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EFFECT OF FEED PROCESSING ON *IN SITU* RUMINAL DEGRADATION OF CEREAL GRAINS AND ON THE DEGREE OF SYNCHRONY OF ORGANIC MATTER AND NITROGEN RELEASE IN THE RUMEN OF GRAZING LACTATING DAIRY COWS

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ABSTRACT

Three rumen-cannulated, lactating Holstein-Friesian cows grazed in a controlled experimental pasture and supplemented daily with concentrates were used to measure effects of different heat treatment of cereal grains (pelleted barley, toasted barley, pelleted maize, toasted maize) on *in situ* degradability of protein and starch and to estimate of the possible rumen synchrony after feeding processed cereal grains as a supplement to perennial ryegrass (*Lolium perenne*). Pressure toasting treatment increased (P < 0.05) the undegradable fraction of DM and OM and tended to reduce (P > 0.05) *in situ* protein degradability of the cereal grains. Undegraded intake protein increased (P > 0.05) after pressure toasting from 36.4 to 52.5% for barley and from 50.3 to 58.2% for maize, respectively. Undegraded intake starch increased (P > 0.05) from 14.9 to 16.7% after toasting barley and decreased from 36.1 to 31.3% for toasted maize, respectively. Pressure toasting reduced washable fractions of each cereal grains for both constituents. The fractional rate of degradation of starch increased in maize, but decreased in barley. From the calculated synhrony index which describes the synchrony of nitrogen and organic matter degradation in the rumen it appears that supplementing grass with processed cereal grains can alter microbial growth and efficiency of utilization of nutrients and results in a more synchronous substrate for the microbes.

Key words: cattle / dairy cows / feed processing / barley / maize /grass / *in situ* ruminal degradation

VPLIV OBDELAVE KRME NA *IN SITU* RAZGRADNJO ŽITNIH ZRN V VAMPU IN NA STOPNJO SINHRONOSTI RAZGRADNJE ORGANSKE SNOVI IN SPROŠČANJA DUŠIKA V VAMPU MOLZNIC NA PAŠI

IZVLEČEK

Pri treh črno-belih kravah v laktaciji in s kanilo v vampu na paši na poskusnem pašniku in dodatkom dnevne količine močnih krmil smo preučevali vplive različno toplotno obdelanih žitnih zrn (peletiran ječmen, pražen ječmen, peletirana koruza, pražena koruza) na *in situ* razgradnjo beljakovin in škroba in na morebitno sinhronost razgradnje v vampu po krmljenju s toplotno obdelanimi žitnimi zrni kot dodatkom k ljulki (*Lolium perenne*). Postopek praženja pod pritiskom je povečal (P < 0,05) nerazgradljivo frakcijo suhe snovi in organske snovi ter zmanjševal (P > 0,05) *in situ* razgradnjo beljakovin iz zrnja. Delež nerazgrajenih zaužitih beljakovin se je povečal (P > 0,05) po praženju pod pritiskom od 36,4 na 52,5 % pri ječmenu oziroma od 50,3 na 58,2 % pri koruzi. Delež nerazgrajenega zaužitega škroba se je povečal (P > 0,05) od 14,9 na 16,7 % po krmljenju s praženim ječmenom, oziroma se je zmanjšal od 36,1 na 31,3 % pri praženi koruzi. Praženje pod pritiskom je znižalo topne frakcije v vseh vrstah žita in obeh sestavinah. Frakcijska stopnja razgradnje škroba se je povečala pri koruzi, vendar znižala pri ječmenu. Iz izračunanega sinhronega indeksa, ki opisuje sinhronost razgradnje dušika in organske snovi v vampu, izhaja, da dopolnjevanje trave s toplotno obdelanimi žiti lahko spremeni rast mikrobov in učinkovitost porabe hranil, kar se kaže v bolj sinhronem substratu za mikrobe.

Ključne besede: govedo / krave / molznice / krma / predelava / ječmen / koruza / trava / vamp / razgkroj / *in situ*

INTRODUCTION

Fresh grass from intensively fertilized swards contains high concentrations of crude protein, of which 70–90% is present as true protein (Tamminga, 1986). It is not only rapidly degraded in the rumen, but its extent of degradation is high and often in asynchrony with that of energy yielding substrates. Hence, only part is captured by rumen microbes. It is estimated that 45–50% of the crude protein ingested with such grass may be lost (Van Vuuren, 1993). This not only means a severe loss of protein, but it may have a detrimental impact on the environment and also on animals health and reproduction. A possible way to reduce N consumption is to supplement fresh grass with concentrates, low in protein but rich in either rapidly degradable structural or non-structural carbohydrates (Van Vuuren *et al*., 1993; Peyraud, 2001). The availability of protein and energy may not only be imbalanced on a daily basis, but also within a day because of differences in rate of degradation. Maize and barley are sources of readily available energy, but their starch degradabilities are very different (Rooney and Plugfelder, 1986). Heat treatments of grains affect rumen protein degradability and also affects degradability of cereal starch (Nocek and Tamminga, 1991; McAllister *et al*., 1993; Sauvant *et al*., 1994; Owens, 2006). The main objective of this experiment was to compare the effects of pressure toasted and subsequently pelleted and grains which were only pelleted on rumen *in situ* degradability of protein and starch. This could result in a range of supplements differing in rumen degradation rates for energy and protein and therefore tailor-made for grasses may differing in quality. It is known that the synchronisation of available N and available OM for rumen microbes seems advantageous for an optimum N economy of a grazing cow. Therefore the second objective of this study was to estimate of the possible rumen synchrony after feeding processed cereal grains as a supplement to grazing dairy cows.

MATERIAL AND METHODS

Animals and management

The *in situ* trial was carried at the experimental farm 'De Ossekampen' of Wageningen University, The Netherlands. Three multiparous lactating Holstein-Friesian dairy cows fitted with a ruminal cannula (10 cm id., Bar-Diamond Inc., Parma, Idaho, USA) were used. At the beginning of the experiment the cows produced 31.0 ± 4.3 kg/day milk. The experimental animals grazed an experimental pasture and were supplemented daily with two equal proportions of 3 kg of a concentrates mixture (1 kg of mixture contained the following ingredients: 250 g pelleted barley, 250 g pelleted corn, 250 g toasted barley and 250 g toasted corn. Chemical composition of the mixtue was 972 g DM /kg mixture, 982.3 g OM/kg DM, 103.4 g CP/kg DM, 640.4 g starch/kg DM, 109.2 g NDF/kg DM and 7.9 g ADL/kg DM) fed in the milking parlour during milking time (06.30 h and 17.00 h).

Experimental feedstuffs and grass

Two cereal grains, that is barley and maize were used in the experiment. The cereals were pelleted for 10 s at 80 ^{o}C (pelleted barley PB, pelleted maize PM) or pressure toasted for 15 min at 135 °C (toasted barley TPB, toasted maize TPM) at the Wageningen Feed Processing Centre (WFPC). After toasting, the grains were dried in a forced air oven for 16 h at 35 °C, subsequently pelleted through a 5 × 65 mm (bore × hole) die. Sward management and perennial ryegrass sampling are reported elsewhere (Tóthi *et al*., 2003). Chemical composition of perennial ryegrass (*Lolium perenne*) are shown in Table 1.

Table 1. Chemical composition and the effect of maturation on washable (W) and undegradable fractions (U) and rate of disappearance of the insoluble potentially degradable fraction (k_d, %/h) of dry matter (DM), organic matter (OM), crude protein (CP), acid detergent lignin (ADL) and neutral detergent fibre (NDF) of perennial ryegrass (*Lorium perenne)* (sampled in June 2 to July 31).

Date of sampling	Period 1	Period 2	Period 3	Period 4	Period 5
	2–6 June	16–20 June	30 June–4 July	14–18 July	28–31 July
DM%	23.82	22.82	17.04	16.39	21.78
k_d, %/h	6.9	6.7	6.4	6.0	5.3
W, %	54.1	46.5	49.9	44.9	44.4
D, %	17.8	27.8	29.1	31.4	30.4
U, %	28.1	25.7	21.0	23.7	25.2
OM, % of DM	91.22	90.82	89.46	89.98	90.24
k_d, %/h	6.1	6.0	5.8	5.4	4.8
W, %	53.0	45.6	48.0	42.7	42.8
D, %	18.2	28.3	30.8	33.2	32.3
U, %	28.8	26.1	21.2	24.1	24.9
CP, % of DM	15.65	21.07	24.79	23.68	20.41
k_d, %/h	16.8	7.5	6.5	6.1	6.1
W, %	54.4	55.8	60.5	52.4	49.8
D, %	24.1	29.2	28.8	34.0	34.0
U, %	21.5	15.0	10.7	13.6	16.2
NDF, % of DM	36.09	38.29	37.10	38.2	37.86
k_d, %/h	2.7	5.1	5.9	5.1	4.3
D, %	59.9	55.9	62.0	59.0	57.2
U, %	40.1	44.1	38.0	41.0	42.8
ADL, % of DM	2.17	2.15	1.88	2.02	2.26
Residue, % of DM	39.48	31.46	27.54	28.1	31.97
ADL/NDF%	6.0	5.6	5.0	5.3	6.0

Nylon bag experiments

Rumen incubations were carried out according to Dutch standard methods (CVB, 1996) and nylon bags with a pore size of 40 μm (PA 40/30, Nybolt, Switzerland) were used. The processed grain samples were ground through a 3.0 mm sieve (Retsch ZM1 centrifugal mill). The coded nylon bags were filled with 5.0 g of DM of cereal grain samples for incubation times of 0, 2, 4, 8, 24 and 48 h, respectively. After incubation the nylon bags were immediately placed in cold water and rinsed with tap water to stop fermentation. The bags were subsequently washed in a domestic washing machine for 50 minutes with 70 l of cold water, without centrifugation. After this procedure the bags were freeze dried, air equilibrated and weighed.

Chemical analysis

All the grain samples were analyzed for DM, ash, crude protein (6.25 × N) and starch contents. Prior to analyses, the samples were ground through a 1 mm sieve. All chemical analyses were carried out following procedures as described by Tóthi *et al*. (2003a).

Calculation of degradabilit

Crude protein and starch degradation characteristics of processed grains were classified in three fractions as described by Tamminga *et al*. (1994) and Sauvant *et al*. (1994). Washable fraction (W) is readily available measured as the fraction disappearing after washing only (0 h incubation). Undegradable fraction (U) is the fraction which will not be degraded, measured as 100 minus the asymptote of the degradation curve at infinite incubation time. Potentially degradable fraction (D) is calculated as D = 100 – W – U. The fractional rate of degradation of the D fraction (k_d in%/h) was calculated using a first order degradation model, without a lag time, as described by Robinson *et al*. (1986). The fraction of effectively rumen undegraded intake starch (%UIS) and rumen undegraded intake protein (%UIP) were also calculated based on the following equations (Tamminga *et al*., 1994). For starch it was assumed that 10% of W escapes rumen fermentation and U is 0 (Tamminga *et al*., 1994). Thus %UIS is $0.1 \times W + D \times k_p / (k_d + k_p)$ and %UIP is $U + D \times k_p / (k_d + k_p)$.

Calculation of synhcrony index

With the calculated grass intake, grain intake (Tóthi *et al*., 2003a) and *in situ* degradation results of grass (Table 1), processed grains (Table 2) and rumen content (Tóthi *et al*., unpublished data) we estimated on an hourly basis, the degradation of OM and N for over 24 hours. The patterns of the first grazing event is based on our own observations and more information for the later hours was adapted from other work about grazing behaviour of dairy cows (Rook *et al*., 1994; Gibb *et al*., 1997, 1998, 2002; Orr *et al*., 2001). The synchrony index (IS) which describes the synchrony of nitrogen and organic matter degradation in the rumen was calculated according to an equation similar to the one proposed by Sinclair *et al*. (1993).

$$I_S = \frac{25 - \sum_{1-12} \frac{\sqrt{(25 - \text{hourly N/OM})^2}}{24}}{25}$$

where 25 = 25 g N/kg OM truly digested in the rumen which was assumed to be the optimal ratio (Czerkawski, 1996). An IS of 1.0 represents perfect synchrony between nitrogen and energy supply throughout the day whilst values less than 1.0 indicate the degree of asynchrony (Sinclair *et al*., 1993). The supply of N and OM was calculated from the sum of the hourly degradation and the ratio of N to OM calculated. Statistical analysis. Variance analyses were performed with GLM procedure in the Statistical Analysis System (SAS, 2001) with treatment and cow included in the model. Significance was declared when $P < 0.05$.

RESULTS AND DISCUSSION

Rumen degradability of processed cereal grains.

DM, OM, CP and starch degradation characteristics are presented in Table 2. No effect of pressure toasting treatment was observed on effective dry matter degradability in barley or in maize. Hovewer the washable DM fraction significantly ($P < 0.001$) decreased in barley by 7.2% and in maize by 6.8% units while the degradable DM fraction significantly increased in barley by 5.8% units ($P < 0.001$). The size of the undegradable DM fraction was significantly elevated by toasting in maize. Pressure toasting elevated OMD by 5.4% units in barley ($P < 0.05$). Undegraded intake protein increased ($P > 0.05$) after toasting from 36.4 to 52.5% for barley and from 50.3 to 58.2% for maize, respectively. Undegraded intake starch increased ($P > 0.05$) from 14.9 to 16.7% after toasting barley and decreased from 36.1 to 31.3% for toasted maize, respectively. The fractional rate of degradation (k_d) of protein decreased, while the k_d of starch increased for maize and decreased for barley. Pressure toasting increased the degradable starch fraction in barley and maize as well ($P < 0.05$). The effect of pressure toasting on the decreased W and the increased UIS% may have been related to the change in starch distribution over the different particle size classes after pressure toasting. The crystallization of gelatinized starch molecules, i.e. retrogradation has received considerable attention because after retrogradation it is difficult to solubilize and this may decrease W as well.

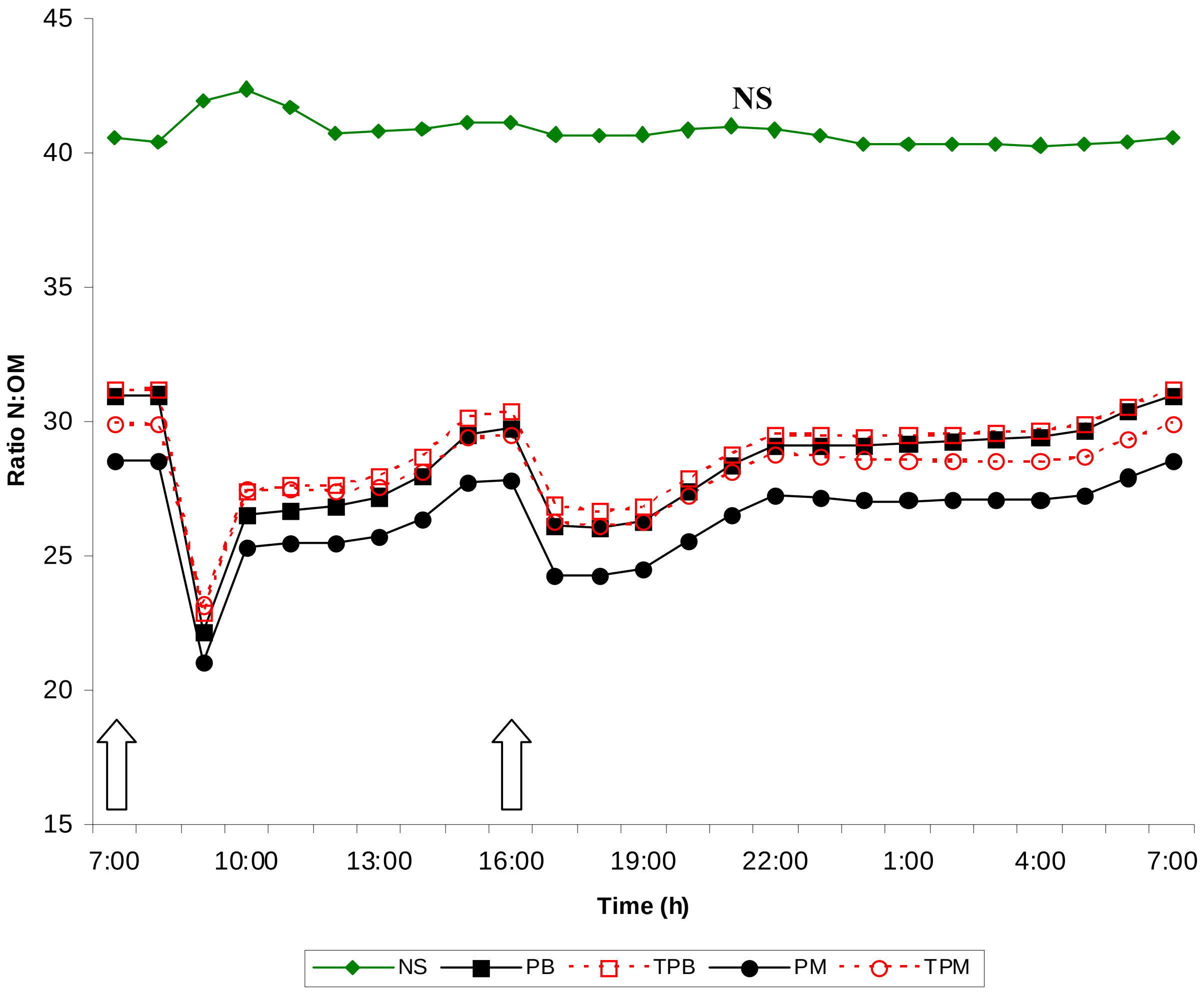

Figure 1. Predicted ratio of nitrogen to organic matter degraded in the rumen of non supplemented (NS) and supplemented dairy cows. Supplement (6 kg per day) consumed two equal meals per day, times of supplement feeding are indicated by the arrows. For abbreviations see Table 2.

Table 2. Chemical composition of the processed grains [1] and *in sacco* rumen degradation characteristics [2] of dry matter (DM), organic matter (OM), crude protein (CP), and starch

	Barley grain		Maize grain		SEM	P [3]		
	PB	TPB	PM	TPM		G	H	GxH
DM, %	97.2	97.3	97.1	97.2				
W, %	45.9 [a]	38.7 [b]	36.6 [c]	29.8 [d]	0.41	<0.001	<0.001	NS
D, %	40.8 [a]	46.6 [b]	52.9 [c]	56.4 [c]	0.56	<0.001	<0.001	NS
U, %	13.3 [a]	14.7 [b]	10.5 [b]	13.8 [a]	0.56	<0.05	<0.05	<0.05
k_d , %/h	18.0 [a]	15.3 [a]	4.9 [b]	6.0 [b]	2.14	<0.05	NS	<0.05
EDMD, %	76.5 [a]	72.3 [a]	60.5 [b]	58.0 [b]	2.75	<0.05	NS	NS
OM, % of DM	97.8	97.9	98.7	98.6				
W, %	51.1	44.3	42.3	38.1	0.35	NS	NS	NS
D, %	35.8 [a]	41.2 [b]	47.4 [c]	48.3 [c]	0.59	<0.001	<0.05	<0.05
U, %	13.1 [a]	14.5 [a]	10.3 [b]	13.6 [a]	0.58	<0.05	<0.05	<0.05
k_d , %/h	17.8 [a]	15.3 [a]	4.8 [b]	5.9 [b]	2.16	<0.05	NS	NS
EOMD, %	77.9 [a]	74.0 [a]	63.4 [b]	62.0 [b]	2.92	<0.05	NS	NS
CP, % of DM	11.5	11.4	9.2	9.3				
W, %	35.5	27.5	34.9	32.4	4.12	NS	NS	NS
D, %	59.0	69.2	63.8	64.1	4.24	NS	NS	NS
U, %	5.4	3.3	1.3	3.5	4.2	NS	NS	NS
k_d , %/h	5.5	2.4	1.8	1.0	1.2	NS	NS	NS
% UIP	36.4	52.5	50.3	58.2	3.60	NS	NS	NS
ECPD, %	48.6	47.5	49.7	41.8	4.32	NS	NS	NS
Starch, % of DM	57.2	59.7	68.3	71.0				
W, %	57.0 [a]	49.5 [b]	39.6 [c]	35.0 [d]	1.26	<0.05	<0.05	<0.05
D, %	43.0 [a]	50.5 [b]	60.4 [c]	65.0 [d]	1.33	<0.05	<0.05	<0.05
k_d , %/h	20.6 [a]	19.0 [a]	4.8 [b]	6.6 [b]	2.53	0.012	NS	0.04
% UIS	14.9 [a]	16.7 [a]	36.1 [b]	31.3 [b]	2.12	<0.05	NS	NS
ESD, %	88.6 [a]	86.7 [a]	65.0 [b]	65.7 [b]	2.27	<0.05	NS	NS

[1] PB = pelleted barley, TPB = toasted and pelleted barley, PM = pelleted maize, TPM = toasted and pelleted maize.
[2] W = washable fraction; U = undegradable fraction; D = not soluble, but potentially degradable fraction; k_d the fractional rate of degradation of D fraction; UIP = rumen undegraded intake protein, calculated for a passage rate of 6%/h., UIS = rumen undegraded intake starch, calculated for a passage rate of 6%/h., EDMD, EOMD, ECPD,ESD = effective degradability of dry matter, organic matter, crude protein, or starch = $W + D \times k_d / (k_d - k_p)$.
[3] = G = effect of type of grain, H = effect of type of heat, GxH = effect of grain type and heat interaction.
[a,b,c,d] figures with different superscript in the same row differ significantly, NS = not significant (P > 0.05)

Effect of feed intake on the synchronisation level

The predicted hourly ratio of N to OM degraded in the rumen throughout the day in the paddock-grazing system where the dairy cows were given their daily pasture allocation after the morning milking, is illustrated in Fig. 1. As could be expected the non supplemented animals (NS) have a higher N to OM ratio throughout the day than the supplemented animals. The high concentrations of ammonia in the rumen (Tóthi *et al*., 2003) and the calculated synchrony index (Is = 0.37, for 24 h) indicate a high degree of asynchrony and a substantial degradation of protein in the rumen. Compared with the non supplemented diet, supplementation with 6.0 kg of processed cereal grains fed in two equal amounts per day in the milking parlour during milking results in a lower ratio of N to OM release in the rumen during the day. In the morning, after feeding 3 kg of concentrates, the easily available fraction of cereal starch increases the OM release in the rumen, therefore the N to OM ratio drops. The first two active grazing hours after milking result in a fast rate of release of herbage nitrogen compared with the release of OM. The ruminal degradation of processed cereals is quite intensive a few hours after feeding and this may result in high amounts of OM available for the microbes and higher propionate and butyrate concentrations (Tóthi *et al*., 2007) and VFA productions than with NS. In the milking parlour at the evening milking time the dairy cows receive the second part (3 kg) of their concentrate meal. In the rumen starch from the morning feeding is still present, because until this time point around 80% of the starch from barley had disappeared and 30 to 35% of the starch from maize. However, the drop in N to OM ratio is smaller than the observed fall in the morning. The reason may be the degradation of protein from the cereal grains, which also elevate the N pool in the rumen. In the first hours of the second large grazing event in the afternoon, the available N and OM for the microbes seems more synchronised than in the morning grazing event. The synchrony index is highest in dairy cows supplemented with pelleted maize (IS = 0.93) than with toasted and pelleted maize ((IS = 0.87) and with barley supplements (pelleted barley nad toated and pelleted barley IS = 0.84 and 0.86, respectively). The starch disappearance of barley is higher than that of maize, which synchronises the rumen shortly after the feeding but the starch release from the lower amount of barley during the day does not provide a sufficient balance of protein and energy for the microbes.

CONCLUSIONS

The rate of crude protein degradation of ryegrass is relatively high, thus for better microbial availability of protein and energy the supplement should have a rate of starch fermentation at least as fast as that of the CP of the grass. The effect of toasting in this respect is favorably than pelleting alone, because this heat treatment decreased the rate of degradation of barley starch but increased the rate of degradation of maize starch. Pressure toasting increased the undegradable fraction of DM and OM in barley and maize compared to pelleting alone. Therefore further research will have to concentrate on the question which chemical compound(s) give a reaction when grains are pressure toasted. From the calculated synchrony indexes it appears that supplementing grass with processed cereal grains can alter microbial growth and efficiency of utilization of nutrients and results in a more synchronous substrate for the microbes.

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