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Evaluation of Models to Describe Ruminal Degradation Kinetics from In Situ Ruminal Incubation of Whole Soybeans

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ABSTRACT

Different mathematical models were evaluated as candidates to describe ruminal dry matter (DM) and crude protein (CP) degradation kinetics of raw and roasted whole soybeans from data obtained using the in situ polyester bag technique. Three models were used: segmented with up to 3 straight lines (model I), negative exponential (model II), and rational function or inverse polynomial (linear over linear; model III). A fourth, a generalized sigmoidal model, was also considered but the data did not exhibit sigmoidicity, so it was dropped from the analysis. Lagged and nonlagged versions of each model were fitted to the DM and CP disappearance curves of 6 different feeds (2 cultivars of raw or differently heat-processed whole soybean). The comparison between lagged and nonlagged versions of each model, based on statistical and behavior characteristics, showed for all models that the discrete lag parameter did not significantly improve the fit to ruminal DM and CP disappearance curves. The comparison between models (using nonlagged equations) showed that models I and II gave better goodness-of-fit than model III. Based on biological characteristics, models II and III underestimated the undegradable DM and CP fractions, but there was no significant difference between models for extent of degradation.
Key words: mathematical model, ruminal degradability, in situ incubation, degradation kinetics

INTRODUCTION

In vivo and in situ incubation of feeds in the rumen serves as a basic procedure in many feed evaluation systems and the formulation of hypotheses concerning underlying biological concepts has led to development of different mathematical models describing the resultant time course disappearance curves of feed fractions. The use of models allows comparison of parameter estimates (or combinations thereof) that ideally reflect these biological concepts, between feeds or feeding systems. Degradation and passage parameters are important aspects of rumen models (e.g., NRC, 2001; Kebreab et al., 2004; Thomas, 2004); therefore, accurate estimates of degradation parameters are required for incorporation into these systems. A number of methodological factors affecting the experimental measurements of in situ disappearance of feed samples has received due attention (Nocek, 1988; Huntington and Givens, 1995), but much less attention has been paid to the choice of mathematical model to fit the curves and goodness-of-fit of the model. In the present study, 3 different mathematical models (Ørskov and McDonald, 1979; France et al., 1990; and Lopez et al., 1999), which were also used to evaluate gas production profiles in a reparameterized form (France et al., 2005), were selected. A fourth model (a generalized sigmoidal function) was also tested. The objective of the study was to evaluate use of these models to determine DM and CP degradability parameters of raw and roasted whole soybean samples for fitting ability.

MATERIALS AND METHODS

Samples and Analyses

Two Iranian cultivars of soybeans (Sahar and Williams), raw, roasted, and steep-roasted, and considered for evaluation of heat-processing effects on DM and CP ruminal degradability in another experiment, were used in this study. For heat processing of soybean seeds, they were fed into a turning cylindrical tunnel (50 cm in diameter, turning at a speed of 2.5 cycles per minute) with a flame and blower at its end, so that the seeds were exposed to burning air. The seeds traversed the cylinder tunnel (4 m long), so that the temperature of the beans exiting the roaster was 130 to 135°C. Then, some seeds were gradually cooled (about 1 h), and the rest were immediately placed in isolated barrels without cooling, and covered with canvas for about 45 min (steeping), and then cooled.

Dry matter and CP of samples (6 feeds) before and after incubations were determined using a forced-air

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Table 1. Dry matter and CP content (g/kg of DM; SD in parentheses) of heat-processed Sahar and Williams cultivars of soybean seeds

	Sahar			Williams		
	Raw	Roasted	Steep-roasted	Raw	Roasted	Steep-roasted
DM	920 (9.5)	970 (9.0)	975 (9.9)	910 (10.1)	985 (9.0)	970 (12.2)
CP	369 (21.9)	381 (25.0)	378 (23.1)	356 (28.1)	376 (37.5)	375 (22.0)

oven at 96°C for 48 h, and the Kjeldahl method (Kjeltec 2300 Autoanalyzer, Foss Tecator AB, Hoganas, Sweden), respectively (Table 1).

In Situ Procedure

Two ruminally fistulated (430 ± 10 kg) Holstein steers fed a TMR twice daily (0900 and 1600 h) were used for incubation of samples. The TMR included (on a DM basis) 2.7 kg of alfalfa hay, 1.75 kg of corn silage and 2.25 kg of concentrate (barley 63.5, cottonseed meal 5.8, beet pulp 17.3, wheat bran 10.0, limestone 1.0, salt 0.4, vitamin-mineral supplement 0.5, and urea 1.5%) per steer per day. To determine the DM and CP degradability coefficients, 5 g of DM equivalent of each sample (ground using 2-mm screen mill) was placed in individual polyester bags (made of artificial silk cloth with a 50-μm pore size and averaging 12 × 19 cm). Bags were placed in the dorsal sac of the reticulorumen of each steer after the 0900 h feeding. Replicate bags of each feed sample were removed at 1, 2, 3, 4, 8, 16, 24, 36, 48, and 72 h of incubation and were hand washed thoroughly in cold running water until the rinsing water was clear. Two bags of each sample were washed without incubation in the rumen (0-h samples). The bags were dried in a forced-air oven (58°C, 48 h) and weighed to determine DM disappearance. The residues were analyzed for N content. Degradability of DM and CP was recorded at each incubation period for each of 6 feeds, yielding a total of 12 disappearance curves for each model.

Mathematical Models

Table 2 shows the 3 models, 1 piecewise linear and 2 diminishing returns, used to describe ruminal degradation of DM and CP of the samples. Model I is a segmented model with 3 spline-lines delimited by 2 nodes or break points, constraining splines 1 and 3 to be horizontal asymptotes, and follows zero-order degradation kinetics (France et al., 1990). Model II is a negative exponential equation (monomolecular or Mitscherlich) assuming first-order kinetics and a constant fractional rate of degradation (Ørskov and McDonald, 1979). Model III is a rational function or inverse polynomial (linear over linear), which describes a rectangular hyperbola and assumes first-order kinetics with a variable fractional rate of degradation that declines with time (Lopez et al., 1999). This latter model is akin to the Michaelis-Menten equation of enzyme kinetics. A discrete lag parameter (L) was included in each model to represent the time interval before degradation commences. A reparameterized and generalized sigmoidal model, the Richards (Thornley and France, 2006), was also used to test whether the degradation profile could be better described using an S-function. The Richards equation was chosen because it encompasses the Gompertz, logistic, and monomolecular (diminishing returns) when its additional parameter (n) has a value of 1, 0 and –1, respectively. In all of the profiles fitted, n was not significantly different from –1; therefore, sigmoidal analysis was dropped and piecewise linear and diminishing return models were used with and without a lag parameter.

Each model was fitted to the DM and CP disappearance curves by nonlinear regression using the PROC NLIN of SAS (SAS Institute, 1999) to estimate ruminal degradation parameters. Several possible starting values were specified for each parameter, so that the NLIN procedure evaluated the model at each combination of initial values on the grid, using for the first iteration of the fitting process, the combination yielding the smallest residual sum of squares. Rapidly soluble fraction (a), slowly degradable fraction (b), degradation rate constant (c), or time constant (T), and L were estimated for each disappearance curve using each model. The extent of degradation (E), for a given passage rate (0.06 and 0.08/h), was calculated from these estimated parameters as shown in Table 2. In calculating E, the washout fraction was assumed to be completely degradable; however, E can be readily calculated based on other assumptions about degradability of the washout fraction as described by Dhanoa et al. (1999). In model III, for calculating E, the function

$$a + bk \int_{L}^{\infty} \left(\frac{t - L}{t - L + T} \right) e^{-kt} \, dt$$

was coded in the advanced continuous simulation language ACSL (Aegis Simulation, Inc., Huntsville, AL)