

Total Dietary and Soluble Fiber Content of Selected Ruminant Feeds

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The advent of more mechanistic models to describe the amount of energy and protein available in the diet of growing and lactating cattle has created a greater need to more accurately describe the chemical fractions of ruminant feeds. Models such as the Cornell Net Carbohydrate and Protein System (1,2,3), Nutrient Requirements of Beef Cattle 1996 (4) and Baldwin (5) (MOLLY) require more precise descriptions of both carbohydrate and protein fractions within feeds to more accurately predict nutrient supply. The model of Baldwin currently partitions carbohydrates into soluble and insoluble fractions (5). The predictions include volatile fatty acids, lactate, rumen pH and amino acids of microbial origin.

Current fractionation schemes rely on nitrogen, neutral detergent fiber, fat and ash analyses to then determine the non-structural carbohydrate content of feeds by difference. Therefore non-structural carbohydrates have traditionally been lumped into a fraction with little characterization beyond that of the by-difference calculation: $NSC = 100 - (CP + (NDF + NDF \text{ protein}) + \text{fat} + \text{ash})$. Recently, commercial laboratories have begun to provide sugar and starch analyses that may improve our understanding of the chemical fractions, however accurate starch analysis remains a challenge. Another approach might be to isolate the total dietary fiber of the feed, which includes both the soluble and insoluble fiber. The total fiber content is a more uniform fraction when considering fermentation end-product formation (acetate, propionate and butyrate) and there are routine validated assays available for such determinations.

The feed fraction NSC includes organic acids, sugars, starch and the non-starch polysaccharides (NSP) such as fructans, galactans, arabans, β -glucans and pectin. Fructans are the primary storage carbohydrate in temperate grasses. β -glucan is primarily identified with oats and barley. Pectin is found in legumes and in byproduct feeds such as beet and citrus pulp. Galactans are found in soybeans and other legumes. In most feeds, the proportion of NSP is inversely proportional to the amount of starch present. For example the amount of NSP contained in corn grain is relatively low compared to the starch content. Alfalfa contains a reasonable amount of pectin (12 to 18%) and very little starch (2 to 3%). However the digestion rate of the NSP fraction can be equal to that of starch. Digestion rates for soluble fiber fractions range from 20 to 40% per hour (6). Hall (6) reported that neutral detergent soluble fiber was completely fermented in vitro by 9 to 14 hr which was similar to previously reported values (7).

Dietary fiber was formally defined as the part of the plant material in the human diet, which is resistant to digestion, by secretions of the mammalian digestive tract (8). This was modified to include all the polysaccharides and lignin that are undigested by endogenous secretions of the mammalian digestive tract (9). At this time there is lively debate about the exact definition of the term dietary fiber. The debate concerns whether fiber is simply a chemical entity to be measured in the laboratory or if the definition should include some of the non-chemical aspects such as fiber behavior in the gut, (e.g. laxative, lipid binding and removal). The definition currently being debated by the American Association of Cereal Chemists is "dietary fiber consists of the remnants of edible plants cells, polysaccharides, lignin and associated substances resistant to (hydrolysis) digestion by the alimentary enzymes of humans." (10)

METHODOLOGY

The current methodology for determining the insoluble fiber content of animal feeds is the neutral detergent fiber (NDF) procedure of Van Soest et al. (11). The residue remaining after an NDF assay is comprised of the hemi-cellulose, cellulose, lignin and associated nitrogen compounds and minerals. After correcting for nitrogen and ash, the remaining residue is the true insoluble fiber fraction. The use of a heat stable α -amylase to aid in removal of starch is common and the use of sodium sulfite is optional. Sodium sulfite is used to reduce disulfide bonds in keratinized proteins and reduce the protein content of the ND residual and has been criticized for lowering the lignin content of the NDF when conducting sequential analyses. For the purposes of this study we elected to use both amylase and sodium sulfite in the NDF procedure.

The Jeraci et al. (12) method for determining total dietary fiber (TDF) was originally chosen because it does not use heat to gelatinize starch which should reduce the potential loss of pectin material through beta-elimination. We used a modified procedure that simplified sample handling. The Jeraci method used 8 molar urea and amylase to reduce the starch matrix for 4 hours. Protease was then added to reduce proteins and the mixture was dialyzed against running tap water at 50° C for 12 hours. The residue was suspended in 80% ethanol for several hours to allow the fiber to precipitate and then filtered and rinsed. A correction was made for ash and nitrogen. The difference between the corrected TDF and NDF represented the soluble fiber content of the feed. All samples were run in quadruplicate for each procedure and repeated twice to determine the variation in the procedures for these types of feeds and to investigate the variation due to operator. We determined this to be a critical step due to the potential variation due to the dialysis step in the Jeraci method.

An additional TDF method by Li et al. (13,14) was examined. An assumption was made that the need to dialyze samples in the Jeraci method might hinder an adoption of the method due to the time and labor involved in that step. Therefore the method developed by Li was evaluated to determine if similar values for TDF and soluble fiber (SF) could be derived. The method of Li et al. utilized autoclaving in an acetate buffer to gelatinize the starch and then relied on amyloglucosidase to reduce the starch to glucose. The autoclaved sample was then precipitated with 80% ethanol as with the Jeraci method. There is a greater need to correct for nitrogen and ash in the method of Li because all of the nitrogen is retained in the sample.

RESULTS

Total dietary fiber, NDF and SF values for selected feeds are found in Table 1 and 2. Values in Table 1 represent feeds that were analyzed by the two TDF procedures for comparison. Table 2 represents values solely determined by the Jeraci et al. method and ranges observed in specific feeds for TDF and SF.

There are few published values for many of these feeds making it difficult to compare to other procedures. We assumed the Jeraci method would provide the most consistent values since there was no heating above 50°C reducing the potential loss due to β -elimination. In general, the use of a TDF assay allows for the recovery the NSP in the insoluble material after precipitation in 80% ethanol. Neutral detergent fiber analysis recovers the insoluble fiber portion of the plant material and solublizes the NSP. After correcting the residual material from each assay for nitrogen and ash, the difference is the soluble fiber component or the NSP fraction. Therefore it is important to ensure all of the starch is removed during the respective assays. Resistant starch might have increased the NSP pool size using the current approach if it is not removed

in the TDF assay and the converse was true if resistant starch was not removed in the NDF assay. The ability to remove resistant starch using the 8-M urea and amylase was evaluated in the development of the Jeraci TDF assay and did not appear to be a confounding factor in the feeds analyzed.

Overall the correlation was high ($r = 0.99$) between the two TDF procedures for the feeds evaluated. The relationship among the feeds analyzed is described in Figure 1. There was a small but non-significant bias in the slope of the relationship between the values. Of the samples evaluated, the greatest differences existed in almond hulls, beet pulp, citrus pulp and two samples of gluten feed. The lower TDF values observed in the assay of Li et al. for beet and citrus pulp and almond hulls were most likely due to the autoclaving step of the procedure and loss of araban side chains from the α 1-4 polygalacturonic structure. Similar degradation reactions might have reduced the material recovered in the analysis of the gluten feed. The TDF values for grasses might be low due to the use of 80% versus 90% ethanol. Fructosans are more readily soluble in 80% ethanol and would thus be lost upon filtration. Use of 90% ethanol to evaluate the insoluble residue indicated a 2 to 3 unit increase in the TDF values for grasses.

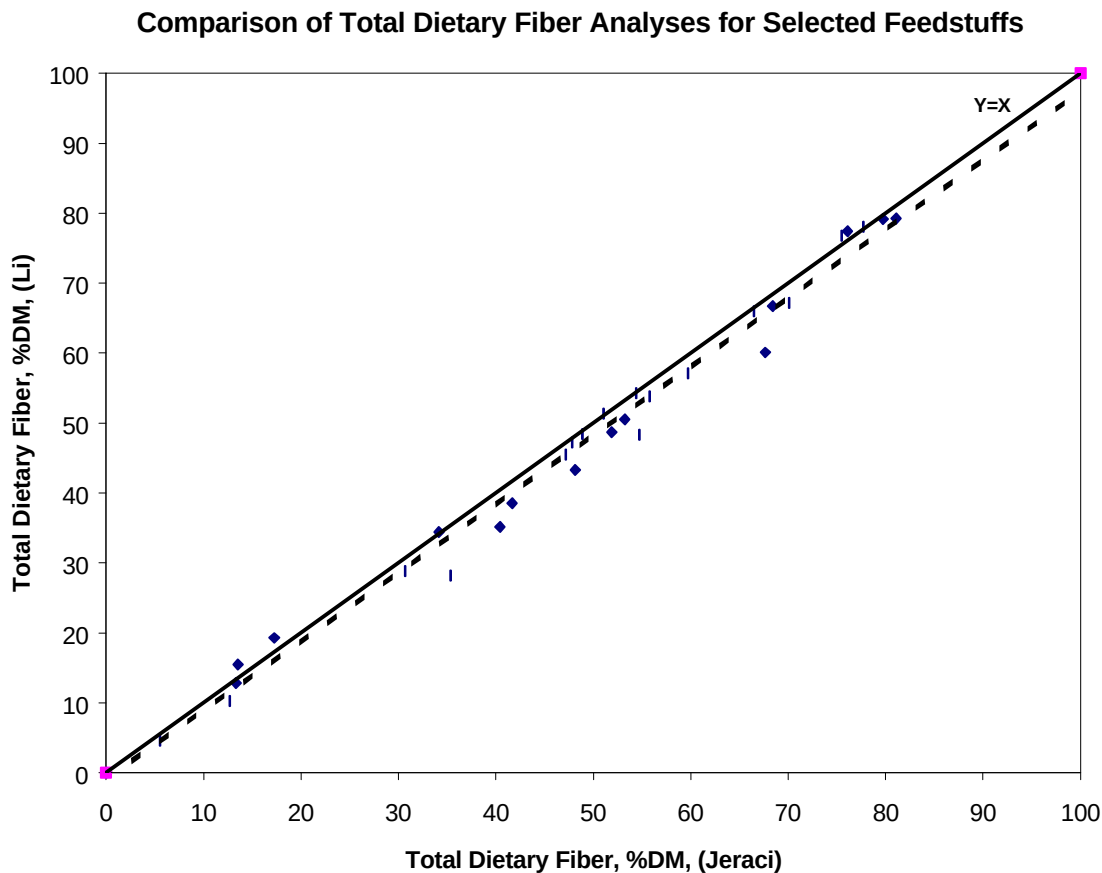


Figure 1. Comparison of total dietary fiber values on selected ruminant feeds derived by two total dietary fiber methods, Jeraci et al. (12) and Li (13,14). The solid line is unity and the hatched line is the regression. The regression equation is $Y = 0.99 X - 1.18$, $R^2 = 0.99$.

Subtracting the TDF from the NDF values resulted in an estimation of the SF component of the feeds. Although the values were derived by difference, the assays were based on our best understanding of the chemical composition of the feeds and the relative accuracy of the procedures. However, due to the nature of the by-difference calculation, the greatest error accumulates in the residual. The SF values determined are found in Table 1 and 2. The correlation between the SF levels determined by the

TDF assays was $r = 0.96$, however there was a significant bias in the relationship based on the lower recoveries of ethanol insoluble residue in the high pectin feeds (beet pulp,

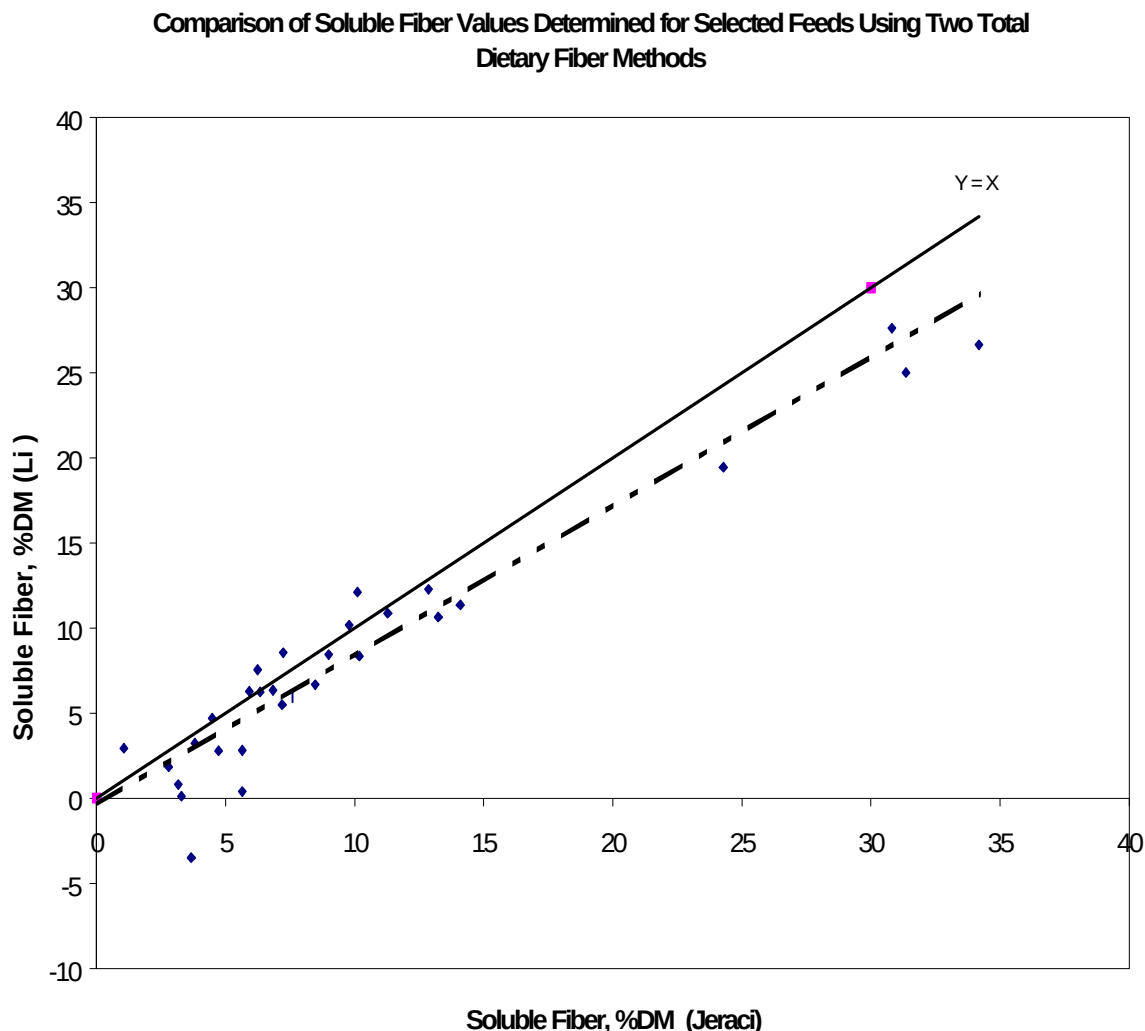


Figure 2. Comparison of soluble fiber content of selected feeds calculated by difference using neutral detergent fiber and two total dietary fiber assays, Jeraci et al. (12) and Li et al.(13,14). The regression equation is $Y = -0.189 + 0.844 X$. $R^2 = 0.92$

citrus pulp, almond hulls) in the procedure of Li. In addition, the gluten feed was greater in NDF content than in TDF content when analyzed by the Li method. This suggested some degradation in the autoclaving step, which led to a lower recovery of ethanol insoluble residue. An additional confounding factor that would favor the TDF assay of Li would be if the gluten feed contained retrograded starch. Although the Jeraci method was validated against retrograded cornstarch, there might have been resistant starch in the gluten feed that could not be gelatinized by the 8-M urea and amylase and may have also been in the residual ND material. The autoclaving step in the Li procedure may have removed the resistant starch, which resulted in the lower value.

The soluble fiber values generated in this comparison are similar to values published elsewhere for various feeds. (15,16). There are few values in the literature for SF in feeds. Soluble fiber values derived by the TDF-NDF method compare favorably with values published by Hall (15) for beet (34.2% vs. 34.4%) and citrus pulp (30.8% vs. 28.5%).

Table 1. Total dietary fiber, neutral detergent fiber and soluble fiber values for selected feeds obtained by two total dietary fiber methods, Jeraci et al. (12) and Li et al.(13,14).

Feed	TDF, (% DM) (Jeraci)	TDF, % DM (Li)	NDF, % DM	Soluble Fiber, %DM, (Jeraci)	Soluble Fiber, %DM, (Li)
Alfalfa ('94)	48.85	48.44	37.57	11.28	10.87
Alfalfa- Centurian	59.67	57.08	46.43	13.24	10.65
Alfalfa Saranac	53.23	50.50	39.14	14.09	11.36
Almond Hulls	48.15	43.15	23.87	24.28	19.43
Barley grain	30.67	28.85	20.50	10.17	8.35
Beet pulp ('94)	67.64	60.10	33.46	34.18	26.64
Citrus pulp (orange)	51.90	48.68	21.07	30.82	27.61
Citrus pulp pellets	54.70	48.36	23.35	31.36	25.01
Corn silage ('91)	47.16	45.49	39.57	7.59	5.92
Corn silage ('92)	54.38	54.27	48.04	6.34	6.23
Corn silage ('93)	55.75	53.80	51.02	4.73	2.78
Corn stover ('91)	75.45	76.76	69.21	6.24	7.55
Cottonseed ('91)	47.80	47.24	38.80	9.00	8.44
Cottonseed ('94)	51.00	51.36	45.09	5.91	6.28
Distillers grains ('91)	34.15	34.37	29.67	4.48	4.70
Gluten feed	35.34	28.16	31.67	3.67	-3.51
Gluten feed ('91)	40.42	35.15	34.77	5.65	0.38
Gluten meal	5.49	4.55	2.71	2.78	1.84
Haylage (MMG) ('92)	77.68	78.05	67.89	9.79	10.17
Hominy	13.55	15.42	12.49	1.06	2.93
Oat Bran	13.36	12.78	9.54	3.82	3.24
Oat Straw	81.08	79.28	72.62	8.46	6.66
Orchard grass	76.08	77.41	68.86	7.23	8.55
Soybean hulls	79.74	79.16	66.89	10.11	12.10
Soybean meal ('91)	17.27	19.26	7.16	12.85	12.27
Timothy (1)	68.41	66.71	64.40	5.64	2.81
Timothy (2)	70.05	67.21	61.22	7.19	5.49
Timothy ('93)	66.45	65.96	59.62	6.84	6.34
Wheat bran ('91)	41.68	38.50	38.38	3.30	0.11
Wheat grain ('91)	12.64	10.28	9.48	3.16	0.80

Table 2. Total Dietary Fiber, Neutral Detergent Fiber and Soluble Fiber Content of feeds determined by the Jeraci et al. (12) dietary fiber method.

Feed	n	Total dietary fiber (% DM)	Neutral detergent fiber (% DM)	Soluble fiber (% DM)	Min.	Max
Alfalfa leaves	10	34.6 ± 1.5 ^a	17.3 ± 0.8	19.2 ± 0.9	16.0	18.9
Alfalfa stems	10	60.3 ± 6.9	47.1 ± 7.2	13.1 ± 0.8	11.7	14.5
Alfalfa silage	3	51.7 ± 5.4	38.5 ± 5.6	13.2 ± 1.4	13	13.5
Corn silage	4	50.2 ± 4.6	42.9 ± 3.7	7.3 ± 1.7	6.0	9.2
Grass silage	5	63.4 ± 13.0	55.9 ± 14.8	7.5 ± 2	5.4	10.2
Brewers grains	1	59.1	52.6	6.5	-	-
Canola meal	1	34.6	21.1	13.5	-	-
Corn grain	1	11.4	10.3	1.1	-	-
Oats	1	28.9	22.3	6.6	-	-
Ryegrass	1	41.8	31.7	10.2	-	-
Wheat midds	1	45.7	40.5	5.2	-	-

^amean ± standard deviation

The soluble fiber content of soyhulls using the TDF methodology is 24% lower than the values reported by Hall (15). This overestimation might be due to interference from other components (i.e. mineral salts) precipitating in the ethanol with the soluble fiber. This could potentially lead to an overestimation of the soluble fiber fraction if some of the mineral is lost during ashing.

To determine if using sodium sulfite in the NDF procedure was affecting the calculation of SF, 5 samples of alfalfa hay were used in the NDF procedure with and without sodium sulfite. The SF values for the alfalfa were 14.3 ± 1.9 (mean ± SD) without sodium sulfite in the NDF and 15.4 ± 2.3 with the sodium sulfite in the assay, a 7% difference. The difference is within the variation of the assay and would not affect ration formulation. Therefore the use of sodium sulfite for this approach to SF determination appears acceptable provided some consideration is given to the sample of interest.

Evaluation of the ranges in TDF and SF contents of the forages in Table 2 suggests that once a data base is compiled of the SF content of feeds, library values might be a reasonable approach for ration formulation. The relationship between the TDF and NDF appears to be uniform within feeds and across maturity, however much more analyses are required to confirm that observation.

CONCLUSION

The present work appears to provide a basis for determining the TDF and SF content of ruminant feeds. This is a different approach and provides a more uniform fraction when considering fermentation end-product production. The procedure of Jeraci et al. (12) is simple, repeatable and provides reasonable values. The values derived by the Li (13) method provided similar TDF and SF values to the Jeraci method with a few exceptions. Further work is necessary to determine what is being lost during autoclaving in the Li method. The method published by Hall (15) requires comparison to the TDF methods but might be a simple alternative.

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