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Ruminal behaviour of structural carbohydrates, non-structural carbohydrates and crude protein from concentrate ingredients in dairy cows

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Abstract

Ruminal degradation characteristics of Neutral Detergent Fibre (NDF), starch and crude protein (CP) in concentrate ingredients were determined in dairy cows by means of nylon bag incubations. Measured characteristics were soluble fraction (starch, CP), undegradable fraction (NDF, CP), lag time (NDF) and rate of degradation of the insoluble but degradable fraction (NDF, starch, CP). All measured characteristics showed large variation. Based on measured and partly estimated characteristics ratio's were calculated between total rumen available CP and carbohydrates, between soluble CP and soluble carbohydrates and between insoluble rumen available CP and insoluble rumen available carbohydrates. Ratio's varied largely between feedstuffs and between soluble and insoluble fractions. It was concluded that such ratio's can be used to optimize the composition of concentrates with regard to rumen fermentation.

Keywords: rumen fermentation, protein, carbohydrates, starch, cell walls

Introduction

For dairy cows, carbohydrates are important precursors of energy yielding nutrients, either as structural polysaccharides like pectins, cellulose or hemicellulose, or as storage polysaccharides like starches and fructosans or as oligo-, di- and monosaccharides. At the same time they are the main energy yielding substrates for the microbial population in the rumen. Finally they may play an important role in stabilizing or destabilizing rumen fermentation.

Until a few years ago, relatively little attention was paid to the role of carbohydrates in dairy feeding other than that structural carbohydrates in roughages acted

as a source of fibre with important stabilizing properties for rumen fermentation and that carbohydrates in roughages and concentrates were an important energy yielding part of the diet. De Visser et al. (1980) were among the first to report differences in ruminal behaviour between non-structural carbohydrates like starch and sugars and structural carbohydrates like (crude) fibre in dairy concentrates. In a recent review Nocek & Russell (1988) also emphasized the importance of differences between carbohydrate sources as a substrate for microbial synthesis. Structural carbohydrates in roughages are usually in a long form and give as such tectile stimuli to induce rumination, salivation and rumen motility and thus influence the conditions in the rumen (buffering capacity, pH, VFA-concentration). In the Netherlands the extent of the stimulus that is expected from a feed is compared with the assumed stimulus of long hay. These (relative) 'structural' values vary from 0 (ground forages and concentrates) to 1.2 (long straw). Based on these structural values it is now recommended that dairy diets have a structural value of at least 0.35.

However, the conditions in the rumen are not only influenced by the structural value of the diet, but also depend on other factors, like the rate and extent of VFA production e.g. the rate and extent of carbohydrate degradation. Thus, structural carbohydrates in ground concentrates probably also play an important positive role in the stabilization of rumen fermentation, whereas large amounts of non-structural carbohydrates sometimes have a negative influence. The exact physico-chemical structure of the structural carbohydrates has not yet completely been established, but it is beyond doubt that their encrustration with lignin and/or cutin is of great importance for their digestive behaviour in the rumen.

Not only structural carbohydrates differ in behaviour in the rumen, large differences were also observed between non-structural carbohydrates, particularly with regard to the rate of ruminal degradation (Malestein et al., 1988; Tamminga et al., 1989b). When large amounts of starch and sugars were included in concentrates fed to dairy cows, ruminal pH could be dramatically reduced with a concomitant equally dramatic rise in the levels of propionic and sometimes lactic acid in rumen fluid (de Visser et al., 1980). This led to the recommendation not to include more than 25% starch and sugars in concentrates fed to dairy cows. Soluble sugars were demonstrated to be an important contributor to the drop in pH but did not give the full explanation (Malestein & van 't Klooster, 1986); differences in ruminal behaviour between starches of different origin were also contributing (Malestein & van 't Klooster, 1986; Tamminga et al., 1989b). Further research showed that the negative influence of non-structural carbohydrates on rumen fermentation is largely caused by easily degradable carbohydrates such as soluble sugars, and rapidly degraded starches (Tamminga, unpublished results).

Although the exact mechanism has yet to be elucidated, it is beyond doubt that feeding starches, particularly less rapidly degradable starches, has an influence on milk composition. It reduces milk fat but enhances milk protein percentage (de Visser et al., 1990).

Proteins in ruminant feeds play two important roles. Firstly they provide the rumen microbes with N, required for their growth and microbial protein synthesis in the rumen, an important source of amino acids for the ruminant animal. In addi-

tion, feed proteins may be a significant source of animo acids themselves, because a varying part of feed proteins escape degradation in the rumen and become available for digestion in the small intestine.

Increasing levels of milk production require increasing amounts of concentrates in the diet. Different ingredients in such concentrate mixtures may have different properties leading to different profiles of absorbed nutrients and hence there is a growing interest in concentrate composition. For that reason, research was started to elucidate the characteristics of concentrate ingredients in terms of ruminal behaviour. The aim of this research was to get data which can be used to manipulate concentrate composition in such a way that combined with forages of different qualities optimum dairy diets can be composed under different physiological conditions.

Materials and methods

Incubation procedures

Three experiments were carried out with 4, 3 and 4 lactating dairy cows, respectively, in which rumen degradation characteristics of cell wall components (NDF), starches and crude protein were determined by means of nylon bag incubations. In all experiments, dairy cows previously equipped with a large rumen cannula with an internal diameter of 10 cm (Bar Diamond Inc., Parma, Idaho, USA) were kept in a tie stall and fed twice daily with two equal portions of a diet consisting of 6 to 7 kg of long meadow hay and 12 to 14 kg of ground and pelleted commercial concentrates.

Rumen incubations to determine degradation characteristics of cell walls (Neutral Detergent Fibre) were with 0.5 g material in small bags (45 × 46 mm), according to the method described by Robinson et al. (1986) with incubation times of 0, 3, 6, 12, 24, 48 and 336 hours. Incubation of concentrate ingredients to determine the degradative behaviour of starch and crude protein in the rumen was with 5 g material in large nylon bags (10 × 17 cm) as described earlier (Tamminga et al., 1990) with incubation times of 0, 1, 2, 4, 6, 8, and 12 hours for starch and 0, 2.5, 5.0, 7.5, 16.5, 24, 48 and 336 hours for crude protein. After incubation the bags containing the residues were washed in a domestic washing machine for 1 hour without spinning and subsequently dried overnight at 70 °C.

Analytical procedures

Neutral Detergent Fibre (NDF) content in feeds was determined according to the method of Goering & van Soest (1970), in residues after incubation according to the procedure described by Robinson et al. (1986) with some minor modifications. After extraction with Neutral Detergent and drying, the residue was ashed in a furnace at 550 °C to estimate NDF rather than NDR. Starch in the feeds and nylon bag residues after rumen incubation was measured enzymatically (Boehringer, Mannheim) with α-amyloglucosidase on an auto-analyser (Breda Scientific, Breda, Netherlands) after the removal of soluble sugars by extraction with 40 % ethanol

followed by autoclaving at 128 °C for 120 minutes. Nitrogen (N) in feeds and nylon bag residues was determined by the Dumas method (Merz, 1979).

Treatment of results

From the nylon bag incubation studies it became apparent that part of the starch and the crude protein could be washed out of the bags without incubation in the rumen. This proportion (S) was considered to be degraded instantaneously and completely. Part of the cell walls and crude protein did not disappear from the bags, not even after prolonged rumen incubations of 336 hours. This proportion (U) was considered to be undegradable. The remaining proportion was termed B and can be calculated as 100-S-U. Results of nylon bag incubations were therefore fitted though iterative procedures by the following mathematical equations:

Crude protein: $Y(t) = U + (100 - S - U) \times e^{-k_d t}$

Cell walls (NDF): $Y(t) = U + (100 - U) \times e^{-k_d (t - L)}$

Starch: $Y(t) = (100 - S) \times e^{-k_d t}$

where:
$Y(t)$ = residue at time = t
S = fraction which can be washed out of nylon bags without rumen incubation
U = residue after 336 hours of incubation
k_d = degradation rate constant (h^{-1})
L = lag phase in hours, with a maximum of 10 hours

Further calculations

Rumen degradation characteristics as collected in this study can provide information which can be used to compose concentrates or diets, which will give an optimum rumen fermentation. As a first approach rumen available carbohydrates and rumen available crude protein were matched. Rumen availability (FNDF, FSST) was estimated from the total amount of NDF, starch or protein present in a feedstuff, corrected for the undegradable fraction (U) and for passage during the lag phase (L). Rumen availability was then estimated as the corrected amount present when degradation starts, multiplied by the ratio between rate of degradation (k_d) and rate of passage (k_p), assuming passage rates of 2.5% per hour for cell walls (Tamminga et al., 1989a) and 6% per hour for protein and starch (Verité et al., 1987).

Results

Results on ruminal degradation of cell walls in concentrate ingredients are shown in Table 1. Based on the best fit of the data to the model, two groups of ingredients

Table 1. Rumen degradation characteristics of cell walls (NDF) in concentrate ingredients.

Feedstuff	NDF/DM (g kg^{-1})	U (%)	L (h)	k_d (% h^{-1})	S+D (g kg^{-1} DM)	FNDF (g kg^{-1} DM)
Babassumeal	655.0	40.6	5.4	7.7	389.1	256.6
Barley	220.0	(27.0)	(0.2)	(14.5)	160.6	136.3
Beans	178.0	(20.0)	(4.0)	(15.0)	142.4	110.4
Beetpulp	462.0	8.8	2.6	6.4	421.6	284.1
Brewers grains	631.0	26.0	0.8	7.2	466.9	339.1
Coconutmeal	563.0	18.1	3.0	7.2	461.1	317.5
Corn	122.0	(10.0)	(3.8)	(5.1)	109.8	67.0
Cornglutenfeed	349.0	14.2	0.0	6.5	299.4	216.3
Cottonseedmeal	270.0	33.9	8.7	6.5	178.5	103.7
Groundnutmeal	125.0	30.4	0.0	11.7	87.0	71.7
Hominyfeed	282.5	6.4	0.0	16.3	264.4	229.3
Linseedmeal	305.0	32.6	0.0	12.8	205.6	172.0
Lupins	334.0	3.2	2.5	8.5	323.3	234.7
Macoyameal	460.0	49.8	9.0	5.0	230.9	122.9
Milo	131.0	(20.0)	(0.0)	(4.5)	104.8	67.4
Millet	164.0	(25.0)	(0.0)	(4.5)	123.0	79.1
Nigerseedmeal	374.0	54.1	0.0	38.6	171.7	161.2
Oats	301.0	(27.0)	(0.0)	(4.5)	219.7	141.3
Palmkernels	342.0	52.5	10.0	4.5	162.5	81.1
Palmkerneloilmeal	692.0	33.0	6.9	6.5	463.6	281.8
Peas	175.0	(20.0)	(4.0)	(15.0)	140.0	108.6
Potato	89.0	(10.0)	(0,0)	(10.0)	80.1	64.1
Rapeseedmeal	286.0	30.4	0.0	16.6	199.1	173.0
Rice	40.0	(40.0)	(1.8)	(4.5)	24.0	14.7
Ricebran	197.0	73.2	0.0	4.8	52.8	34.7
Sunflowerseedmeal	394.0	53.1	0.0	8.2	184.8	141.6
Tapioca	80.0	(27.0)	(0,0)	(5.0)	58.4	38.9
Wheat	135.5	(30.0)	(0.0)	(15.0)	94.9	81.3
Wheat flour	22.0	(30.0)	(0.0)	(12.5)	15.4	12.8
Wheat shorts	114.0	(30.0)	(0.0)	(10.0)	79.8	63.8
Wheat middlings	399.0	39.7	0.0	9.4	240.6	190.1
Wheat bran	543.0	(30.0)	(0.0)	(7.7)	380.1	286.9

U = undegradable fraction.
L = lag period.
k_d = rate of degradation.
S + D = potential degradable NDF.
FNDF = rumen available NDF.
( ) = estimated value from literature.

became apparent. One group in which degradation was best described by a model which has included a distinct lag phase, and one group for which the model does not include a distinct lag phase. The undegradable fraction (U) varied from less than 10 % (hominy feed, beet pulp, lupins) to over 50 % (macoyameal, nigerseedmeal, sunflowerseedmeal). Rate of degradation (k_d) varied from less than 5 % per hour (macoyameal, palmkernels, ricebran) to almost 15 % (hominyfeed, rapeseedmeal). These results correspond with those reported by Varga & Hoover (1986). Nigerseedmeal behaved exceptionally with over 50 % not available for ruminal degradation

Table 2. Rumen degradation characteristics of starch plus sugars (SST) in concentrate ingredients.

Feedstuff	SST (g kg^{-1})	S (%)	k_d (% h^{-1})	S + D (g kg^{-1} DM)	FSST (g kg^{-1} DM)
Babassumeal	42.0	84.5	(12.5)	6.5	4.4
Barley	604.0	64.5	24.2	214.4	171.8
Beans	416.5	40.5	10.6	247.8	158.2
Beetpulp	147.0	89.8	(12.5)	15.0	10.1
Brewers grains	63.0	39.7	(12.5)	38.0	25.7
Coconutmeal	113.2	90.1	(12.5)	11.2	7.6
Corn	735.5	27.6	4.0	532.5	211.4
Cornglutenfeed	324.3	62.0	10.2	123.2	77.6
Cottonseedmeal	60.0	78.3	(12.5)	13.0	8.8
Groundnutmeal	157.0	65.0	(12.5)	55.0	37.1
Hominyfeed	495.0	33.9	5.3	327.2	152.7
Linseedmeal	69.0	60.1	(12.5)	27.5	18.6
Lupins	67.0	91.0	(12.5)	6.0	4.1
Macoyameal	162.0	89.9	25.4	16.4	13.2
Milo	740.0	32.6	3.6	498.8	187.0
Millet	664.0	41.6	8.3	387.8	225.1
Niegerseedmeal	56.0	85.7	(12.5)	8.0	5.4
Oats	473.0	96.1	18.8	18.4	14.0
Palmkernels	20.5	80.5	(12.5)	4.0	2.7
Palmkerneloilmeal	35.0	57.1	(12.5)	15.0	10.1
Peas	505.0	42.9	10.5	288.4	183.5
Potato	781.0	33.9	4.9	516.2	232.1
Rapeseedmeal	125.0	89.2	(12.5)	13.5	9.1
Rice	865.0	26.0	7.6	640.1	357.7
Ricebran	331.5	27.8	11.8	239.3	158.6
Sunflowerseedmeal	71.0	81.7	(12.5)	13.0	8.8
Tapioca	786.0	75.7	11.8	191.0	126.6
Wheat	687.5	69.1	18.2	212.4	159.7
Wheat flour	830.0	87.2	19.8	106.2	81.5
Wheat Shorts	575.0	86.6	15.7	77.1	55.7
Wheat middlings	287.4	88.5	24.2	33.1	26.5
Wheat bran	191.0	87.0	20.8	24.8	19.3

SST = starch plus sugars.
S = soluble fraction.
k_d = rate of degradation.
S + D = potential degradable insoluble starch.
FSST = rumen available insoluble starch.
( ) = estimated value.

and a rate of degradation of the rumen available part of 38.6 % per hour. Length of the lag phase was usually between 0 and 4 hours. Exceptions were cottonseedmeal, macoyameal, palmkernels and palmkerneloilmeal, showing lag periods of up to 10 hours. Regression analysis revealed no significant relationships between cell wall content and fraction U, rate of degradation or length of the lag phase. This finding also agrees with the results of Varga & Hoover (1986).

Ruminal degradation characteristics of starches of different origin are shown in Table 2. The washed out fraction (S) varied from less than 30 % (corn, rice,

Table 3. Rumen degradation characteristics of crude protein (N × 6.25) in concentrate ingredients.

Feedstuff	CP/DM (g kg^{-1})	S (%)	U (%)	k_d (% h^{-1})	S + D (g kg^{-1} DM)	FN (g kg^{-1} DM)
Babassumeal	201.5	0.6	12.0	2.2	176.1	47.9
Barley	112.5	(25.0)	(5.0)	(12.5)	78.8	53.2
Beans	263.0	62.8	0.4	10.8	96.8	62.2
Beetpulp	103.0	12.2	6.3	5.2	83.9	38.8
Brewers grains	249.0	4.6	30.1	5.1	162.6	74.6
Coconutmeal	215.2	16.6	3.4	2.9	172.2	56.4
Corn	103.1	(15.0)	(5.0)	(3.5)	82.5	30.4
Cornglutenfeed	201.8	44.9	5.5	5.2	100.1	46.2
Cottonseedmeal	486.0	13.4	1.8	7.6	412.1	230.0
Groundnutmeal	545.0	24.5	0.0	14.8	411.5	292.6
Hominyfeed	141.5	27.9	1.7	7.8	99.6	56.4
Linseedmeal	333.5	17.2	4.1	5.0	262.5	119.8
Lupins	341.5	25.5	0.3	12.9	253.6	172.9
Macoyameal	108.0	27.8	10.9	2.3	66.2	18.3
Milo	125.0	(10.0)	(10.0)	(3.5)	100.0	36.8
Millet	137.5	(15.0)	(10.0)	(5.0)	103.1	46.9
Nigerseedmeal	361.0	9.4	5.4	10.6	307.6	196.1
Oats	125.0	(30.0)	(5.0)	(10.0)	81.3	50.8
Palmkernels	103.5	8.0	6.6	2.4	88.4	25.1
Palmkerneloilmeal	151.0	8.8	6.8	3.5	127.4	46.6
Peas	254.1	55.6	0.0	9.0	112.8	67.5
Potato	93.8	(15.0)	(5.0)	(7.5)	75.0	41.7
Rapeseedmeal	369.0	21.2	5.9	13.8	269.0	187.6
Rice	94.0	(15.0)	(10.0)	(5.0)	70.5	32.0
Ricebran	143.0	23.2	10.3	8.3	95.1	55.3
Sunflowerseedmeal	371.5	14.7	3.4	14.7	304.4	216.1
Tapioca	31.2	(25.0)	(5.0)	(5.0)	21.8	9.9
Wheat	137.5	(25.0)	(6.0)	(20.0)	94.9	73.0
Wheat flour	118.8	(25.0)	(6.0)	(17.5)	82.0	61.0
Wheat shorts	200.0	(25.0)	(6.0)	(17.5)	138.0	102.8
Wheat middlings	191.1	11.1	6.4	13.4	157.7	109.0
Wheat bran	168.8	(25.0)	(6.0)	(15.0)	116.5	83.2

U = undegradable fraction.
S = soluble fraction.
k_d = rate of degradation.
S + D = potential degradable insoluble crude protein.
FN = available insoluble crude protein.
( ) = estimated value from literature.

ricebran) to over 90 % (oats, lupins). Rate of degradation (k_d) of insoluble starch varied from less than 5 % (corn, milo, potato) to almost 25 % per hour (barley, macoyameal, wheat middlings). No relationship was found between solubility and rate of degradation.

In Table 3 ruminal degradation characteristics are shown for crude protein in a variety of feedstuffs. Washed out fraction ranged between less than 5 % (babassumeal, brewer's grains) and over 50 % (beans, peas), the undegradable proportion between 0 % (groundnutmeal, peas) and 30 % (brewer's grains) and rate of degra-

Table 4. Ratio between total (FN), soluble (SN) and insoluble nitrogen (EN) and total (FCB), soluble (SCB) and insoluble (ECB) rumen available carbohydrates.

Feedstuff	n	FN/FCB (g kg^{-1})	SN/SCB (g kg^{-1})	EN/ECB (g kg^{-1})
Babassumeal	2	26.5	5.5	29.3
Barley	1	18.7	11.6	27.6
Beans	4	83.2	156.7	37.1
Beetpulp	2	19.3	15.2	21.1
Brewers grains	1	35.3	73.3	32.7
Coconutmeal	5	34.5	56.0	27.7
Corn	2	15.2	12.2	17.5
Cornglutenfeed	3	44.2	72.1	25.2
Cottonseedmeal	1	296.1	221.8	327.2
Groundnutmeal	1	323.3	209.3	430.3
Hominyfeed	2	27.9	37.6	23.6
Linseedmeal	2	122.2	221.3	100.6
Lupins	2	138.7	228.1	115.9
Macoyameal	1	27.5	33.0	21.6
Milo	1	15.9	8.3	23.2
Millet	1	18.6	11.9	24.7
Nigerseedmeal	1	171.5	113.1	188.3
Oats	1	23.2	13.2	52.3
Palmkernels	2	53.2	79.8	48.0
Palmkerneloilmeal	2	30.7	106.4	25.5
Peas	2	65.7	104.3	37.0
Potato	1	15.9	8.5	22.5
Rapeseedmeal	2	144.9	112.3	164.9
Rice	1	12.4	10.0	13.8
Ricebran	3	49.6	57.6	45.8
Sunflowerseedmeal	1	207.7	150.1	229.9
Tapioca	1	3.7	2.1	9.6
Wheat	2	24.0	11.6	48.5
Wheat bran	1	17.7	6.6	103.5
Wheat flour	1	39.6	16.1	137.5
Wheat middlings	2	44.2	13.3	80.5
Wheat shorts	1	42.5	40.6	43.5

FN/FCB = ratio between total nitrogen and total carbohydrates.
SN/SCB = ratio between soluble nitrogen and soluble carbohydrates.
EN/ECB = ratio between insoluble nitrogen and insoluble carbohydrates.
n = number of batches.

dation between 2 % (babassumeal, palmkernels) and almost 15 % per hour (groundnutmeal, sunflowerseedmeal). No relationship was found between S and k_d or between U and k_d.

From the rumen degradation characteristics as collected in these studies it was possible to estimate the proportion of protein or starch escaping degradation in the rumen. Rumen escape of starch appears to be very variable between grains (Tamminga et al., 1989b). High escape values were observed for corn and milo, low values for wheat and oats. Escape values for starch in by-product ingredients largely reflected those of the original seeds or tubers. Variation in rumen escape was equally

dependant on S and k_d. These factors explained 67 and 68 % of the total variation, respectively. Rumen escape values for crude protein were very variable (Tamminga & Ketelaar, 1988). High values were observed for ingredients high in cell wall components, which could partly be explained by the high proportion which was resistant against degradation.

Results on the estimated ratio between rumen available crude protein and rumen available carbohydrates, expressed as gN kg^{-1} carbohydrates are presented in Table 4. Data for feed ingredients which were not investigated for one of the components were estimated from literature values. Rate of cell wall degradation and length of the lag time were calculated from Varga & Crooker (1986) and McBurney et al. (1986), protein solubility values from Crooker et al. (1979) and Waldo & Goering (1979), protein undegradability from ADIN (Khrishnamoorthy et al., 1982) and rate of protein degradation from de Boever et al. (1984). These estimates may not always be sufficiently accurate, but because the proportion of cell walls, insoluble starch or insoluble protein in the ingredients not investigated was usually of minor importance, this seems a reasonable approach. Balancing concentrates for an optimum rumen fermentation was refined further by comparing soluble protein and carbohydrates as well as insoluble but degradable protein and carbohydrates. The results are also shown in Table 4.

Discussion

Validation of degradation models

Information as presented in this paper could be useful for ration formulation. The figures presented in Tables 1 to 3 can be regarded as a first attempt to set up a data base. To become succesful in this respect, a certain degree of standardisation will be required. This is as yet far from achieved. Various models to describe rumen degradation of feed components are possible. In the choice of variables used to describe the model, biological or mathematical considerations may prevail. The most widely used model is a first order kinetics equation. Methods used to solve such an equation include non-linear iterative least square regresssion, least square regression of logarithmic-transformed residuals with or without correction for an estimated or measured ruminally undegraded residue, and curve peeling. Alternatives are models with a more mathematical background, such as Gompertz curves (Sauvant et al., 1985). Although they may be more accurate in fitting the data (Sauvant et al., 1985), their biological interpretation is often difficult, reason why biologically orientated models are more popular.

In models used to describe the ruminal degradation of cell walls in a biological sense, the number of pools usually varies between 1 and 3 (Nocek & English, 1986; Robinson et al., 1986). Rate of degradation may be assumed constant per pool (Nocek & English, 1986; Robinson et al., 1986) or variable (Sauvant et al., 1985) and the model may or may not contain a discrete lag phase. Finally the mathematical procedure to describe the model may vary (Nocek & English, 1986).

In a comparison of a number of biological models Robinson et al. (1986) showed

that the degradation of cell walls can often be described quite adequately by a first order kinetics equation with two fractions, one degradable and one undegradable. They also showed that for some ingredients (e.g. babassumeal and brewers' grains) rumen degradation of structural carbohydrates could be described more accurately by assuming 3 discrete fractions, one rapidly degradable, one slowly degradable and one undegradable. The number of measuring points in the research reported in this paper was however too small to make such a distinction.

Rumen degradation of starches was described quite satisfactorily by assuming two fractions, one soluble fraction which can be washed out without rumen incubation and one insoluble fraction which is degraded exponentially.

Rumen availability is not only determined by (rate of) degradation. Rate of passage may be equally important. Little information is available on the variation in rate of passage of concentrate feeds.

In our approach a constant value for each feed component was used, but differences seem apparent particularly due to differences in level of feed intake (Eliman & Orskov, 1984; Robinson et al., 1987). Other factors such as the specific gravity of the feed particles may also be important (Fox et al., 1988). In their carbohydrate/protein system these authors attribute a rumen passage value to concentrate ingredients depending on the relative feed weights. However more research in this area is needed.

Characterization of dietary carbohydrates

Polysaccharides can be divided in structural and non-structural carbohydrates. One important difference between both groups is that in non-structural carbohydrates glucose is the predominant monomer, whereas in structural carbohydrates other than cellulose, other monomers like xylose, arabinose, mannose, fructose and glucuronic acids are also important. A second important difference is that in non-structural carbohydrates monomers are predominantly linked together with alpha-1, 4 glycosidic linkages, whereas in structural carbohydrates the beta-1,6 linkage is predominant. Due to their differences in characteristics, structural and non-structural carbohydrates play a different role in ruminant nutrition.

At present, carbohydrates in concentrates for dairy cows are valued only on the basis of their capacity to yield net energy for the host animal. Other important aspects are their value as an energy yielding substrate for anaerobic rumen microbes and the effect they may have on rumen fermentation. Characteristics, which largely determine the value of a feedstuff as an energy yielding substrate for rumen microbes, are its rumen availability and its rate of degradation. The latter also influences the type of end products which will result from fermentation (Murphy et al., 1982).

Large differences were observed with regard to rumen availability between cell-wall-rich feedstuffs. This means that the amount of energy which can be extracted by rumen microbes also differs between feedstuffs. Examples of poor energy yielding substrates are babassu-, macoya- and nigerseedmeal, palm kernels, sunflowerseedmeal and wheat middlings. Such feed ingredients not only yield comparatively

little energy to the rumen microbes, they also contribute to the rumen fill and cause a high substitution rate when fed together with forages (Varga & Hoover, 1985; Jarrige et al., 1986). For the majority of cell-wall-rich concentrate ingredients, the ruminal rate of degradation was between 5 and 15 % per hour and therefore they have a ruminal fermentation pattern which does not vary to a great extent.

Non-structural carbohydrates play a different role in ruminant nutrition. Their potential rumen availability is believed to be complete. Actual degradation then depends on solubility and the ratio between rate of degradation and rate of passage. Contrary to structural carbohydrates, solubility of non-structural carbohydrates is often high, resulting in a high proportion being degraded very rapidly. In addition rate of degradation shows a wider variation than that of structural carbohydrates and ranges between 5 and 25 % per hour. Rate of degradation of non-structural carbohydrates is important in various ways. First of all it determines the rate at which energy becomes available for microbial growth, often a limiting factor for microbial activity in the rumen, which in turn is believed to be important with regard to rumen capacity. Rate of degradation of non-structural carbohydrates also influences the fermentation pattern (Murphy et al., 1982), which in turn determines the amount of energy which is extracted (Tamminga, 1979) by the microbes. Because of their much wider range in degradation rates as compared to those of structural carbohydrates, rate of degradation of non-structural carbohydrates can be used as a means to match the availability of different nutrients for rumen microbes (Nocek & Russel, 1988). This could be important in the utilisation of non-protein nitrogen and rumen degradable protein as source of N for microbial synthesis.

On the other hand different carbohydrate sources may interfere with each other. Large amounts of easily degradable non-structural carbohydrates may inhibit the degradation of structural carbohydrates, either directly as a competitive substrate or indirectly through causing a reduced pH (Hoover, 1986).

Finally the proportion of carbohydrates escaping degradation in the rumen is to a large extent dependant on rate of degradation. Escape of structural carbohydrates is undesirable, because the rumen is by far the most important compartment where structural carbohydrates can be degraded. For the host animal structural carbohydrates, which are not degraded in the rumen, are largely bulk, which has to be cleared from the intestinal tract at the expense of sloughing of intestinal cells, giving rise to the loss of considerable amounts of endogenous protein (NRC, 1989).

Escape from rumen degradation of non-structural carbohydrates may be benificial, because they can be digested in the small intestine. This usually results in a reduced milk fat content and a somewhat enhanced milk protein content. The reasons why that happens are not entirely understood yet.

Optimizing ration composition

Feed evaluation in domesticated animals is at present on the basis of energy and protein. Yet for maintenance as well as (re)production domestic animals need nutrients such as glucose, amino acids and fatty acids. New approaches on feed evaluation recognize this (McRae et al., 1988) and attempts were already made to take such ap-

proaches into account (Webster et al., 1988; Fox et al., 1988). In ruminant nutrition the amount and nature of nutrients is very much influenced by rumen fermentation (Tamminga & van Vuuren, 1988). Ensuring optimum rumen fermentation cannot be achieved on the basis of feed evaluation systems presently in use. For that purpose data as presented in the Tables 1 to 3 in this report seem more appropriate. To achieve optimum microbial growth yields the ratio of rumen available nitrogen (FN) to rumen available carbohydrate (FCB) should be around 25 g nitrogen per kg available carbohydrates (Czerkawski, 1986), based on the assumption that the organic matter truly fermented in the rumen almost entirely consists of carbohydrates. Variation in total nitrogen to total carbohydrates available (FN/FCB in Table 4) varies between 4 (tapioca) and 293 (cottonseedmeal). Hence based on these results, it is possible to optimize rumen fermentation. However the moment at which N and carbohydrates become available may not coincide. A further refinement is then possible by matching not only FN/FCB, but to do this for the soluble (SN/SCB) and insoluble (EN/ECB) fractions separately. As can be seen from Table 4 variation in the N to carbohydrate ratio in soluble and insoluble fractions is between 5 (babassumeal) and 228 (lupins) and between 10 (tapioca) and 430 (groundnutmeal), respectively.

The next step in optimizing rumen fermentation should be the inclusion of the roughage part of the diet. Therefore simular rumen degradation characteristics should be determined for forages, which in the future will make it possible to optimize rumen fermentation of the whole diet. In optimizing rumen fermentation too large amounts of soluble or rapidly degradable carbohydrates should be avoided, because they may give rise to an excessive VFA production resulting in a low pH, which will slow down the degradation of structural carbohydrates. Also too large amounts of soluble or rapidly degradable protein should be avoided, because they may result in excessive NH_3 production followed by urea excretion.

Conclusions

Date presented and the approach outlined in this paper are a first attempt for the construction of a data base of rumen characteristics of feeds for ruminants. Before sufficient information is available to build reliable and robust prediction models, much more information has to be collected in the near future. Especially information is needed on the variation between different batches of the same concentrate ingredient. Also information on rumen characteristics of forages differing in species, origin, age, level of fertilisation, season, way of harvesting, and so on, is required.

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