South African Journal of Animal Science 2009, 39 (Supplement 1)
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Peer-reviewed paper: 10th World Conference on Animal Production

Fractional rate of degradation (k_d) of starch in the rumen and its relation to *in vivo* rumen and total digestibility

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Abstract

Fractional rate of degradation (kd) of fermentable nutrients in the rumen is an important parameter in modern feed evaluation systems based on mechanistic models. Estimates of kd for starch was obtained on 19 starch sources originating from barley, wheat, oat, maize and peas and treated in different ways both chemically and physically. The starch sources were fed in mixed diets together with grass silage and soya bean meal and allocated *ad libitum* to fistulated dairy cows. The starch content varied between 13 and 35% in ration dry matter for the different starch sources. The design was a series of cross-over experiments with two cows and two periods. Ruminal starch pool was estimated from rumen evacuation and starch flow was estimated by duodenal and faeces sampling. Fractional rate of rumen degradation was estimated from the equation [kd = rumen degraded/rumen pool] and rumen and total digestibility of starch from flow measurements. The relation between kd and rumen digestibility (RD) was estimated to [kd = 1.139 - 3.580*RD + 3.078*RD2; R2 = 0.45; valid for 0.58<RD<0.90] and to total digestibility (TD) to [kd = 7.888 - 19.33*TD + 11.89*TD2; R2 = 0.57; valid for TD>0.81]. It is concluded that the relations between kd and starch digestibility can be used to estimate kd for feed table use from experiments where starch digestibility is known and within the range valid for the equations estimated.

Keywords: Dairy cattle, kinetic parameters, rumen evacuation
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Introduction

Starch is an important nutrient in diets for high producing dairy cows. The rumen is the main site of starch digestion where the starch is fermented to volatile fatty acids or incorporated into microbial matter. Rumen escape starch can be enzymatically digested in the small intestine resulting in glucose absorption. However, digestion in the small intestine may be limited and further fermentation in the hindgut may occur (Larsen *et al.*, 2009).

Feed evaluation systems are changing from empirical models towards mechanistic dynamic models. A mechanistic model of starch digestion has the potential to improve predictions of substrate supply with regard to the effect of the site of starch digestion on the profile of absorbed nutrients. To be successful this approach requires reliable and accurate predictions of nutrient supply from the digestive tract including kinetic parameters of starch digestion. Fractional rate of starch degradation in the rumen (k_d) has been estimated using different methods including *in situ* technique, *in vitro* methods including the gas production method and rumen evacuation technique, as discussed in a recent review by Huhtanen & Sveinbjörnsson (2006). The objective of this study was to relate k_d obtained for different starch sources using the rumen evacuation technique to *in vivo* rumen and total tract digestibility.

Materials and Methods

The experiments complied with Danish Ministry of Justice Law no. 382 (June 10, 1987), Act no. 726 (September 9, 1993), concerning experiments with animals and care of experimental animals. Animals used were lactating Danish Holstein cows fitted with ruminal (#1C; Bar Diamond, Inc., Parma, ID, USA), duodenal and ileal cannulas. Open T-piece cannulas were used for fistulation approximately 60 cm caudal to the pylorus (duodenal) and approximately 20 cm cranial to the caecum (ileal). Chromic oxide (Cr_2O_3) was used as intestinal digesta flow marker by administering 10 grams via the rumen cannula at each of the two daily feedings. Cows were housed in tie stalls with rubber mats and milked twice daily.

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The experiment was conducted as a cross-over design with two cows and two periods. Two crosses were conducted at the same time. Ten crosses were conducted giving 20 treatments.

The starch sources originated from barley, wheat, oat, maize and peas and were treated in different ways both chemically and physically. All rations consisted of the starch source and grass-clover silage balanced with soyabean meal and a mineral premix and were composed to fulfil requirement for rumen degradable protein and fibre and to maximize starch intake. Rations were administered *ad libitum* as total mixed rations. After an adaptation period of 10 days, 12 sets of duodenal and ileal digesta, and faeces samples were taken over five consecutive days from each cow to give a representative sample of the diurnal digesta flow. Feed offered and refused were recorded and sampled daily at each sampling day. One rumen evacuation was performed 5 hours after the morning feeding on the last day in each period, as described by Tothi *et al.* (2003). Two composite samples were composed on weight basis from sub-samples of rumen liquid and mat and used for immediate dry matter determination and for later chemical analysis. Feed, ruminal, duodenal and faecal samples were frozen (-20 °C), freeze dried and pooled within cow and treatment prior to chemical analysis.

Dry matter was determined by forced oven drying at 60 °C for 48 hours. Chromic oxide was determined calorimetrically after oxidation to chromate according to Schürch *et al.* (1950). Ash content was determined by combustion for 6 h at 525 °C (AOAC, 1990). Crude protein was determined as elementary nitrogen using the Dumas method (Hansen, 1989). Starch was determined enzymatically according to Bach Knudsen *et al.* (1987). NDF content was determined according to Mertens (2002) using a Fiber-Tec system.

Ruminal starch pool was estimated from rumen evacuation and starch flow was estimated from duodenal and faeces sampling. Fractional rate of rumen degradation was estimated from the equation [k_d = rumen degraded/rumen pool] and rumen and total digestibility of starch from flow measurements. Calculation of k_d from the above equation assumes steady state conditions and that the rumen pool obtained from evacuation only one time (5 hours after feeding) is representative for the mean pool. Relation between k_d (h^{-1}) and rumen and total digestibility was calculated by the GLM procedure in SAS (SAS, 2003).

Results & Discussion

One rumen evacuation failed for grinded wheat leaving 19 diets in the dataset. Dry matter intake ranged from 11.8 to 21.7 kg for the different treatments as shown in Table 1. Also shown is the variation in key nutrients and although a high starch content in all diets was the aim, this was not possible in all cases as the starch content in the different starch sources used varied between 30% in wrinkled peas and 71% in maize resulting in a variation between 13 and 35% starch in ration dry matter. All diets were sufficient in rumen degradable protein and structural carbohydrates.

Table 1 Intake of dry matter and different nutrients as well as key values for starch pool in the rumen, fractional rate of starch digestion in the rumen (k_d), digestibility of starch in the rumen and total tract digestibility given as mean, minimum and maximum values

	n	Mean	Minimum value	Maximum value
Dry matter (kg/day)	19	17.9	11.8	21.7
Crude ash (kg/day)	19	1.41	0.90	1.93
Crude protein (kg/day)	19	3.38	1.97	4.85
Starch (kg/day)	19	4.53	2.52	7.08
NDF (kg/day)	19	4.45	3.00	6.16
Rumen starch pool (g)	19	722	193	2146
Fractional rate of degradation (/h)	19	0.269	0.078	0.785
Rumen digestibility of starch	19	0.79	0.53	0.90
Total tract digestibility of starch	19	0.93	0.73	0.99

NDF – neutral detergent fibre

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The rumen starch pool varied between 193 g in the diet with ground oat and 2146 g for the diet with whole gelatinised barley. This difference is also reflected in the calculated fractional rate of degradation where starch from whole gelatinised barley showed the lowest value of 0.078/h and ground oat starch the highest value of 0.785/h. The calculated k_d values are within the range found by other authors using the rumen evacuation technique (Oba & Allen 2003; Tothi *et al.*, 2003) and also within the range found by Offner *et al*. (2003) in a review of available data from the *in situ* method covering 22 different feedstuffs.

Rumen digestibility of starch from the different sources varied between 0.53 and 0.90 with the lowest value for whole oat and the highest for rolled barley. Total tract digestibility showed variation between 0.73 and 0.99. Whole oat showed the lowest total tract digestibility and several of the starch sources used reached the highest value close to total digestibility. The low digestibility of starch in whole grains, as shown for whole oat and also for whole gelatinised barley (0.76), highlights that using whole grain to increase intestinal supply of starch is not an applicable method as whole grains cannot be fed to cows without a substantial loss of starch in the faeces.

Figure 1 shows the relation between fractional rate of degradation of starch in the rumen as a function of rumen digestibility and of total tract digestibility of starch.

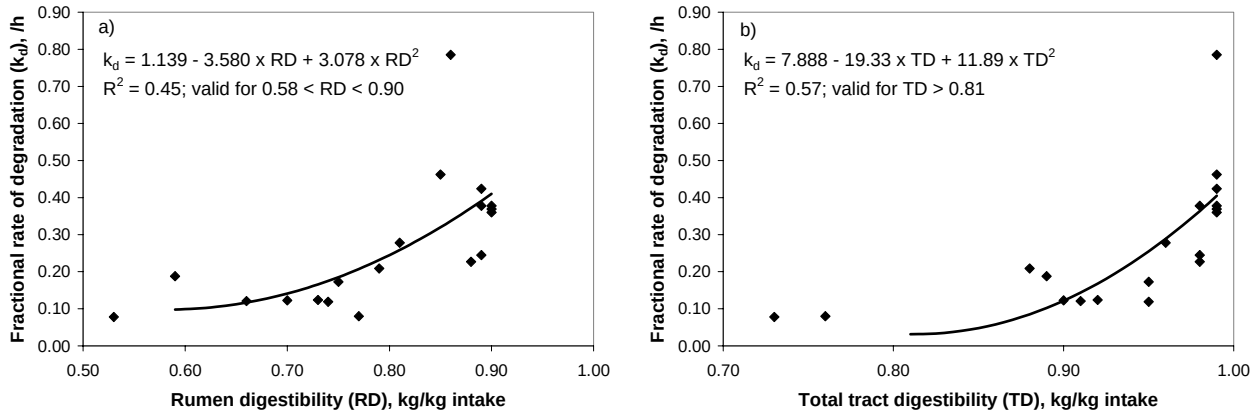

Figure 1 Fractional rate of degradation (k_d) for starch in the rumen as a function of (a) rumen digestibility (RD) or of (b) total tract digestibility (TD).

For rumen digestibility the relation is valid for the range between 0.58 and 0.90 and for total tract digestibility above a digestibility of 0.81. Both equations show a relatively low coefficient of determination but the relations are evaluated as a useful tool in situations where values on digestibility are known without any information on k_d. Therefore, the relations shown in the Figure 1 can be used to predict k_d for rumen starch degradation if rumen or total tract digestibility is known and this will often be the case for total digestibility which is known for most of the starch sources used in dairy cow rations.

The relation between rumen digestibility and the kinetic parameters k_d and fractional rate of passage of starch from the rumen (k_p) given by the equation [digestibility = k_d/(k_d +k_p)] was used to test the range of k_p values which should be applied in the equation to obtain the actual values for rumen digestibility. This range varied between a k_p value of 0.068/h for the low digestibility and a value of 0.046/h at the high digestibility within the range valid for the prediction equation shown in Figure 1a. This calculated range of k_p values is in agreement with values obtained for concentrate feeds by Offner & Sauvant (2004) and also within the mean range found by Tothi *et al.* (2003) who, however, showed diurnal variation in passage rate.

Conclusion

It is concluded that the relations between k_d for rumen starch degradation and starch digestibility can be used to estimate k_d for feed table use from experiments where starch digestibility is known and within the range valid for the equations estimated.

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Acknowledgements

The authors would like to thank the Danish Cattle Federation and the Commission of the European Communities, FP7, KBBE-2007-1 for financial support and DLG (Copenhagen, Denmark) and HaGe (Kiel, Germany) for provision of many of the starch sources used.

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