05$), is in agreement with the findings of Lund et al. (1998). In accordance with our results, they found only minor reduction in EPD by increasing the temperature during expander processing from 115 to 130°C. Thus, for peas the attainable increase in protein protection from rumen degradation is probably achieved at approximately 110°C in the expander process.

For the majority of feeds studied, expander treatment had relatively small effects on IP, which is in line with other studies (Lund et al., 1999; Prestløkken, 1999a). However, increasing temperature during expander treatment of oats tended to increase IP ($P>0.05$), while EPD was lowered ($P<0.05$). In contrast, for barley and sorghum, increased expander temperature caused increased IP, although EPD was not further decreased. Condensed tannins are not destroyed by heat treatment or cooking (Cheeke, 1998) and may have contributed to the high IP fraction in sorghum independent of treatment. In the study of Lund et al. (1999) expander treatment at 115°C had no effect on the IP of peas. However, in the present study the IP of peas increased after expander treatment at 130°C.

Rumen degradation and intestinal digestion of starch in untreated feeds

Ranking of the untreated cereal grains according to ESD was in the present study similar to the *in situ* findings of Herrera-Saldana et al. (1990) and *in vivo* results reported by Huntington (1997), except for maize starch that showed higher degradability than sorghum starch in the referred studies. The variation in ESD among

the feeds may partly be related to the construction of the protein–starch matrix that differs among the feeds studied (McAllister et al., 1993). In oats, protein and starch granules appear as spherical bodies in a loose arrangement (Fulcher, 1986), allowing a rapid amylolytic attack resulting in high ESD. In barley, wheat and in the floury endosperm of maize and sorghum, proteins form a more rigid protein matrix in which the starch granules are embedded. In the horny endosperm of maize and sorghum very dense proteins surround the starch granules (McAllister and Cheng, 1996). These characteristics of the protein matrix of maize and sorghum probably explains why the ESD of these feeds is only 40-60%, as the protein matrix must be disrupted before amylolytic attack can appear (Herrera-Saldana et al., 1990; McAllister and Cheng, 1996). Untreated peas behave differently from cereals, since the ESD is relatively low although EPD is high. This could be explained by the high amylose proportion in pea starch (Hoseney, 1994; Sosulski et al., 1997), since starch digestibility is inversely proportional to amylose content (Rooney and Pflugfelder, 1986).

Effect of treatment on rumen degradation and intestinal digestion of starch

Starch that has lost its crystalline structure (so-called gelatinized starch) is more digestible than intact native starch (Goelema, 1999). A minimum water-to-starch ratio of 0.3:1 is necessary to allow start of gelatinization, whereas complete gelatinization requires a 1.5:1 ratio (Lund, 1984). Gelatinizing temperature at excess water is lowest for barley (51^{o}C), followed by oats, wheat, maize and sorghum (78^{o}C; Hoseney, 1994). Low moisture level during processing limits gelatinization at temperatures below 100^{o}C (Lund, 1984; Keetels, 1995). The feeds in the present experiment contained 15-18.3% moisture during pelleting (treatment below 100^{o}C) and 15.1-18.7% moisture during combined expanding and pelleting (treatment above 100^{o}C; calculated according to Operation Manual for Kahl Expander). Thus, the moisture level during processing was insufficient for complete gelatinization. This could be the reason why rumen degradation of starch in barley, oats and wheat did not increase by pelleting in the present study. Goelema et al. (1999) found with a mixture of broken peas, lupins and faba beans, significantly increased rumen starch degradation after pelleting. This is in agreement with our findings for maize, sorghum and peas. When the treatment temperature was increased above 100^{o}C, gelatinization and thereby increased rumen degradation of starch should be expected, at least when combined with mechanical treatment (Trei et al., 1970) and pressure drop at the end of the expander. In the present study, increased ESD after expander treatment was observed only for maize, sorghum and peas. The lack of effect of expander treatment on the ESD of barley, oats and wheat may be surprising since the gelatinizing temperatures are lower for these feeds than for maize and sorghum (Malcolm and Kiesling, 1993; Hoseney, 1994). However, the results

may be explained by the low water content during treatment, short treatment time and limited potential for increasing ESD compared to maize, sorghum and peas. For the latter three feeds, the treatment effect on the IS fraction was parallel to the effect on ESD. Thus, factors that increased rumen degradation of the starch also made the rumen escape fraction more available for digestion in the intestine. Our results support Ørskov (1986) and Mills et al. (1999), who concluded that maize and sorghum benefit to a greater extent than other cereals from processing designed to increase rumen and total tract starch digestion.

CONCLUSIONS

Pelleting at 81°C decreased EPD significantly for barley, wheat and wheat bran, and increased ESD in maize. Expander treatment designed for decreasing EPD, did not affect ESD in barley and wheat, but increased ESD in peas and oats. Maize and sorghum starch responds to expander treatment by increased ESD and increased total tract digestion.

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STRESZCZENIE

Wpływ granulowania i ekspandowania pasz roślinnych na trawienie białka i skrobi *in situ* u krów

Oznaczano metodą *in situ* strawność białka i skrobi następujących pasz: jęczmienia, owsa, pszenicy, otrąb pszennych, kukurydzy, sorgo, grochu i soi po zmieleniu (nietraktowane), granulowaniu (około 81ºC) oraz procesie ekspandowania w dwóch temperaturach (110 lub 130ºC). Efektywny rozkład białka ogólnego (EPD) i skrobi (ESD) w żwaczu krów oraz niestrawionych wzdłuż całego przewodu pokarmowego frakcji białka (IP) i skrobi (IS) oznaczano metodami *in situ*.

W następstwie granulowania istotnie obniżył się EPD pszenicy i otrąb pszennych o 14 i 10 jednostek procentowych, odpowiednio, a zwiększył się w przypadku kukurydzy, o 10 jednostek procentowych. Ekspandowanie efektywne chroniło białko wszystkich pasz, z wyjątkiem kukurydzy, przed rozkładem w żwaczu. ESD kukurydzy, sorgo, grochu i owsa zwiększało się odpowiednio o 31, 18, 22 i 5 jednostek procentowych po ekspandowaniu w temperaturze 130ºC. Frakcje IP sorgo i grochu zwiększały się, a frakcje IS kukurydzy, sorgo i grochu zmniejszały się w wyniku traktowania tych pasz temperaturą.

Na podstawie otrzymanych wyników stwierdzono, że trawienie białka i skrobi pasz roślinnych przez krowy mleczne można modyfikować poprzez termiczne traktowanie pasz.