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ANIMAL PRODUCTION

Physically effective fiber changes nutrient levels of total mixed ration and fecal parameters in beef feedlots

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ABSTRACT: *This study evaluated the effects of the physically effective fiber (peNDF) content on nutrient composition of the total mixed ration (TMR), orts and fecal parameters in 15 commercial beef feedlots. The particle size distribution of TMR was measured adopting Penn State Particle Size Separator (PSPS). Samples were evaluated for dry matter (DM), ash, ether extract (EE), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and starch content. Fecal samples were also evaluated for pH and score. The feedlots were categorized into peNDF<20% and peNDF ≥ 20%. Data were analyzed by a model that included fixed effects of treatment and covariates (sex and genetic groups). Levels of DM, CP, EE and starch were lower in TMR with peNDF ≥ 20% (P<0.05). Fecal dry matter was higher and morning fecal pH was lower for TMR with peNDF<20% (P<0.05). Physically effective fiber changed nutrient levels in TMR, orts, fecal pH and DM. So, using PSPS and fecal parameters are practical and indirect tools for measuring fecal starch and assessing the effectiveness of the diet supplied to ruminants.*

Key words: *particle size distribution, starch, fiber effectiveness.*

A fibra fisicamente efetiva altera os nutrientes da dieta e parâmetros fecais em confinamentos de bovinos de corte

RESUMO: *O objetivo desse estudo foi avaliar o teor de fibra fisicamente efetiva (FDNfe) de dietas totais e seus efeitos nos nutrientes da dieta, das sobras e nos parâmetros fecais de bovinos de corte em 15 confinamentos comerciais. As amostras da dieta foram separadas utilizando a peneira Penn State Particle Size Separator (PSPS). As amostras foram analisadas quanto aos teores de matéria seca (MS), matéria mineral (MM), extrato etéreo (EE), proteína bruta (PB), fibra em detergente neutro (FDN), fibra em detergente ácido (FDA) e amido. Nas amostras de fezes também foram avaliadas o escore e pH fecal. Os confinamentos foram categorizados em dois tratamentos: FDNfe<20% e FDNfe≥20%. Os dados foram analisados por um modelo que incluiu os efeitos de grupo e covariável (sexo e grupo genético). Os teores de MS, PB, EE e amido foram menores nas dietas com FDNfe≥20%(P<0,05). A MS fecal foi maior e pH fecal matinal foi menor nas dietas com FDNfe<20% (P<0,05). Sendo assim a efetividade da fibra alterou os nutrientes da dieta total e sobras, bem como as variáveis pH e MS fecal. Com isso, o uso de PSPS e parâmetros fecais são ferramentas práticas e indiretas para medir o amido fecal e a efetividade da dieta em confinamentos de bovinos comerciais.*

Palavras-chave: *tamanho de partícula, amido, fibra efetiva.*

INTRODUCTION

The challenge of today's beef cattle feedlot systems using high-concentrate diets is to balance the levels of readily fermentable carbohydrates with physically effective fiber (peNDF), which is important to reduce the risk of disorders and maintain a healthy rumen environment. The peNDF is the fraction of the fiber that stimulates chewing activity and maintains a healthy rumen environment by combining the chemical and physical properties of feeds (MERTENS, 1997). Consequently, increasing fiber effectiveness can help increase rumen pH by stimulating the production of saliva and chewing activity. Moreover, fiber creates a more suitable rumen environment for the degradation of nonstructural carbohydrates and maintains an adequate balance in short-chain fatty acid production (ALLEN, 1997; STONE, 2004).

The Penn State Particle Separator (PSPS) is the main method for measuring particle size distribution of total mixed ration (TMR) and silages. The original model of PSPS consisted of two screens with circular holes sized 19 mm (Upper) and 8 mm

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(Middle), and a bottom pan (Bottom) (LAMMERS et al., 1996). The PSPS now include an additional third screen with 4-mm (Lower). Feed particles reported on this sieve can be easily broken down with minimal rumination or by rapid microbial action, thereat will have a small, yet significant, impact on ruminal health (HEINRICHS, 2014).

Using fecal starch concentration as an indicator of total tract digestibility in cattle (ZINN et al., 2007) and as an indirect measure of dietary peNDF is an outstanding technique given the increasing use of starch in current diets and its high cost for feedlot operations. Therefore, total tract starch degradation can be accurately assessed based on fecal starch due to their high correlation (ZINN et al., 2007). In practical terms, fecal pH and score are also indirectly related to ruminal starch digestibility because the higher the starch concentration in the feces, the lower the pH and fecal score (GENTRY et al., 2016; MELENDEZ & ROY, 2016). Despite the importance of measuring the effects of digestibility on fecal parameters, experimental data correlating peNDF and fecal parameters in cattle, whether beef or dairy cattle, are still scarce.

PSPS and fecal indicators can be possible tools to evaluate digestive health, starch and effectiveness of feeding that could be used in commercial beef feedlots. So, this study evaluated the particle size and the physically effective fiber content of total diets and their effects on nutrient composition of TMR, orts and fecal parameters in commercial beef feedlots.

MATERIALS AND METHODS

Fifteen commercial beef feedlots were visited just once and information on the genetic group (Nellore, Angus x Nellore, and animals crossed with other Zebu breeds or from dairy crosses) animal category (female, male, castrated or intact) was collected from 2 to 4 random pens in each feedlot.

The samples of TMR and orts from each farm were taken, directly from the mixer and bank, just before the TMR distribution at the beginning. Samples were collected in the middle of the feedlot period, after adaptation to TMR. The TMR consisted of different sources of roughage (grass, sugar cane, corn and sorghum silages) and concentrate (differently processed corn kernels, soybean hulls, sorghum and citrus pulp).

Samples of TMR were immediately sieved on the farm to determine their particle size by using the new PSPS (19, 8 and 4 mm) (HEINRICHS, 2014). Samples of TMR were collected in three points of the bunk feed (beginning, middle and end) and the average particle size of each farm was calculated. The peNDF concentration was calculated using two methodologies: 1) peNDF - percentage of particle fraction retained (greater than 4 mm) multiplying by the percentage of NDF in TMR sample (HEINRICHS, 2014); 2) peNDFa- percentage of particle fraction retained (greater than 4 mm) multiplying by the percentage of NDF from each screen after sieving [Adapted of HEINRICHS (2014)]. Theses method assumptions, in which fiber fraction when sieved contain varying levels of NDF and that partially explains the many contradictions in the literature about effects of peNDF on animal performance.

The farms were divided into two groups: peNDF<20% (8 feedlots) and peNDF ≥ 20% (7 feedlots). The groups were divided based on a threshold value of 20% peNDF content because farmers of the study region use high levels of roughage in feedlot TMR and, furthermore, following recommendations to optimize forage degradation (NRC, 2016; FOX & TEDESCHI,2002).

After collecting TMR and art samples, fecal disorders were evaluated, both in the morning and afternoon, from three animals at each bunk feed where was collected TMR and orts. Fecal score (FS) was determined by visual assessment according to IRELAND-PERRY & STALLINGS (1993). Fecal samples were saved straight from the floor after FS assessment, taking a sample from the top of the pile to avoid soil contamination. Fecal pH was determined immediately after sampling mixing 100 ml of distilled water and 15 g of fresh feces in a glass flask using a portable thermometer and a pH meter (AK 103®) (TURGEON JR et al., 1983). The feces of the three animals were pooled to make one composite fecal sample, then placed in plastic bags, identified and taken to the laboratory to assess the chemical composition.

Samples of TMR, orts and feces were dried in a forced ventilation oven at 55 °C ± 5 °C for 72 h and processed in a Willey mill to pass a 1-mm sieve. The samples were analyzed for dry matter content at 105 °C, ash, ether extract (EE) and crude protein (CP) according to the procedures of the Association of Official Analytical Chemists (AOAC, 1990); neutral detergent fiber and acid detergent fiber (ADF) were analyzed according to the methodology of VAN SOEST et al. (1991). Starch was determined using the method described by HALL (2008).

Statistical analysis

The animal was used as the experimental unit for pH and score fecal analysis, whereas the farm was used for the chemical composition of TMR orts and feces. The model included feedlot as a random effect, sex as a fixed effect and genetic group as covariates: $y_{ijk}=\mu+G_i+S_j+T_k+e_{ijk}$; where: μ = overall mean; G_i = effect of the genetic group; S_j = effect of sex; T_k = effect of the group; e_{ijk} = residual error, assumed to be independently and identically distributed in a normal distribution with mean zero and variance σ^2. Data were analyzed using PROC MIXED (SAS, 2004) and mean separation was calculated running the LSMEANS test at $P\leq0.05$. The effects were considered significant at 5%.

Concordance Correlation Coefficient (CCC) according LAWRENCE & LIN (1989), was performed using the PROC IML (SAS, 2004) for evaluating agreement between the methods of peNDF estimation. Lin's CCC is the concordance between a new test or measurement (Y) and a gold standard test or measurement (X). This statistic quantifies the agreement between these two measures of the same variable. The CCC was considered low for values <0.40, moderate >0.40, and <0.75, excellent > 0.75 and confidence interval (CI) of 95% were used.

RESULTS AND DISCUSSION

Diets with peNDF ≥ 20% had a higher number of particles retained on the 19, 8, and 4-mm sieves ($P<0.05$), higher number of particles larger than 4 mm ($P<0.0001$) and a lower amount of particles smaller than 4 mm ($P<0.0001$), compared to diets with peNDF<20% (Table 1). Despite the difference, the upper fraction (19 mm) of TMR for both treatments were within the guidelines reported by HEINRICHS (2014). Nevertheless, the middle and lower screen fraction (8 and 4 mm) of TMR for both treatments were lowest and highest the guidelines reported by HEINRICHS (2014), which suggested a mean incidence of middle fraction ranging from 30 to 50% and 10 to 20%, respectively. In particular, the highest percentage of particles collected in the bottom pan (< 4 mm) for diets with peNDF<20% probably

Table 1 - Analysis of total mixed rations (TMR) and according to the estimated peNDF[1].

Item	peNDF<20%	peNDF≥20%	SEM	P-value
---Particle Separator of TMR, %---				
19 mm	2.53	5.04	1.136	0.0336
8 mm	12.61	21.98	2.595	0.0008
4 mm	25.54	34.86	1.893	<0.0001
Particles > 4mm, %	39.49	62.18	2.528	<0.0001
Particles < 4mm, %	60.50	37.81	2.528	<0.0001
peNDF, %	16.28	26.07	1.015	<0.0001
peNDFa[2], %	18.35	28.00	1.275	<0.0001
---Nutrient composition of TMR, %---				
Dry matter	54.08	43.43	1.924	<0.0001
Crude protein	14.86	11.61	0.552	<0.0001
Ether extract	6.62	4.45	0.539	0.0002
Neutral detergent fiber	40.01	43.15	1.791	0.0868
Acid detergent fiber	21.88	23.59	1.159	0.1489
Starch	33.32	27.20	2.265	0.0100
---Nutrient composition of orts, %---				
Dry matter	69.88	53.55	2.445	<0.0001
Crude protein	14.13	11.58	0.427	<0.0001
Ether extract	5.99	5.83	0.487	0.7483
Neutral detergent fiber	26.87	38.07	2.849	0.0003
Acid detergent fiber	12.80	20.55	1.858	0.0002
Starch	50.39	33.03	2.938	<0.0001

[1]Physically effective fiber: percentage of particle fraction retained (greater than 4 mm) multiplying by the percentage of NDF in TMR sample (HEINRICHS, 2014).
[2]Physically effective fiber: percentage of particle fraction retained (greater than 4 mm) multiplying by the percentage of NDF from each screen after sieving [Adapted from HEINRICHS (2014)].

occurred because many processed grains, byproducts, and pelleted grains have accumulated below.

The concentration of peNDF and peNDFa was higher for diets with peNDF ≥ 20% ($P<0.0001$). This suggests that the physical effectiveness of TMR was not similar despite the same inclusion of NDF. Therefore, the particle size of the diet is the most influential factor affecting physical effectiveness, and NDF is not a useful parameter to evaluate the fiber in feedlot diets (MERTENS, 1997).

The CCC analyses between the two methodologies were considered moderate [CCC = 0.75; CI 95% (0,44-0,90)]. Despite the moderate correlation between the two methods and the greater accuracy of the method by peNDFa, using peNDF in ration balancing, even using a single NDF value, is less expensive and more practical for daily field operations (ZEBELI et al., 2012; HEINRICHS, 2014). However, farmers using the peNDF in TMR containing whole grains and pelleted supplements should be careful because these ingredients can be retained on the 4-mm sieve. Thus, they will increase the peNDF content, even though they are rapidly fermented ingredients (HEINRICHS, 2014). NATIONAL ACADEMIES OF SCIENCES and MEDICINE (2016) suggests to overcome this limitation calculating the peNDF of forages in TMR, ignoring the peNDF of processed ingredients.

The levels of DM, CP, EE and starch were higher for diets with peNDF<20% ($P<0.05$); although, the NDF and ADF contents were similar between treatments ($P>0.05$) (Table 1). The higher concentration of nutrients in TMR with low fiber effectiveness can be attributed to the low inclusion of roughage in the diet. Feeding high levels of roughage to finishing cattle dilutes dietary energy and may affect both the availability of metabolizable energy and nutrient availability depending on the roughage quality. In this study, similar contents of NDF and ADF can be attributed to the substitution of roughage with a co-product or high-fiber roughage in farms feeding TMR with peNDF<20%. In some farms that fed a high concentrate: roughage ratio, co-products such as soybean hulls and roughage with high NDF content, such as grass and sugarcane silages, were also used.

The levels of DM, CP and starch in orts were higher for diets with peNDF<20% ($P<0.05$), as well as their levels in TMR (Table 1). Although, there were no differences between treatments in NDF and ADF concentrations in TMR, their levels in the orts were higher for diets with peNDF ≥ 20% ($P<0.001$) (Table 1). This demonstrates that animals fed with TMR with higher levels of physically effective fiber were selective and possibly refused the long particles.

Fecal score was not influenced by the fiber effectiveness of diets ($P>0.05$), as well as the fecal output of NDF, ADF, CP, EE and starch ($P>0.05$) (Table 2). Fecal score variables were probably similar because TMR samples and fecal score were taken on the same day. There is a correlation between particle size and fecal score two days after the intake of TMR (MELENDEZ & ROY, 2016). The authors observed that almost 20% of the variability in fecal score was explained by the distribution of the particle size of TMR fed 48 h earlier. Furthermore, they reported that the fecal score increased with increasing percentage of particles retained on the 19-mm sieve, over 15% of the total DM. In this study, the maximum percentage of particles retained on the 19-mm sieve was 5%, which shows that the low levels of long particles in the TMR were not enough to modify the fecal consistency. Alternatively, the study by SILVA et al. (2012) on the use of whole corn grain-based diets and two types of roughage in feedlot showed that animals fed TMR with the lowest level of peNDF had a lower fecal score (2.92).

Despite no difference in fecal starch excretion had been observed, fecal morning pH was lower for animals fed diets with peNDF ≤ 20% ($P<0.05$) (Table 2). It is probably because the difference in TMR starch content. However, microbial fermentation can occur in the large intestine, producing lactic acid and short-chain fatty acids, consequently decreasing fecal pH (CHANNON et al., 2004; SILVA et al., 2012)

However, fecal DM was lower for animals fed diets with peNDF ≥ 20% ($P<0.05$) (Table 2). Fecal DM was lower, probably because TMR with high fiber effectiveness may have increased the chewing activity and had a positive effect on ruminal function, which resulted in high DM digestibility in the total tract. Thereby, fecal parameters can be practical and indirect tool for measuring fecal starch in commercial beef feedlots.

These results are in agreement with some reports (BEAUCHEMIN & YANG, 2005) but in discord to other researchers (HALES et al., 2014; WEISS et al., 2017). BEAUCHEMIN and YANG (2005) observed that the clear total tract digestibility of DM increased linearly with increasing peNDF in diets for lactating cows, whereas WEISS et al. (2017) observed that decreasing DM digestibility can be effect of increasing forage in feedlot diets. These discrepancies between studies are probably related to differences in the concentration of dietary

Table 2 - Fecal score, pH and chemical composition (dry matter basis) according to the estimated peNDF[1].

Item	peNDF<20%	peNDF≥20%	SEM	P-value
----------Fecal score----------				
Morning	2.63	2.85	0.187	0.2270
Afternoon	2.92	3.03	0.178	0.5213
----------Fecal pH----------				
Morning	6.06	6.31	0.128	0.0500
Afternoon	6.14	6.26	0.103	0.2713
---------- Fecal Chemical composition, %----------				
Dry matter	24.08	20.99	0.728	0.0001
Crude protein	13.68	13.28	0.475	0.4094
Ether extract	4.27	3.73	0.509	0.2938
Neutral detergent fiber	51.45	53.01	1.708	0.3657
Acid detergent fiber	29.63	30.41	1.270	0.5412
Starch	15.44	14.20	1.967	0.5349

[1]Physically effective fiber: percentage of particle fraction retained (greater than 4 mm) multiplying by the percentage of NDF in TMR sample (HEINRICHS, 2014).

peNDF, that is, peNDF levels ranging from 7 to 18.4% (BEAUCHEMIN & YANG, 2005; WEISS et al., 2017) vs. 16%-26% in this study. The particle size affects DM digestibility, depending on the concentration of peNDF in the diet (BEAUCHEMIN & YANG, 2005).

CONCLUSION

Diets with more than 20% peNDF have a larger particle size, lower nutrient content and lower concentration of dietary starch; and consequently, less fecal DM. So, physically effective fiber changed nutrient levels in TMR, orts, fecal pH and dry matter. Using PSPS and fecal parameters can be practical and indirect tools for measuring fecal starch and effectiveness of feeding in commercial beef feedlots.

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DECLARATION OF CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest. The financial support had no influence or role in the experimental design, data analysis, writing of the paper, or the decision to publish this paper.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

BIOETHICS AND BIOSSECURITY COMMITTEE APPROVAL

All experimental procedures were approved by the Ethics Committee on Animal Use (CEUA) of the Federal University of Minas Gerais under the protocol number 195/2017.

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