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# Rumen degradation and passage kinetics of silage made from different corn hybrids

**Karoline Guedes Araújo[1], Severino Delmar Junqueira Villela[1], Fernando de Paula Leonel[2], Wagner Pessanha Tamy[3], Raphael dos Santos Gomes[3], Matheus Lima Corrêa Abreu[3]**

[1] *Universidade Federal dos Vales do Jequitinhonha e Mucuri, Diamantina, MG, Brasil.*
[2] *Universidade Federal de São João del-Rei, São João del-Rei, MG, Brasil.*
[3] *Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes, RJ, Brasil.*

**ABSTRACT** - The objective of the present study was to evaluate the parameters related to the digestion of the fiber from silages of four corn hybrids (BX1280, SHS4070, 2B433, and DKB390) developed for silage production. Four rumen-cannulated castrated Holstein × Zebu crossbred cattle with approximate initial weight of 400 kg were distributed in a Latin square design. To determine the fiber passage rate and degradability, the techniques of chromium-mordant and *in situ* incubation of the neutral detergent fiber of the silages in nylon bags were used. The profiles of concentration of the marker in the feces were described by the generalized two-compartment model. Corn hybrid DKB390 is the most indicated for production of better-quality silages, because its fiber is more degradable in the rumen as compared with the other hybrids tested.

Key Words: fiber, passage rate, ruminal degradability

## Introduction

Corn silages are the main source of neutral detergent fiber and energy for high-producing dairy cattle (Weiss and Wyatt, 2002). Especially in the current scenario, in which large territorial extensions which were once used for cattle farming are now serving for agricultural production, more specifically production of grains and sugarcane, due to the better cost of land of opportunity and greater financial return provided by these cultures when they are used in extensive cattle husbandry.

Companies that produce corn hybrids intended for silage production give the following estimates related to the plant: plant size, fresh mass production, crude protein, insertion of the ear, mulching, characteristics of the cycle of the plant, information on the root system and stem quality, etc. Such estimates do not provide the adequate support to influence the decision-making of the farmer at the choice for the best hybrid to be cultivated. Therefore, the knowledge of the kinetics of transit of fibrous particles and the fiber degradability in the rumen is an important tool for the estimation of the nutritional value of this forage resource.

Neutral detergent soluble carbohydrates in the corn silages are rapidly degraded when they reach the rumen (Van Soest, 1994), and thus the characteristics of retention and passage of the feed through the rumen-reticulum are mainly influenced by the fibrous portion of the feed (Vieira et al., 2008), which implies that the difference in their quality is associated with the fiber characteristics of each silage. Thus, it is important to quantify the kinetic parameters of degradation and passage and estimate the rumen digestibility and rumen fill of the different hybrids.

The objective of the present study was to evaluate parameters related to the fiber digestion of silages of four corn hybrids developed for silage production.

## Material and Methods

The experiment was conducted in São João Del Rei (21º 08' 00" S and 44º 15' 40" W; 898 m of altitude), Minas Gerais, Brazil. The area is located in a region with a Cwa climate (Köppen standards), on a soil classified as Dark-Red Latosol, in dry land farming conditions. Four corn hybrids (BX1280, SHS4070, 2B433, and DKB390) were cultivated to produce the experimental silages. Four Holstein × Zebu crossbred castrated cattle with an initial weight of approximately 400 kg were rumen-cannulated, according to the technique described by Leão et al. (1978) and Leão and Silva (1980), and distributed in a Latin square design. The animals were housed in individual pens and fed a diet composed of corn silage, provided *ad libitum*, and 2 kg of a concentrate on the basis of corn and soybean

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Corresponding author: wagnertamy@yahoo.com.br
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meal (884, 215.5, 34.2, 111.2, 8.4, and 30.3 g kg$^{-1}$ of dry matter [DM], crude protein [CP], ether extract [EE], neutral detergent fiber [NDF], lignin, and ash, respectively), and a mineral mixture *ad libitum*. The diet was divided in two equal portions, which were offered at around 07.00 h and 15.00 h. A 4 × 4 Latin square design was used with the single objective of obtaining the profiles of fiber passage and degradability by assuming independence and homogeneity of incubations, so that each time profile pooled across periods by animal and was considered an independent subset. The chemical analysis of silages was determined according to AOAC (1990), except NDF (Van Soest et al., 1991).

The particle transit kinetic parameters were estimated by employing the chromium-mordant technique on the fiber from the silages, according to Udén et al. (1980). The labeled samples were inserted directly in the rumen via rumen fistula, at 200 g per animal. Feces were collected at times zero (immediately after administering the chromium-mordant 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 hours, to estimate the parameters of particle passage kinetics (Vieira et al., 1997). After the collections at the indicated times, samples were dried in a forced-ventilation oven at 60±5° C for 72 to 96 hours, processed in a mill with 1 mm mesh sieve and stored for later analyses of the chromium content, according to the method proposed by Willians et al. (1962).

The *in situ* degradability of the neutral detergent fiber (NDF) from silages was obtained gravimetrically before and after rumen incubation and expressed as percentage; for the use of bags (nylon), the recommendations of Nocek and Russell (1988) were followed.

In the study of the fiber degradability, the plots refer to the times corresponding to the incubation periods, and the sub-plots, to the treatments. The treatments were the different corn hybrids developed for silage production (BX1280, SHS4070, 2B433, and DKB390). Samples of corn silages to compose the different treatments were dried in a forced-circulation oven at 60±5 °C for 72 hours and ground in sieves with 4 mm mesh. Samples were weighed, conditioned in nylon bags (6 × 12 cm) with an aperture of 50 µm at approximately 3 g DM/bag, so as to keep a ratio close to 20 mg DM/cm$^2$ of bag surface area, according to Nocek and Russell (1988).

The incubation periods corresponded to times 8, 18, 48, and 96 h, according to Sampaio et al. (1994); bags were placed at different times, to be removed all at the same time, thereby promoting uniform washing of the material during its withdrawal from the rumen. Bags corresponding to time zero were not incubated in the rumen, but they were washed simultaneously with the others. After they were removed, bags were washed in running water until it showed clear; next they were dried at 60±5 °C in a forced-ventilation oven for 48 h and taken to the desiccators. After, their respective weights were determined. Dry matter was determined in an oven at 65 ºC, for 72 h, using the samples for analyses of NDF, according to the methodology described by Van Soest et al. (1991).

The profiles of concentration of the marker in the feces were described by the generalized two-compartmental model suggested by Matis et al. (1989). The parameters of the model above provide estimates that explain the dynamics of passage rate or transit of fiber particles through the gastrointestinal tract of ruminants.

The model utilized to estimate the parameters of fiber digestion kinetics consists of a simple first-order equation (Smith et al., 1971), with addition of discrete lag time, as described by Mertens and Loften (1980).

Fractions A and U, both expressed in g kg$^{-1}$, were normalized to demonstrate an adequate proportion between each other (Waldo et al., 1972), namely An and Un. The variables tested in the present study were: potentially digestible fraction of the standardized fiber (An), indigestible fraction of the standardized fiber (Un), discrete lag (L), digestion rate ($k_d$), true digestibility (TD) of fiber, rumen fill effect of fiber (RF), mean retention time in the ruminoreticulum (MRT), retention time of particles in the raft pool (N/λ) and in the escapable pool (1/k), transit time representing the time for an escaped particle transit from the reticulo-omasal orifice to feces (τ), and total retention time in the gastro intestinal tract (GIT) (TMRT).

The parameter L (h) explains the time of preparation and colonization of the substrate in the rumen until digestion effectively starts. Variable $k_d$ represents the fractional degradation rate of fiber per unit of time (h$^{-1}$).

The true digestibility coefficient is dimensionless and the rumen fill effect (days) of the fiber was estimated using the model of Vieira et al. (2008b). The RF was calculated by discarding the multiplication by the fiber intake of the animal as follows:

$$\mathrm{RF} = \mathrm{A}\left\{v\sum_{i=1}^{N}\left[\lambda^{i-1}/(\lambda+c)^{i}\right] + \lambda^{N}/\left[(\lambda+c)^{N}(k+c)\right]\right\} + \mathrm{U}[N/\lambda + 1/k]$$

The turnover, or mean retention time in the rumen-reticulum (days), was estimated based on biological interpretations, in which both ascending and descending phases of the marker excretion profile in the feces play roles in the retention of particles in the ruminoreticulum (Vieira et al., 2008b). The MRT was estimated according to the equation listed by Matis et al. (1989). Parameters N/λ, 1/k, and τ are outputs of the analysis from passage rate kinetics and can be expressed in hours or days. The MRT and TMRT are calculated as follows: MRT (h or days) = $N/\lambda + 1/k$, and TMRT (h or days) = MRT + $\tau$ (Matis et al., 1989).

The parameters of the model fitted to the degradation profiles and particle passage kinetics were estimated with the NLIN procedure of SAS (Statistical Analysis System, version 9.0). Both algorithms of Newton and Marquardt were used. Initially, the form or algorithm preferred was that of Newton, due to its good performance in terms of convergence, but whenever correlations between the estimates of the parameters became high, the algorithm of Marquardt was preferred (Vieira et al., 2012).

The selection of the best version of the order of time dependency (N) and consequently of the best model to explain the passage rate was evaluated by the calculation of Akaike's information criterion ($AICc_h$) (Akaike, 1974; Burnham and Anderson, 2004). The $AICc_h$ was calculated by the sum of the squared errors ($SSE_h$), number of estimated parameters ($\Theta_h$) including the residual variance, and the size of the sample ($n_h$) for all the different versions of $N, \forall h=1,2,\ldots,6$. The differences between the $AICc_h$ values ($\Delta_h$), the likelihood probability ($w_h$), and the evidence ratio ($ER_h$) of the h-th versions of the models used were computed by using the equations described by Vieira et al. (2012).

The estimates of the parameters of the passage rate profiles were adjusted according to robust regression procedures (Beaton and Tukey, 1974), to reduce the effect of discrepant observations (outliers) and eliminate subjectivity during the elimination of outliers.

Statistical analyses of the estimates of the parameters of rumen digestion and transit kinetics were performed. Because periods were pooled by animal, the statistical model adopted was the following equation:

$$Y_{ij} = \mu + \alpha_i + a_j + e_{ij}$$

The fixed effects are the mean ($\mu$) and the treatments ($\alpha$). The random effects are attributed to the animal (a) and to the error (e). The statistical model was fitted by using the PROC MIXED procedure of SAS (Statistical Analysis System, version 9.0). The Tukey test was adopted to detect differences among least squares means and the probability level adopted was 0.05 unless otherwise stated. Different variance and covariance structures were tested to fit the linear mixed statistical model. The likelihood of these models was verified with Akaike's criterion and the likelihood criteria derived from it, i.e., $\Delta_h$, $w_h$, and $ER_h$. The following structures were tested: variance components, compound symmetry with constant correlation and homogeneous variance, compound symmetry with constant correlation and heterogeneous variance, heterogeneous variances allocated in the main diagonal with null covariances, and unrestricted structure of variances and covariances.

## Results

The chemical analysis of the corn hybrids (Table 1) yielded NDF values that were not within the confidence interval for a corn silage with a DM content of 320-380 g $kg^{-1}$, i.e., 446.8-453.2 g of NDF $kg^{-1}$ of DM (NRC 2001), except for DKB390, which is within the confidence interval reported by the NRC. The crude protein and lignin values reported for the hybrids were below and above the confidence intervals computed from NRC (2001) for CP and lignin, i.e., 87.3-88.7 and 24.2-27.8 g $kg^{-1}$ DM, respectively.

The variance components was the structure that yielded the most likely results among the variance-covariance structures tested by $AICc_h$.

The commercial Hybrid DKB390 presented the best performance in relation to the variables tested (An, Un, and TD) when compared with hybrid BX1280. The discrete lag time (L) was not significant for some profiles, i.e., the confidence interval estimate for L did not exclude the value zero. With regard to parameters $k_d$ and RF, hybrid SHS4070 had worse estimates than hybrid DKB390 ($P<0.05$). Hybrid 2B433 shared common estimates with other hybrids and was considered intermediate for all parameter estimates, except for parameter TD; hybrid DKB390 was more digestible ($P<0.05$) than the others (Table 2).

No statistical differences were observed with regard to parameters MRT, $N/\lambda$, $1/k$, $\tau$, and TMRT ($P<0.05$); this means that the different hybrids analyzed were equivalent

Table 1 - Chemical composition of the silages of different corn hybrids

| Parameters, g/kg | Hybrids | | | |
|---|---|---|---|---|
| | BX1280 | SHS4070 | 2B433 | DKB390 |
| Dry matter | 286.9 | 284.8 | 327.0 | 286.1 |
| Crude protein | 61.6 | 57.6 | 59.0 | 59.7 |
| Ash | 43.0 | 32.4 | 32.0 | 36.5 |
| Ether extract | 41.1 | 35.5 | 45.6 | 41.5 |
| Neutral detergent fiber | 486.3 | 488.6 | 415.0 | 449.3 |
| Lignin | 44.0 | 44.0 | 34.6 | 34.9 |
| Total digestible nutrients | 697.5 | 699.7 | 751.0 | 719.0 |

Table 2 - Estimates of the parameters of the transit of particles through the gastrointestinal tract of the steers fed the different corn silages

| Parameters | Hybrids | | | |
|---|---|---|---|---|
| | BX1280 | SHS4070 | 2B433 | DKB390 |
| An | 594.0b±97.1 | 640.1ab±97.1 | 683.1ab±97.1 | 790.9a±97.1 |
| Un | 406.0a±97.1 | 359.9ab±97.1 | 316.9ab±97.1 | 209.1b±97.1 |
| kd | 0.0529ab±0.0259 | 0.0305b±0.0259 | 0.0620ab±0.259 | 0.0903a±0.0259 |
| TD | 0.3919b±0.0859 | 0.3386b±0.0859 | 0.4284b±0.0859 | 0.6206a±0.0859 |
| RF | 1.1ab±0.2 | 1.2a±0.2 | 0.9ab±0.2 | 0.7b±0.2 |
| L | 3.5±0.5 | 2.8±0.5 | 2.6±0.5 | 2.7±0.5 |
| MRT | 45.1±6.3 | 45.1±6.3 | 43.8±6.3 | 49.3±6.3 |
| N/λ | 26.2±9.7 | 30.3±9.7 | 25.3±9.7 | 28.2±9.7 |
| 1/k | 18.9±5.4 | 14.9±5.4 | 18.5±5.4 | 21±5.4 |
| τ | 10.8±8.2 | 11.7±8.2 | 14.2±8.2 | 15.3±8.2 |
| TMRT | 55.9±9.4 | 56.8±9.4 | 58±9.4 | 64.6±9.4 |

Means in the same row followed by the same letters do not differ (P<0.05, adjusted Tukey's test).
An - potentially digestible fraction of the standardized fiber (g kg$^{-1}$); Un - indigestible fraction of the standardized fiber (g kg$^{-1}$); kd - digestion rate (h$^{-1}$); TD - true digestibility (dmls); RF - rumen fill (d); L - discrete lag (h); MRT - mean retention time in the rumen-reticulum (d); N/λ - retention time of particles in the raft pool (h); 1/k - retention time of particles in the escapable pool (h); τ - transit time representing the time for an escaped particle transit from the reticulo-omasal orifice to feces (h); TMRT - total retention time in the GIT (d).

regarding the mean time they remain inside the rumen and within the rest of the GIT (Table 2). Hybrid DKB390 showed a lower rumen fill (RF) than the other hybrids, with a time of approximately 0.73 days.

## Discussion

The chemical composition indicates that silages resulting from hybrids showed a poorer quality of fiber and lower protein content.

The fitting algorithm zeroed the parameter variance estimate of the L, which is a clear indicative of the absence of a lag time. Perhaps the inclusion of additional time points at earlier degradation times may help the detection of time lags in future studies, because time lags are essential for determining the rumen fill effect (Vieira et al., 2008a,b; 2012).

The calculation of Akaike's criterion allows for the comparison of multiple hypotheses and the model that best predicts reality was chosen based on the data (Burnham and Anderson, 2004).

The analyses of hybrid DKB390 exhibited higher potentially digestible fraction of the standardized fiber (An) and consequently lower indigestible fraction of the standardized fiber (Un). The estimates for the confidence interval of An and Un fractions of hybrid DKB390 were similar to hybrid AG7575, i.e., 719 and 281 g kg$^{-1}$, respectively, as reported by Pires et al. (2010), and hybrid DAS8420, i.e., 716.2 and 303 g kg$^{-1}$, respectively, as reported by Gimenes et al. (2006). The higher the value of indigestible fiber the lower is the expected nutritive value of forages of the POACEAE family (Smith et al., 1971; Mertens, 1987; Vieira et al., 2012).

These results are confirmed when we observe the other variables analyzed, e.g. digestion rate, which was significantly higher in hybrid DKB390, as well as the true digestibility, which differed statistically from the other hybrids (P<0.05), and its degradation rate was almost twice as fast as the hybrids found in the literature; e.g., AG7575 and DAS8420 (Pires et al., 2010; Gimenes et al., 2006), which reflected mostly the true digestibility of corn hybrid DKB390.

The fiber digestibility is a very important criterion for cultivar selection; it should be used in conjunction with other measures. The increase in fiber digestibility increases both the digestible and metabolizable energies available from the feed (Jardim et al., 2013), and the enhanced fiber digestibility in corn silage increases milk yield in lactating cows, particularly for early lactating, high producing dairy cows. This increase in milk yield has real economic impacts for dairy production systems, and shall influence how dairy farmers choose corn hybrids for silage making (Knowlton, 1999).

The RF of hybrid DKB390 demonstrates the superior quality of its fiber in relation to the other studied corn hybrids; according to the current theories of intake regulation (Mertens, 1987), this factor can also increase the dry matter intake, and thus, nutrient intake. Moreover, it is increasingly important to develop corn hybrids of higher rumen DM digestibility (Ivan et al., 2005). A NDF of higher digestibility is recommended, aiming at increased DM intake, and consequent increase in nutrient intake (Mertens, 1987).

## Conclusions

Corn hybrid DKB 390 has a higher fiber degradability in the rumen than hybrids BX1280, SHS4070, and 2B433. Therefore, it is possible to infer that hybrid DKB 390 potentially generates corn silage that presents a faster clearance rate of the consumed fibrous matter from the rumen. This property may alleviate the digesta load and is likely to be coupled with a higher potential feed intake and performance by animals.

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