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Original article

In situ starch degradation of different feeds in the rumen

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Summary — The *in situ* starch degradation of 5 feeds (barley, maize, pea, oats and wheat bran) has been measured (trial 1), and the influence of particle size on starch degradation investigated with 3 feeds (barley, maize, pea) (trial 2). The starch degradability of barley, oats and wheat bran was found to be higher than that of pea, and higher again than that of maize: 98, 97, 96, 90 and 58% respectively. For barley, oats and wheat bran, starch was degraded more rapidly than the other dry matter (pm) components. Maize and pea starches were degraded at the same rate as non-starchy components. The particle size variations between feeds ground on the same screen may partly explain variations in starch degradability. When the particle size increased from 0.8 to 6.0 mm screen grinding, *in situ* starch degradability decreased; the decrease was higher for maize (13.8 points) than for barley (7.4 points) or pea (10.4 points).

starch / *in situ* degradation / particle size / nylon bag technique

Résumé — Étude de la dégradation *in situ* de l'amidon de différents aliments dans le rumen. *La dégradation* in situ *de l'amidon de 5 aliments (avoine, orge, maïs, son fin de blé) a été mesurée (essai 1), ainsi que l'influence de la taille des particules de l'échantillon pour 3 de ces aliments (orge, maïs, pois) (essai 2). La dégradabilité de l'amidon de l'orge, de l'avoine et du son de blé est plus élevée que celle du pois, qui est elle-même plus élevée que celle du maïs, soit respectivement 98, 97, 96, 90 et 58%. Par ailleurs la dégradabilité de l'amidon d'orge, et surtout celle de l'avoine et du son de blé, est plus élevée que celle des autres constituants de la matière sèche. Pour le maïs et le pois, la dégradabilité de l'amidon est égale à celle des constituants non amylacés. Les variations de taille de particules entre aliments broyés à la même grille (0,8 mm) pourraient expliquer en partie les variations de dégradabilité* in situ *de l'amidon dans le rumen. Dans l'essai 2, l'augmentation de la taille des particules, par le changement de la grille de broyage de 0,8 à 6,0 mm, se traduit par une diminution de la dégradabilité* in situ *de l'amidon plus importante pour le maïs (13,8 points entre les 2 broyages extrêmes), que pour l'orge (7,4 points) ou le pois (10,4 points).*

amidon / dégradation* in situ *| taille des particules / technique des sachets de nylon

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INTRODUCTION

The energetic value of a diet or a feed depends on organic matter digestion in the rumen and in particular on starch digestion, although this is not the only factor. Ruminal starch digestion depends on the intrinsic characteristics of diet or feed (degradability) and on the intensity and duration of bacterial activity in the rumen (Malestein *et al,* 1982, 1984; Ørskov, 1986). Starch digestion by ruminants has been reviewed and discussed (Ørskov, 1986; Owens *et al,* 1986). These reviews underline the importance and the site (ruminal or intestinal) of starch digestion, as well as the influence of the nature of feed and technological processing.

In order to demonstrate the influence of the latter 2 phenomena, the kinetics of *in situ* starch degradation in the same ruminal conditions were compared for several feeds (trial 1). The second trial was performed to investigate the influence of particle size upon ruminal starch degradation by *in situ* technique (trial 2).

MATERIAL AND METHODS

Trial 1

Feeds

Starch degradation in 5 feeds was measured: 3 whole and uncooked cereal grains (maize, barley, oats), one cereal by-product (wheat bran) and one legume grain (smooth pea); the chemical characteristics of these are shown in table I. Nitrogen was determined according to a micro-Kheldahl method (N x 6.25), cell wall constituents were analyzed (Van Soest and Wine, 1967) and an amylase was added to improve filtration (Giger and Pochet, 1987). The feeds were ground using a hammer mill with a 0.8-mm sieve, in view of the *in sîtu* technique.

In situ technique

In situ measurements of degradation were carried out using 3 dry Holstein cows fitted with a ruminal cannula. At 08.00 and 17.00 h, they were fed 7 kg dry matter (DM) per animal per day of hay and concentrate (70:30); the composition of concentrate (percent of dry matter) was: barley (43), sugar-beet pulp (40), soybean meal (10), molasses (5), minerals (2) (Michalet-Doreau *et al,* 1987). After grinding, the foodstuffs were placed in nylon (pore size, 46 μm) bags (internal dimensions 6 x 11 cm), with 3 g per bag, and a sample mass/area ratio of 20 mg/cm^2. The bags were then placed in the rumen at the same time just before the morning feed, and then removed after 2, 4, 8, 16, 24 or 48 h of incubation. Six measurements were made for each incubation time (3 cows x 2 replications). Following incubation the bags were washed in a washing machine with cold water (3 x 3 min), then dried at 80 °C and weighed.

The 2 bags for each animal and each point in time were combined to carry out the starch content determination by the enzymatic method (Thivend *et al,* 1965). After starching, the starch was degraded to glucose by an amyloglucosidase; the glucose thus formed was determined by colorimetry (Trinder, 1969). The foodstuff starch degradation kinetics were described by a single exponential equation (Ørskov and McDonald, 1979), as follows:

$$D(t) = a + bx\,(1 - e^{-ct})$$

Table I. Chemical composition of feeds.

Feed	% DM *Crude protein*	*Starch*	*NDF**	*ADF**	*ADL**
Barley	13.4	46.2	14.0	5.1	0.7
Maize	12.6	54.8	10.1	7.2	0.7
Oats	12.1	30.1	25.1	13.5	2.4
Pea	23.9	40.5	11.9	5.5	0.6
Wheat bran	20.1	24.9	20.5	7.4	2.0

* NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin.

which implies 3 fractions in the sample: one rapidly degradable fraction (a), one slowly and potentially degradable *(b)* with a rate reducing exponentially (e^{-ct}), and one non-degradable (Ind = 100–*a*–*b*).

Parameter values were obtained by fitting the data, using a non-linear regression procedure based on Marquardt's method (Marquardt, 1963), performed by the NLIN procedure of the statistical analysis system (SAS Institute, 1985). This technique is an iterative curve fitting procedure to reduce the residual sum of squares which is associated with regression model. In order to compare nitrogen degradability of foodstuffs in the rumen, a feed passage rate out of the rumen of 0.06 per h was taken (Vérité *et al*, 1987), and the ruminal degradability of DM and starch calculated by integrating the quantity of DM and starch remaining in the bag with the particle turnover rate (Ørskov and McDonald, 1979) for each time interval:

$$\text{Deg} = a + bc/(c + 0.06).$$

Statistical analysis

Variance analysis was performed on data using the general linear model procedure of SAS (SAS Institute, 1985), with a controlled factor (nature of the feed). Duncan's multiple range test was employed to separate means when significant effects were observed ($P < 0.05$) (Duncan, 1955).

Trial 2

Feeds

The influence of particle size *in situ* starch degradation was investigated; 3 feeds (barley, maize and pea) were ground through either 0.8, 3.0 or 6.0-mm screens. Foodstuff particle size was determined by wet sieving (Grenet, 1984). Each 10 g sample was first soaked for 15 min in water, then sieved for 20 min in a stream of water using an electromagnetic screener (3 000 vibrations/min) and 8 sieves, with mesh sizes respectively of 4, 2.5, 1.6, 0.8, 0.4, 0.25, 0.1 and 0.05 mm. Waste water was filtered (Durieux filter 2B) to recover particles that were insolubilised and < 50 m. Each measurement was carried out in triplicate. Dry matter content was determined for each batch of given particle size thus obtained. The particle size distribution was taken as the percentage distribution of total DM contents found by sieving and filtration (table II).

Table II. Particle size distribution of feeds after grinding (% of dry matter retained on screens and filter papers).

Feed	*Grinding (mm)*	*<0.05*	*0.05–0.1*	*0.1–0.25*	*0.25–0.4*	*0.4–0.8*	*0.8–1.6*	*1.6–2.5*	*2.5–4.0*	*> 4.0*	*%DM solub**	*Arithmetic mean*
Barley	0.8	41.3	6.6	8.6	12.3	26.2	5.0	0.0	0.0	0.0	12.8	0.288
	3.0	30.3	3.7	6.3	5.6	22.9	25.3	5.9	0.0	0.0	7.0	0.540
	6.0	17.9	1.9	3.0	2.6	14.4	27.2	20.0	13.1	0.0	5.7	1.267
Maize	0.8	10.4	7.6	25.7	21.5	33.0	1.7	0.0	0.0	0.0	14.6	0.342
	3.0	9.0	5.3	15.3	14.7	36.5	18.2	1.0	0.0	0.0	8.9	0.540
	6.0	10.5	2.4	8.2	7.8	23.7	29.4	14.1	3.8	0.2	1.7	0.966
Pea	0.8	64.0	1.3	4.7	9.1	20.0	0.8	0.0	0.0	0.0	20.4	0.186
	3.0	52.4	1.0	2.8	4.9	19.7	17.3	1.8	0.1	0.0	22.3	0.411
	6.0	35.2	0.4	1.2	2.0	12.7	24.3	16.9	4.4	2.8	12.0	1.032

* DM solubilized in water.

After grinding the foodstuff particle size was characterized by the arithmetic mean (Israelsen, 1968) calculated from the median of each particle size class indexed to its percentage by weight. In the case of the coarse screen (4.0 mm), the mean value was taken to be 5.5 mm ([4 + [4 – 2.5]]).

In situ technique

In situ kinetics and parameter values were established with the same experimental procedure and calculations as in trial 1.

Statistical analysis

Variance analysis was performed on data using the SAS general linear system procedure (SAS Institute, 1985), by a factorial model with interaction:

$$Y_{ij} = m_{ij} + F_i + G_j + F_i \cdot G_j + e_{ij}$$

where Yij represented DM or starch degradation (Degradability, a, b, c, Ind), F_i and G_j, the 2 main effects, representing respectively the feed (corn, barley and pea) and the diameter of the grinding sieve (0.8, 3.0 or 6.0 mm), and $F_i \cdot G_j$, the crossed effect. Duncan's multiple range test was employed to separate means when a significant effect was observed ($P < 0.05$) (Duncan, 1955).

RESULTS

Trial 1

The starches of cereals and cereal by-products studied were divided into 2 groups according to their degradability: on the one hand, barley, oats, and wheat bran whose degradability reaches 95%, and on the other hand, maize whose starch degradability does not exceed 50% (table III). Pea degradability is as high (90%) but significantly different from that of barley or oats. For barley, oats and wheat bran, 82–95% starch was degraded very rapidly, whereas this fraction only represented 56% of pea, and 26% of maize. The rate of ruminal degradation of the potentially degradable fraction of maize starch was also low: 0.045 *vs* 0.571 h^{-1} for barley. Maize starch, as well as that of pea, was degraded in the rumen at the same rate as the non-starchy constituents, and DM degradability was similar to that of the starchy fraction (table III). On the other hand barley starch, and even more so that of oats and wheat bran, were degraded more rapidly than other constituents of the DM feed, the degradability of the starchy fraction being 98, 97 and 96% respectively for barley, oats and wheat bran, while that of dry matter only reached 86, 75 and 77% respectively.

Trial 2

When particle size increased, starch degradability decreased from 57.8 to 44.0% when maize was ground through a 0.8 or 6.0-mm screen. For the other feeds, although less important, the difference in starch degradability between the ground samples through the 0.8-mm and those through the 6.0-mm screen was equally significant. The variations were principally a consequence of a decrease in the rapidly degraded fraction, which passed from 26 to 0% for maize, from 82 to 47% for barley and from 56 to 28% for pea (table IV). The degradation rate of potentially degradable starch in the rumen remained constant whatever the particle size of maize and pea, and varied slightly for barley. The decrease in degradability linked to the increase in particle size was significantly more important for the least degraded feeds such as maize (13.8 points) than for the feeds whose degradability is high, like barley (7 points).

Table III. Influence of type of feed on the *in situ* degradability and the values of parameters of degradation.

		Dry matter			
Feed	*Degradability*	*Ind*	*a*	*b*	*c*
Barley	82.8^{b}	12.3^{a}	62.5^{a}	25.2^{ad}	0.249^{a}
Maize	58.0^{a}	0.0^{b}	28.2^{b}	71.8^{b}	0.043^{b}
Oats	74.6^{d}	15.8^{a}	63.6^{a}	20.6^{a}	0.07^{b}
Pea	88.6^{c}	0.4^{b}	60.3^{a}	39.3^{c}	0.159^{c}
Wheat bran	77.2^{d}	14.9^{a}	51.6^{c}	33.6^{cd}	0.209^{ac}
		Starch			
Feed	*Degradability*	*Ind*	*a*	*b*	*c*
Barley	98.3^{a}	0.0^{a}	82.0^{a}	18.0^{a}	0.571^{a}
Corn	57.8^{b}	0.0^{a}	26.5^{b}	73.5^{b}	0.045^{b}
Oats	97.4^{ca}	0.0^{a}	94.5^{c}	5.5^{c}	0.071^{b}
Pea	90.0^{d}	0.0^{a}	55.9^{d}	44.1^{d}	0.207^{c}
Wheat bran	96.4^{c}	0.3^{a}	82.8^{a}	16.8^{a}	0.254^{c}

Different letters in the same column indicate a significative difference ($P < 0.05$).

Table IV. Influence of grinding fineness on the *in situ* starch degradability and on the parameter values of the starch degradation.

Feed	*Grinding (mm)*	*Degradation*	*Degradation parameters*			
			Ind	*a*	*b*	*c*
Barley	0.8	98.3^{a}	0.0^{a}	82.0^{a}	18.0^{a}	0.571^{a}
	3.0	94.6^{ab}	0.0^{a}	50.8^{b}	49.2^{b}	0.490^{b}
	6.0	90.9^{b}	0.4^{a}	46.6^{b}	53.0^{b}	0.304^{c}
Maize	0.8	57.8^{a}	0.0^{a}	26.5^{a}	73.5^{a}	0.045^{a}
	3.0	61.0^{a}	3.3^{b}	30.5^{a}	66.2^{a}	0.055^{a}
	6.0	44.0^{b}	0.7^{a}	0.0^{b}	99.3^{b}	0.048^{a}
Pea	0.8	90.0^{a}	0.0^{a}	55.9^{a}	44.1^{a}	0.207^{a}
	3.0	85.5^{a}	0.0^{a}	42.8^{b}	57.2^{b}	0.177^{a}
	6.0	79.6^{b}	0.0^{a}	28.2^{c}	71.8^{c}	0.152^{a}

Different letters in the same column indicate a significative difference ($P < 0.05$).

The influence of grinding fineness on DM degradability or starch degradability was similar. Between the 2 grinding extremes (0.8 and 6.0 mm), the degradability differences were 13, 5 and 12 points respectively for maize, barley and pea DM and 14, 7 and 10 points for starch of the same feeds.

DISCUSSION

The present experiments have shown large differences in the degradation of starch from different feeds. The *in situ* starch degradability of barley and oats was higher than that of pea, and higher again than that of maize. These variations in starch degradability between feeds could be due to variations in the percentage of particles escaping through the bag pores and not being degraded. The percentage of fine particles (< 50 μm) varied from 10.4–41.3 for maize and barley respectively after grinding with a 0.8-mm screen. The particle losses were greater as the percentage of fine particles increased. If the lost particles are digested at the same rate as those in the bag, feed degradability is then overestimated. But this overestimation of DM degradability was almost equal between feeds: 9.0 points for maize and 7.8 points for barley. Nevertheless, the feed particle size variations must explain part of the starch degradability variations between feeds, the finer particles being degraded more rapidly in the rumen. The smaller the particle size, the higher the percentage of maize degraded *in vitro* (Cone *et al,* 1989), or the *in situ* degradability of maize (Galyean *et al,* 1981) and of sorghum (Figroid *et al,* 1972) DM.

The difference in *in situ* degradation between maize and the other cereals is in accordance with the results of Herrera-Saldana *et al* (1988), although the percentage of degraded starch after 2 h incubation in the rumen was higher in this trial: 28,10 and 95% respectively of the starch from maize, barley and oats disappeared during the first 2 h of incubation in this trial against 9, 36 and 80% in the study of Herrera-Saldana *et al* (1988). The composition of the diet given to the animal could have been the origin of these differences. Indeed, in *in vitro* degradation measurements, the amylolytic activity in rumen fluid from a concentrate-fed cow is higher than that of a hay-fed cow (Cone *et al,* 1989), and the increase is greatest for the starch sources with low degradability (Malestein *et al,* 1988). After 6 h incubation in rumen fluid, fermentability of pea is lower than that of barley when the animals which give the rumen fluid are fed hay (Malestein *et al,* 1988). On the contrary, the fermentability of these 2 feeds, like their *in situ* degradability in this trial, is similar when the animals are fed a diet based on hay and concentrate. So, the ranking of starch degradability from different sources can be modified by the composition of the diet.

In trial 2, the increase in grinding fineness led to an increase in *in sacco* starch degradability. This result agrees with other results on *in situ* dry matter or nitrogen degradability (Nordin and Campling, 1976; Weakley *et al,* 1977; Lindberg, 1981; Freer and Dove, 1984; Nocek, 1985). In this study, the increase of *in situ* starch degradability with grinding was greater for maize than for barley. The feed particle size was reduced with the increase in grinding fineness, and differences in degradation according to particle size were more important for maize than for wheat and oats (Cone *et al,* 1989).

CONCLUSION

The proportion of starch digested in the rumen (measured as *in situ* disappearance) or in the small intestine varies between feeds, which could alter the energy value of feeds. Starch digestion in the rumen is accompanied by energy loss in the form of methane and fermentation heat. Furthermore, efficiency of metabolizable energy utilization for both maintenance and production is higher for glucose than for volatile free acids. Consequently, starch escaping from the rumen should improve energetic efficiency of production by ruminants (Owens *et al*, 1986).

In vivo, increased processing generally increases ruminal digestion of maize starch. Finely ground grains are more extensively digested in the rumen than whole or rolled grains (Owens *et al*, 1986). Two factors act in an opposite manner. When grains are ground, potential digestion of starch grains increases, but the passage rate of grains through the rumen is accelerated and ruminal digestion time is reduced. In *in situ* measurements, only potential starch digestion is studied.

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