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Passage and degradation kinetics of solid particles from agricultural residues

Cinética de passagem e degradação de partículas sólidas de resíduos agrícolas

Marco Aurélio Teixeira Andrade[1]; Bruna Cardoso Braga[2]*; Severino Delmar Junqueira Villela[3]; Raphael dos Santos Gomes[4]; Maria Eduarda Lara Resende[5]; Guilherme Campos Leitão[5]; Fernando de Paula Leonel[6]

Highlights

The degradation kinetics of corn residue and corn silage are similar
The mean fiber retention time is similar between corn residue and corn silage.
Soybean and wheat residues have worse degradation kinetics than corn.
All foods analyzed share the same characteristics of fiber passage kinetics.

Abstract

The use of waste generated in the agroindustry can result in increased production at a relatively low cost compared to traditional ingredients, especially for producers with easy access to this waste. This study proposes to estimate the kinetics of passage and degradation of corn, soybean, wheat residues and corn silage in the gastrointestinal tract of cattle. Four rumen-fistulated animals with an average weight of 450 ± 50 kg were assigned to four treatments (corn, soybean, wheat residues and corn silage) in a 4×4 Latin square experimental design. The fiber from the residues and corn silage used to estimate the passage kinetics was marked with potassium dichromate, whereas the *in situ* technique was employed to estimate the fiber degradation kinetics. A larger potentially degradable fraction and a smaller undegradable fraction were observed for corn residue and corn silage, whereas no differences were detected between the materials for passage kinetics. The residue from corn processing is similar to corn silage in terms of degradation kinetics and mean fiber retention time, while the other residues

[1] Student of the Master's Course of the Postgraduate Program in Animal Science, Universidade Federal dos Vales de Jequitinhonha e Mucuri, UFVJM, Diamantina, MG, Brazil. E-mail: marco_aurelio_01@hotmail.com
[2] Student of the Doctoral Course of the Postgraduate Program in Animal Science, Universidade Federal de Goiás, UFG, Goiânia, GO, Brazil. E-mail: braga.braga@discente.ufg.br
[3] Prof. Dr., UFVJM, Diamantina, MG, Brazil. E-mail: sdjvillela@gmail.com
[4] Prof. Dr., Instituto Federal de Educação, Ciência e Tecnologia de Rondônia, IFRO, Colorado do Oeste, RO, Brazil. E-mail: raphael.gomes@ifro.edu.br
[5] Students's Animal Science Course, Universidade Federal de São João del Rei, UFSJ, São João del Rei, MG, Brazil. E-mail: mariaeduardalara19@hotmail.com; guilhermecamposleitaoc@gmail.com
[6] Prof. Dr., UFSJ, São João del Rei, MG, Brazil. E-mail: fernandoleonel@ufsj.edu.br
* Author for correspondence

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have worse degradation kinetics than corn, which is due mainly to the elevated undegradable fraction. All the analyzed residues, as well as corn silage, share the same characteristics of fiber passage kinetics.
Key words: Corn residue. Grain processing waste. Soybean residue. Wheat residue.

Resumo

A utilização de resíduos gerados na agroindústria pode resultar no aumento da produção a um custo relativamente baixo se comparado aos ingredientes tradicionais, principalmente para produtores com fácil acesso a esses resíduos. Este estudo propõe estimar a cinética de passagem e degradação de resíduos de milho, soja, trigo e silagem de milho no trato gastrointestinal de bovinos. Quatro animais fistulados no rúmen com peso médio de 450 ± 50 kg foram distribuídos em quatro tratamentos (resíduos de milho, soja e trigo e silagem de milho) em delineamento experimental em quadrado latino 4×4. A fibra dos resíduos e da silagem de milho utilizada para estimar a cinética de passagem foi marcada com dicromato de potássio, enquanto a técnica in situ foi empregada para estimar a cinética de degradação da fibra. Foi observada maior fração potencialmente degradável e menor fração indegradável para resíduo de milho e silagem de milho, enquanto não foram detectadas diferenças entre os materiais para cinética de passagem. O resíduo do processamento do milho é semelhante à silagem de milho em termos de cinética de degradação e tempo médio de retenção da fibra, enquanto os demais resíduos apresentam pior cinética de degradação que o milho, o que se deve principalmente à elevada fração indegradável. Todos os resíduos analisados, bem como a silagem de milho, compartilham as mesmas características de cinética de passagem das fibras.
Palavras-chave: Resíduo de milho. Resíduo de processamento de grãos. Resíduo de soja. Resíduo de trigo.

Introduction

Feedstuffs derived from industrial by-products or waste from grain-processing industries have often been used in animal production, especially by virtue of the increasing feed costs in ruminant farming. The quality of these feedstuffs must, however, be determined so that they can be included in diet-balancing programs and be effectively used by the producer. The use of by-products in animal feeding could mitigate the issue of pollution in the agricultural industry (Pen et al., 2006), and, if not used, it presents a high cost of waste treatment (Nkosi & Meeske, 2010).

The use of waste generated by agroindustry shows promise in feeding ruminants. Its use can result in increased production at a relatively low cost compared to traditional ingredients, especially for producers with easy access to these residues. Research seeks to qualify such residues and determine the optimal levels of inclusion in diets, which can allow animal productivity, and preferably, provide quality to products and increase the profitability of production systems (Kotsampasi et al., 2017).

Knowledge of the feedstuffs used in diets is important to allow animals to express their maximum production potential (Senger

et al., 2007). Some methods are used to evaluate foods, such as fiber degradation kinetics, which is estimated by the technique involving nylon bags incubated in rumen-fistulated cattle and used in the evaluation of feedstuffs (Orskov et al., 1980), it provides a rapid and simple estimate of the degradation of nutrients. However, in this technique, the feed is not subjected to all the digestion events such as chewing, rumination, and passage (Van Soest, 1994; Vieira et al., 1997). Passage rate of feed particles through the reticulum-rumen depends on feed properties and the characteristics of the animal. This passage rate has a direct influence on the degradation of the feed (Agricultural and Food Research Council [AFRC], 1993), in addition to being another tool for the evaluation of feedstuffs for ruminants.

Understanding the kinetics of passage and degradation is an important step for these residues to be recognized as feed for ruminants. Therefore, this study proposes to estimate the kinetics of passage and degradation of corn, soybean and wheat residues in the gastrointestinal tract of cattle and compare them with corn silage.

Material and Methods

All experimental procedures were approved by the Committee on Animal Use and Care at the Minas Gerais Agricultural Research Company (CEUA EPAMIG 02/2019). The experiment was conducted in an Experimental Farm from partners UFSJ/EPAMIG in São João del Rei, Minas Gerais, Brazil (21º 08' 08" S latitude and – 44º 15' 42" W longitude). The foods tested to investigate the kinetics of passage and degradation were residues from grain processing and corn silage, resulting in four treatments: (1) residues from the processing of corn grains, (2) residues from the processing of soybean grains, (3) residues from wheat grain processing, and (4) corn silage, used as a control treatment.

Samples of the tested feedstuffs were weighed and dried in a forced-air oven at 55ºC for 72 h. Then, the material was weighed again to obtain the partial dry matter (DM). Feedstuffs were ground in Wiley mills to pass through a 1-mm round-curved sieve (Theodorou et al., 1994). Total dry matter, method 976.03 (Association of Official Analytical Chemists [AOAC], 1990), crude protein, method 987.04 (AOAC, 1990), neutral detergent fiber (method AOAC 2002.04), and acid detergent fiber (ADF) of feedstuffs were determined (Table 1).

Table 1
Chemical composition of the studied residues and corn silage

Nutritional components [I]	Corn residue	Soybean residue	Wheat residue	Corn silage
Dry matter (g kg^{-1} NM)	710.88	737.30	806.20	325.23
Crude protein (g kg^{-1} DM)	36.10	198.52	45.00	71.08
Neutral detergent fiber (g kg^{-1} DM)	540.87	513.70	538.40	512.41
Acid detergent fiber (g kg^{-1} DM)	313.30	298.43	314.54	312.07

[I] NM: natural matter; DM: dry matter.

These residues (corn, soybean, and wheat) originate from the pre-cleaning of grains and consist of fragments of vegetative parts, fragmented grains and/or grains at inadequate degrees of maturity or "fill", plant debris, and seeds from native vegetation. The samples used for the complexation of the fiber from the wheat, corn, and soybean residues with potassium dichromate originated from a grain processing unit in the municipality of Lagoa Dourada - MG, Brazil.

To study the kinetics of fiber degradation and the rate of passage of food particles, four Holstein × Gir crossbred castrated cattle with an approximate weight of 450 kg, cannulated in the rumen according to the technique described by Leão and Silva (1980) and Leão et al. (1978), were assigned to four treatments in a Latin square design with four animals and four experimental periods. The animals were kept in a confined regime in individual pens where they were fed a diet consisting of corn silage supplied *ad libitum* plus 2 kg of a concentrate based on corn, soybean meal (25% crude protein), and a mineral mixture during the trial. The feed was supplied twice daily, at around 7 a.m. and 3 p.m..

To analyze the ruminal degradability of fiber the *in situ* technique was used, which consists of incubating the materials under study for predetermined times in the rumen of the animals. Nylon bags (13 × 7 cm; 50 µm pore) containing approximately 1 g of sample each were used, maintaining a bag surface ratio of 25 mg DM/cm^2, in accordance with recommendations of Kirkpatrick and Kennelly (1987). The incubation times adopted were 0, 6, 18, 48, and 96 h, according to Sampaio (1994); at each time, all treatments were incubated in each animal. The bags were tied in sequential order on the links of a chain, which contained a weight on its extremity. This weight worked as an anchor, causing the bags to be immersed in the ruminal content, which promoted an effective activity of the ruminal microorganisms on the samples.

Bags were incubated in the rumen in reverse chronological order (infused at the pre-determined times and removed all at the end of the countdown). Upon removal, bags were washed in running water until it was completely clear and then dried in a forced-air oven at 55 ± 5 ºC for 72 h. Bags corresponding to time zero were not incubated in the rumen but underwent the same cleaning process simultaneously with the others. After the drying process, the bags were opened and their contents were analyzed for the levels of dry matter, method 976.03 (AOAC, 1990) and neutral detergent fiber, method 2002.04 (Mertens, 2002).

For the estimate of the fiber passage kinetics, approximately 3 kg of material from each treatment were placed in a container to boil for one hour with a commercial neutral detergent at the rate of 100 g of dry sample per 100 mL of detergent per liter of water, as described by Udén et al. (1980). After this procedure, the material was filtered through a cotton-fabric bag and washed with running water from the tap until the water was clear to remove the soluble contents, and then oven-dried at 55 ± 5 ºC for 72 h.

Next, a potassium dichromate solution ($K_2 Cr_2O_7 .2 H_2O$) was prepared at the proportion of 13% chromium in relation to the weight of the fiber to be stained. This solution was diluted in water in a glass container with previous immersion of the fiber in this solution. The container was covered with

foil and kept in an oven at 105 ºC for 24 h. After this procedure the material was placed in a cotton-fabric bag and washed in running water to remove the excess of potassium dichromate. Afterwards, the material was immersed in a commercial ascorbic acid solution at the proportion of half the weight of the fiber and left to rest for one hour until acquiring an intense green color. Soon after this, the material was once again placed in a cotton-fabric bag, washed several times until the water was completely transparent, and then dried in a forced-ventilation oven at 55 ± 5 ºC for 72 h, thus generating the chromium-mordant neutral detergent fiber (NDF).

Stained samples were placed directly in the rumen via ruminal cannula in the amount of 200 g per animal. Feces were collected at times zero (immediately after administering the chromium-complexed fiber), 1, 2, 4, 6, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 56, 64, 72, 80, 88, 96, 120, 132, 144, and 196 h, to estimate the passage kinetic parameters of the particles. After these collections at the indicated times, the samples were dried in a forced-air oven at 55±5 °C for 72 h and then ground through a mill to 1-mm particles. Approximately 200 mg of feces corresponding to each incubation time, animal, and period were diluted in a nitric-perchloric acid solution to remove the organic matter and for subsequent reading of the chromium concentration by atomic absorption spectrometry, following the methodology described by Williams et al. (1962).

The profiles of marker concentration in the feces were described in the generalized mono-compartment model suggested by Pond et al. (1988). The parameters generated in this model provide estimates that explain the dynamics of the rate of passage of fibrous particles through the gastrointestinal tract of ruminants in general.

The model used to estimate the fiber degradation kinetic parameters consists of a simple first-order equation, which was proposed by Smith et al. (1971). A parameter representing the discrete lag time was added to this model; this inclusion was suggested by Mertens and Loften (1980) and reaffirmed by Vieira et al. (2008a), who justified its use based on the substantial improvement of its predictive ability.

In the degradability trial, the tested variables were the potentially digestible fraction of the normalized fiber (B), indigestible fraction of the normalized fiber (U), discrete lag (L), digestion rate (kd), mean retention time in the reticulum-rumen (MRTR), and true digestibility (TD). Variable L, expressed in hours, represents the time for preparation and colonization of the substrate in the rumen until the effective start of digestion. Variable c, in turn, quantifies the proportion of fiber digested in the rumen per time unit, and is expressed in h^{-1}.

Turnover, or MRTR, was estimated based on biological interpretations, in which both ascending and descending phases of the profile of excretion of the markers in the feces exerted an influence on the retention of the particles in the reticulum-rumen (Vieira et al., 2008b). This parameter in the model is expressed in hours and was estimated according to the equation of Matis et al. (1989).

The true digestibility coefficient (TD) of fiber is dimensionless and was estimated using the model deduced by Vieira et al. (2008b), expressed in days.

The general structure attributed to the degradation is shown below:

$Y_t = \mu_{R_t} + e_t$ Eq. (1) and

$Y_t = \mu_{C_t} + e_t$ Eq. (2),

in which R_t = residue from *in situ* incubation at time t; and C_t = concentration of marker in the feces at time t, assuming Y_t~Normal (μ_{R_t}) " or " μ_{C_t}; $\sigma^2_{Y_t}$). However, in the in situ gravimetric degradation profiles, the general form was assigned (Mertens, 1977):

$R_t = B \exp(-kd * t) + U$ Eq. (3),

$R_t = B + U$, if t< L, and

$R_t = B \exp(-kd * (t - L)) + U$, if t≥L; Eq. (4)

in which B = potentially degradable fraction of fiber; U = indigestible fraction of fiber; k = degradation rate (1/h); and L = discrete lag (h), assuming R_t~*Normal* (μ_{R_t}),$\sigma^2_{R_t}$).

The general form attributed to the marker excretion profiles was the segmented one-compartment model described by Pond et al. (1988):

$C_t = d$, if t <tt and

$C_t = d + C_0 \times \frac{\lambda^N \times (t-tt)^{N-1} \times \exp[-\lambda \times (t-tt)]}{(N-1)!}$, if t≥tt; Eq. (5),

in which d = scale parameter without biological meaning necessary for the use of uncorrected reading data; C_0 = marker concentration in the reticulum-rumen at t = 0; λ = asymptotic rate of passage of the marker that emerges from the reticulum-rumen; N = positive integer that denotes the time-dependence order; and tt = time taken by the marker from the reticulum-omasal orifice until its output in the feces.

Conventional assumption and homoscedasticity were evaluated as proposed by Pinheiro and Bates (2000):

$\sigma^2_{Y_t} = \sigma^2$ Eq. (6) and

$\sigma^2_Y = \sigma^2 (Y_t)^{2\psi}$. Eq. (7),

in which σ^2 = homogeneous residual variance ($\sigma^2_{R_t} = \sigma^2$) as shown in equation (6). Equation 7 represents the residual variance ($\sigma^2_{R_t} = \sigma^2$) scaled by the potential (ψ) as a function of the expected mean, Y_t. The correlation between the means was also assessed using the continuous autoregressive correlation (CAR1) of the nlme package of R software (Pinheiro & Bates, 2000).

The models were fitted to the fiber *in situ* degradation and marker-excretion profiles via the nlme package of R software (Pinheiro & Bates, 2000). The best fit of the model to the profile was evaluated by computing the information criteria derived from corrected Akaike's criterion (Akaike, 1974; Sugiura, 1978; Burnham & Anderson, 2004). Further, the decision of the best model to describe the profile was achieved based on recommendations of Vieira et al. (2008a).

Additional estimates were obtained for the marker excretion profiles using the NLMIXED package of SAS (Statistical Analysis System, version 9.2), employing the estimates of the nlme package of R as input, as follows:

$MRTR = \frac{N}{\lambda}$ Eq. (8) and

$MTRT = \frac{N}{\lambda} + tt$ Eq. (9)

in which MRTR = mean retention time in the reticulum-rumen; and MTRT = mean total retention time.

Treatments effects were compared based on their 95% confidence intervals.

Results and Discussion

The calculation of Akaike's criterion (Akaike, 1974) allows us to compare different hypotheses and, based on the obtained results, select the one that best predicts reality according to the evaluated dataset. The model of degradation and lag combined with scaled residual variance (Eq. (4) and (7)) and random error on parameter L showed the lowest Akaike's information criterion. Therefore, it was considered the best-fitting model (Table 2).

Table 2
Best fitting models for the degradation kinetics

Model	Random effect[1]	$AICc_r$	Δ_r	w_r	ER_r	Θ_r
Eq. (4) and (7)[2]	L	–706.6	0	0.753	1	26
Eq. (4) and (7)[2]	U, L	–703.9	2.7	0.195	3.9	27
Eq. (4) and (7)[2]	B	–700.2	6.4	0.031	25	26
Eq. (4) and (7)[2]	-	–697.4	9.2	0.008	99	25
Eq. (4) and (7)[2]	U	–697.4	9.2	0.008	99	26

[1] Random animal × period interaction effect. [2] Autoregressive correlation. AICcr - Akaike's information criterion corrected for the r-th model; Δ_r - AICc difference between the models; w_r - likelihood probability for the r-th model; ER_r - evidence ratio of the r-th model; Θ_r - number of parameters in the r-th model. L - discrete lag; U - undegradable fraction; B - potentially degradable fraction.

Mathematical models applied to animal nutrition have been used to quantify the nutritional value of diets and estimate the animal performance (Fialho et al., 2015). These models are based on the evaluated substrate and on the ruminal digestion kinetics to estimate the availability of nutrients (carbohydrates and proteins) for microbial growth (Abreu et al., 2014). The optimization of diets for ruminants has been widely investigated, especially concerning their ability to ingest and consume fiber (Vieira et al., 2008a; Jardim et al., 2013).

A larger potentially degradable fraction (B) was observed in corn residue and corn silage as compared with the other residues, which did not differ from each other (Table 3). For the undegradable fraction (U), however, the opposite response was observed, with the soybean and wheat residues having higher values. Although the soybean residue showed a smaller potentially degradable fraction along with the wheat residue, its degradation rate (kd) was higher than that of the other treatments. The soybean residue had 2.5 times higher kd value than corn residue, which obtained the lowest degradation rate. Wheat residue, in turn, had an intermediate result for this variable. No significant effect was observed for discrete lag (L). Thus, this variable can be represented by the estimated mean value, which was 5.15 ± 2.22 h, regardless of the treatment.

Table 3
Fiber degradation kinetic parameters

Feedstuff	Parameter				
	B	Kd (1/h)	U	L (h)	Variance[1]
Corn residue	0.627±0.089[a]	0.025±0.007[c]	0.381±0.0861[b]	5.6±2.59	σ = 0.032±0.0298 ψ = –0.981±0.6104
Soybean residue	0.428±0.0309[b]	0.064±0.0144[a]	0.579±0.0307[a]	6.1±1.92	σ = 0.019±0.0069 ψ = –1.914±0.913
Wheat residue	0.369±0.00698[b]	0.040±0.0143[b]	0.629±0.06673[a]	5.4±2.03	σ = 0.019±0.0178 ψ = –3.815±0.9817
Corn silage	0.675±0.041a	0.029±0.0037[bc]	0.327±0.0276[b]	3.5±2.33	σ = 0.031±0.0309 ψ = 0.302±0.6122

* Common lowercase letters in the column do not differ statistically by the 95% confidence interval. [1] Variance per feedstuff. σ_L = 1.384±0.8492. Correlation: 0.120±0.1825. B - potentially degradable fraction; Kd - degradation rate; U - undegradable fraction; L - discrete lag.

Discrete lag represents the time microorganisms take to colonize the particle; i.e., to promote the events of adhesion and consortium formation to subsequently initiate the degradation process. Discrete lag also estimates, by approximation, the time necessary for the preparatory events of the degradation activities to occur, involving physical (e.g., hydration) and microbiological (e.g., fixation to the substrate, enzyme synthesis, etc.) aspects. In this study, this variable was not influenced by the treatments (Table 3), suggesting that all studied residues as well as corn silage are colonized and consequently degraded by the same pool of microorganisms and that the chemical and physical traits of the fiber from the different feedstuffs do not have particularities that may hinder their respective initial degradation phases.

The model for the kinetics of passage rate combined with scaled residual variance and random effect (Eq. (5) and (7), N=3) on parameter C_0 (marker concentration) showed the lowest Akaike's information criterion (AICcr) as well as a better evidence ratio (ERr), in addition to having one (1) fewer parameter (Θr) in relation to the second best-fitting model (Table 4).

Table 4
Best fitting models for the kinetics of the fiber passage rate

Model	Random effect[1]	$AICc_r$ [1]	Δ_r [1]	w_r [1]	ER_r [1]	Θ_r [1]
Eq. (5) and (7), N = 3	C_0	5732.8	0	≅ 1,000	1	19
Eq. (5) and (7), N = 3^2	C_0	5759.2	26.4	10^{-6}	540365	20
Eq. (5) and (7), N = 3^2	tt	5759.2	26.4	10^{-6}	540365	20
Eq. (5) and (7), N = 3^2	-	5760.1	27.3	10^{-6}	847461	19
Eq. (5) and (7), N = 2^2	tt	5761.7	28.9	10^{-7}	1886059	20

[1] Random animal × period interaction effect. [2] Autoregressive correlation. $AICc_r$ - Akaike's information criterion corrected for the r-th model; Δ_r - AICc difference between the models; w_r - likelihood probability for the r-th model; ER_r - evidence ratio of the r-th model; Θ_r - number of parameters in the r-th model. C_0 - concentration of marker in the reticulo-rumen at zero time, tt - time taken by the marker from the reticulo-omasal orifice until tis output in the feces.

The parameters estimated for the passage kinetics of corn silage and of the corn, soybean, and wheat residues did not have a significant effect (Table 5). Thus, their mean values can be estimated irrespective of the imposed treatment. In this way, the following fitted mean values were estimated for each parameter: C_0 = 86432 ± 17503, λ = 0.066 ± 0.0073, tt = 7.3 ± 1.27, d = 11.37.

Table 5
Estimated parameters of the passage kinetics and its respective 95% confidence intervals (amplitude/2)

Feedstuff	C0	λ	Tt	d	Variance
Corn residue	74051±15145.3	0.060±0.0069	6.7±1.27	9.0±5.80	σ = 1.59 ± 0.349;
Soybean residue	106096±21045.3	0.077±0.0074	8.8±0.92	11.0±5.68	ψ = 0.904 ± 0.0380;
Wheat residue	82549±17281.9	0.076±0.0085	8.4±1.33	14.8±7.31	σ_{co} = 41.08 ± 5.30
Corn silage	83035±16537.7	0.053±0.0064	5.3±1.55	10.7±7.29	× 10^{29}

C_0 - concentration of marker in the reticulo-rumen at zero time, λ - asymptotic rate of passage of the marker that emerges from the reticulo-rumen; tt - time taken by the marker from the reticulo-omasal orifice until tis output in the feces; d - scalar parameter with no biological meaning necessary for the use of uncorrected reading data.

Passage kinetics refers to the flow of feed residues that are not digested throughout the digestive tract. It is influenced by the intake level, physical form of the diet, differences in rumination existing between animals, type of marker used in the determination of the fecal excretion curve (Mertens & Ely, 1982), roughage-to-concentrate ratio, and climatic factors (Faichney, 1993). Other authors suggest that the main factors determining the rate of passage are the size and specific gravity of particles (Hristov et al., 2003; Oshita et al., 2004; Ellis et al., 2005), since they define how long the feed particles remain the reticulum-rumen as well as their distribution across the different regions of these compartments. Therefore, it can be suggested that none of the afore-mentioned factors, separately or combined, were able to change the dynamics of particle flow in the residues or in corn silage. In the present study, no significant effect was observed for the variables that represent the passage kinetics.

In the calculation of additional predictions, the passage kinetic parameters were used to estimate the MTRT and the MRTR for the different residues as well as for corn silage (Table 6). The mean total retention time and MRTR estimated for corn residue and corn silage were higher than those obtained for the soybean and wheat residues. The treatments that showed the longest estimated total retention time and retention time in the reticulum-rumen also had the highest estimate of potentially degradable fraction (B). Likewise, the treatments that showed the shortest retention time had the highest undegradable fraction (U) estimates.

The longer estimated retention time of corn residue and corn silage (Table 6) for both total retention and retention in the reticulum-rumen can influence the true digestibility of the feedstuff (Vieira et al., 1997; Fialho et al., 2015). In this case, the variable that can corroborate this finding is the potentially degradable fraction (B), which was higher in the treatments that obtained higher estimated retention values (Table 3).

An increase in MRTR is expected to also result in increased true digestibility of the feedstuff, since a longer residence of the feed particle in the rumen will theoretically provide a greater effect of fermentation and degradation. However, this effect can vary according to the characterization of microorganisms, which has a direct relationship with the feeding type (Van Soest, 1994). Mertens (1977), on the other hand, stated that ruminal retention is one of the factors that can influence the utilization of the diet, since digestion and passage are competing processes.

Table 6
Additional predictions of mean total retention time (hours), mean retention time in the reticulum-rumen (hours) and its respectives upper and lower limits of 95% confidence intervals

	Estimated	Lower	Upper
Feedstuff		Mean total retention time	
Corn residue	56.6[a]	52.71	60.49
Soybean residue	47.8[b]	45.72	49.88
Wheat residue	47.8[b]	44.92	50.68
Corn silage	62.1[a]	56.39	67.81
		Mean retention time in the reticulum-rumen	
Corn residue	49.9[a]	45.46	54.34
Soybean residue	39.1[b]	36.68	41.52
Wheat residue	39.3[b]	36.06	42.54
Corn silage	56.6[a]	50.72	62.88

*Common lowercase letters in the column do not differ statistically by the 95% confidence interval.

In forage-fed animals, the flow of saliva and rumination are stimulated and the rate of fluid dilution is high (Russell, 2002). This fact indicates that ruminal escape is facilitated by the salivation and dilution provided by forage feeds, and when roughage feeds are proportionally substituted for concentrate sources, which are more rapidly degraded in the rumen, salivation and the rate of dilution of the rumen fluid decrease by around 15% (Russell, 2002), which may extend the time of residence of this material inside the organ and consequently increase MRTR (Fialho et al., 2015).

Conclusions

The residue from corn processing is similar to corn silage in terms of degradation kinetics and mean retention time of the fiber. The soybean and wheat residues, in turn, have a worse degradation kinetics than corn silage, which is mainly due to the large undegradable fractions. All the analyzed residues as well as corn silage share the same characteristics of fiber passage kinetics.

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