NIRS: a tool to predict ruminal degradability in feedstuffs

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Introduction

The knowledge of how the nutritive value of feeds changes as a result of rumen fermentation is needed to achieve preplanned modifications of intestinal digesta composition through dietary manipulation. In this way, degradability of dry matter or organic matter and crude protein in the forestomachs of ruminants are the key criteria of the new protein evaluation systems. [1] However, the availability of *in vivo* and *in sacco* degradability values are limited because those methods require working with animals and are complicated, intensive and expensive labour.

Near infrared (NIR) spectroscopy has been widely demonstrated as a successful tool in compositional analysis of food and feed and it could be shown as a powerful technology to predict animal response to be used on animal nutrition. [2] The aim of this work has been the development of NIR calibrations to predict degradability parameters for dry matter (DM) and crude protein (CP) on raw feedstuffs to avoid grinding samples. This process requires a large input of work and time and it is possible to change some degradability parameters due of the heat from the grinding process.

Material and methods

In situ degradation

A set of 46 feedstuffs was evaluated using the *in situ* method. The technique of nylon bags was used to determine the rumen degradation kinetics. The soluble (a) and insoluble potentially degradable (b) fractions and the fractional degradation rate of the slowly degradable fraction (c) and the effective degradability (ED) were estimated according to the equation obtained by Ørskov and McDonald.[3]

In situ degradation characteristics were carried out with three non-lactating Holstein-Friesian cows, provided with a rumen cannula (Bar Diamond, Idaho, USA). The animals were adapted to a ration at maintenance level with alfalfa hay and concentrate (60:40 dry matter basis). The feedstuffs were milled through 2-mm screen and 1 gram weighting in dacron bags with 50 ± 10 micron pore size (Ankom Technology Corporation) at 12.5 mg cm^{-2}. The incubation times were 0, 2, 4, 8, 12, 16, 24, 48 y 72 h.

Parameters a, b and c were estimated individually for each animal by a nonlineal regression. The adjustment of the kinetic values of rumen degradation to that equation was made by the procedure NLIN from the SAS statistical package.[4] The effective degradability of the DM and CP were calculated for a rumen outflow rate (k) of 6 % h^{-1} by the equation (1)

$$ED = a + \frac{b \times c}{c + k} \qquad (1)$$

Reference analyses

Bag residues were dried in a ventilated oven at 60ºC; then, residual moisture was determined by oven drying at 103ºC for 3h and nitrogen content by Dumas.

NIR scanning and calibration procedures

Two identical populations with the total of 46 samples each one were built, one whole (population A) and another one ground (population B). All samples were scanned using a Foss-NIRSystem 6500 monochromator with transport sampler, over a wavelength range from 400 to 2500 nm in steps of 2 nm.

The samples of population A were analysed in their original form using the natural product cell with a rectangular quartz window of 4.5 cm x 20 cm. and measured in four replicates (RMS<2000). The average of replicate spectra obtained as log 1/R (R= Reflectance) were recorded to use in the calibration. The samples of population B were grounded at 1 mm and scanned using a ¼ rectangular cup, measured in two replicates, before average spectra. Population boundaries were stablished with a maximum standardised H distance from the average spectrum of 3.0. [5]

Calibration equations were performed using WINISI II ver. 1.5 sofware (Infrasoft International, Port Matilda, PA, USA). A modified partial least squared (MPLS) method was used as regression model to predict: the fractions soluble (a), insoluble potentially degradable (b), the fractional degradation rate of the slowly degradable fraction (c) and the effective degradability (DE) of dry matter and crude protein. Standard Normal Variate (SNV) and Detrending (DT),[6-8]was the spectral pre-treatment employed to avoid scatter correction and second derivative as mathematical treatment.

Results and discussion

In Table 1, the chemical composition and energy content of the 46 feedstuffs are summarised. The nutritive values showed an usual range for compound feeds.

Table 1. Proximate composition and energy content of feedstuffs (n=46)

Parameter (%)	Mean	Range
Dry Matter	90.09	87.69 - 92.20
Ash	6.76	5.22 - 9.29
Crude protein	17.96	13.65 - 23.55
Crude Fibre	7.25	2.92 - 14.32
NDF	18.38	8.52 - 24.77
ADF	10.05	4.54 - 17.70
Fat	6.61	3.07 - 10.78
ME (MJ/kg DM)	12.30	10.93 - 14.13

NDF: neutral detergent fibre; ADF: acid detergent fibre;

ME: Metabolizable energy

Calibrations for predicting rumen degradation characteristics of dry matter are displayed in Table 2 for grounded samples and Table 3 for whole samples.

Table 2. Statistical results of calibrations for dry matter degradability parameters on grounded samples.

Parameter	Range	SD	SEC	RSQ	SECV	1 – VR	RDP	RER
a (%)	38.87 – 55.90	5.311	2.215	0.826	2.254	0.776	2.08	6.67
b (%)	38.53 – 55.60	5.001	2.075	0.828	2.597	0.740	1.93	6.57
c (h^{-1})	0.047 – 0.123	0.018	0.005	0.902	0.009	0.733	1.95	8.39
ED (%)	69.19 – 83.25	4.367	1.498	0.882	1.698	0.846	2.57	8.28

SD: Standard Deviation; SEC: Standard error of calibration; RSQ: Coefficients of determination for calibration; SECV: Standard error of cross validation; 1-VR: Coefficients of determination for cross validation; RDP: SECV/SD; RER: Range/SECV.

Table 3. Statistical results of calibrations for dry matter degradability parameters on whole samples.

Parameter	Range	SD	SEC	RSQ	SECV	1 – VR	RDP	RER
a (%)	38.87 – 55.90	5.317	0.582	0.988	0.917	0.972	5.80	18.57
b (%)	38.53 – 55.60	4.859	0.692	0.980	1.198	0.941	4.08	14.25
c (h^{-1})	0.047 – 0.123	0.018	0.006	0.885	0.008	0.755	2.03	8.91
ED (%)	69.19 – 83.25	4.147	0.642	0.976	1.077	0.933	3.85	12.39

SD: Standard Deviation; SEC: Standard error of calibration; RSQ: Coefficients of determination for calibration; SECV: Standard error of cross validation; 1-VR: Coefficients of determination for cross validation; RDP: SECV/SD; RER: Range/SECV.

The calibrations for rumen degradation characteristics of dry matter show a good predictive ability, evaluated by high r^2 (1-VR) values and low SECV values recorded. The results obtained have an adequate degree of precision and accuracy, with values 1-VR and SECV for soluble fraction 0.78 and 2.25; for degradable fraction 0.74 and 2.60; for digestion fraction rate 0.73 and 0.009; for effective degradability 0.85 and 1.70, respectively on grounded compound feed. Determination coefficient of cross validation (1-VR) and errors (SECV) in the calibrations for raw compound feed displayed an excellent results: 0.97 and 0.92 for a; 0.94 and 1.20 for b; 0.76 and 0.008 for c; 0.93 and 1.07 for ED, respectively.

Table 4 and Table 5, show statistical results for calibrations and cross-validation to predict rumen degradation characteristics of crude protein for grounded and whole samples.

Table 4. Statistical results of calibrations for crude protein degradability parameters on grounded samples.

Parameter	Range	SD	SEC	RSQ	SECV	1 – VR	RDP	RER
a (%)	25.90– 60.23	8.282	3.620	0.809	4.808	0.682	1.72	7.14
b (%)	36.47– 78.00	9.414	4.852	0.734	5.954	0.598	1.58	6.98
c (h^{-1})	0.063 – 0.123	0.014	0.0045	0.894	0.0065	0.784	2.14	8.72
ED (%)	66.45 – 84.98	4.814	2.373	0.757	2.517	0.723	1.91	7.36

SD: Standard Deviation; SEC: Standard error of calibration; RSQ: Coefficients of determination for calibration; SECV: Standard error of cross validation; 1-VR: Coefficients of determination for cross validation; RDP: SECV/SD; RER: Range/SECV.

The statistical results obtained for rumen degradation parameters of crude protein require a special discussion. Previous working according to Atanassova et al.[9]; De la Roza et al.[10] ; Andueza

et al.[11] and De Boever et al.[12] had shown relationship between the NIR data and rumen degradation parameters of crude protein with intermediate predictive ability. The reason of lower accuracy was imputable to a possible microbial contamination of the bag residues. However, in this study, we obtain an excellent predictive ability in terms of coefficient of determination and errors. Calibrations for predicting a, b, c and ED parameters on grounded samples obtained an adequate degree of precision with values for 1-VR ranged from 0.60 to 0.78 and lower SECV. Nevertheless, the calibrations obtained using ungrounded samples were better, probably attributed to the greater product-scanning surface, according to Garrido-Varo et al, [13] due by using the rectangular natural product cell, and the fact the samples were used in their natural form. The equations offer excellent precision, for predicting a, b and ED parameters the values obtained for 1-VR was upper than 0.80 (form 0.81 to 0.88) and 0.75 for fractional degradation rate. As regards, the SECV values obtained were low in all degradation parameters.

Table 5. Statistical results of calibrations for crude protein degradability parameters on whole samples.

Parameter	Range	SD	SEC	RSQ	SECV	1 – VR	RDP	RER
a (%)	24.30– 60.23	8.639	2.022	0.945	3.281	0.855	2.63	10.95
b (%)	36.4– 78.00	9.414	2.771	0.913	4.094	0.811	2.30	10.14
c (h-1)	0.005– 0.016	0.016	0.0054	0.880	0.0078	0.750	2.01	7.31
ED (%)	66.45 – 84.98	4.891	1.042	0.955	1.662	0.884	2.94	11.15

SD: Standard Deviation; SEC: Standard error of calibration; RSQ: Coefficients of determination for calibration; SECV: Standard error of cross validation; 1-VR: Coefficients of determination for cross validation; RDP: SECV/SD RER: Range/SECV.

Considering the relations of SECV/SD and Range/SECV, according to Williams and Sobering[14] as criterion for the predictive ability. In Tables 2 to 4 can be seen those values. Ratios (RER and RDP) appear low in the development of calibrations for prediction degradation parameters on grounded samples, as for dry matter degradability parameters as for crude protein degradability parameters, with ratios ranged from 1.6 to 2.6 for RDP and ratios ranged from 6.6 to 8.7 for RER. However, those for raw samples appear good for a and b degradability constants for dry matter, RDP ratio 4.1 and 5.8 and RER ratio 18.6 and 14.3, respectively, fairly good for effective degradability for dry matter (3.9 and 12.4) and intermediate for the rest of parameters.

Conclusions

The preliminary results confirmed that NIR spectroscopy could accurately predict the degradability parameters in feedstuffs to cover the most common situations of practical nutrition. In this vein, it is important to emphasise that the better results were obtained working on raw materials (pellets, small pill and flour) as compared with the same materials grounded.

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