Fibre analysis and fibre digestibility in pet foods – a comparison of total dietary fibre, neutral and acid detergent fibre and crude fibre*

L. D. de-Oliveira¹, F. S. Takakura¹, E. Kienzle², M. A. Brunetto¹, E. Teshima¹, G. T. Pereira¹, R. S. Vasconcellos¹ and A. C. Carciofi¹

1 College of Agrarian and Veterinarian Sciences, Sao Paulo State University, Jaboticabal, SP, Brazil, and
2 Chair of Animal Nutrition, Ludwig Maximilians University, Munich, Germany

Introduction

Commercial dry pet foods for healthy animals contain significant amounts of carbohydrates. Most of these carbohydrates are digestible (starch), and the non-digestible part is generally classified as dietary fibre. Dietary fibre is physiologically important as it affects gastrointestinal transit time (Burrows et al., 1982; Fahey et al., 1990a), faecal volume (Lewis et al., 1994; Wichert et al., 2002), gastric emptying (Russell and Bass, 1985, Armbrust and Milliken, 2003), short-chain fatty acid production in the

Keywords
carbohydrates, cat, dog, methods, nitrogen-free extract, fibre

Correspondence
Dr A. C. Carciofi, Departamento de Clínica e Cirurgia Veterinária. Universidade Estadual Paulista Júlio de Mesquita Filho (UNESP), Via de Acesso Prof. Paulo Donato Castellane, s/n, Postal code 14884-900, Jaboticabal, SP, Brazil. Tel: +55 16 3209 2626; Fax: +55 16 3203 1226; E-mail: aulus.carciofi@gmail.com

*Supported by Fundação de Amparo à Pesquisa do Estado de São Paulo, São Paulo, Brazil (FAPESP; process 03/07496-0 and 01/08639-3), and Mogiana Alimentos (Guabi), Campinas, Brazil.

Received: 19 June 2011; accepted: 20 June 2011

Summary

Six dry dog foods and six dry cat foods with different carbohydrate sources were investigated in digestion trials. Food and faecal samples were analysed for CF, TDF and starch. In dogs, also neutral detergent fibre (aNDFom) and acid detergent fibre (ADFom) were analysed. N-free extract (NfE) was calculated for CF, and similarly for all other fibre analyses. Linear regressions were calculated between fibre intake and faecal fibre excretion. True digestibility was calculated from the regression coefficients [true digestibility in % = (1 – regression coefficient)*100], with the intercept of the equation representing excretion of material of non-food origin. Crude fibre analyses gave the lowest values, and TDF the highest, while ADFom and aNDFom were in between. Total dietary fibre, aNDFom and ADFom in food were positively correlated. Crude fibre in food did not correlate with any other method. The NfE analogue for TDF was closest to the starch content. Methods of fibre analyses in faeces did not agree very well with each other. Crude fibre had the lowest apparent digestibility, followed by ADFom, TDF and aNDFom. For all fibre analyses, there was a significant correlation between fibre intake and faecal fibre excretion. True digestibility was close to zero for CF, with a high uniformity in both species. In dogs, true digestibility of aNDFom was 53%, of ADFom 26% and of TDF 37%; in cats, true digestibility of TDF was 31%. Except for CF, the intercept of the regression equations suggest that faecal excretion of some material of non-food origin is analysed as fibre. A combination of TDF and CF analyses might give good information on the content of total (TDF), unfermentable (CF) and partially fermentable fibre (TDF-CF) in pet foods.

Introduction

Commercial dry pet foods for healthy animals contain significant amounts of carbohydrates. Most of these carbohydrates are digestible (starch), and the non-digestible part is generally classified as dietary fibre. Dietary fibre is physiologically important as it affects gastrointestinal transit time (Burrows et al., 1982; Fahey et al., 1990a), faecal volume (Lewis et al., 1994; Wichert et al., 2002), gastric emptying (Russell and Bass, 1985, Armbrust and Milliken, 2003), short-chain fatty acid production in the
Methods of fibre analysis in pet food

L. D. de-Oliveira et al.

Methods of fibre analyses using detergents [acid detergent fibre (ADF) and neutral detergent fibre (NDF)] were developed by Goering and Van Soest (1970) for analysing forages. The detergent approach provides a more satisfactory alternative to better typify the carbohydrates in the plant cell wall (Van Soest et al., 1991). Such analyses have been conducted with grains and co-products (Dong and Rasco, 1987; Campbell et al., 1997; Miron et al., 2001). For pet food, the results are not entirely satisfactory; ADF can recover partially pectins and may solubilise part of the lignin, recovering a variable amount of plant cell wall. Both ADF and NDF fractions can include different amounts of silica (when expressed inclusive of residual ash) and nitrogen. Also, the large amount of gelatinized starch in kibble diets can interfere in the NDF analysis, which requires a pretreatment with amylase. Some non-starch polysaccharides, such as pectin, may also appear in fractions like acid detergent lignin, leading to analytical errors (Schrag, 1999; Kienzle et al., 2001a; Hindrichsen et al., 2006). Even if there are no errors, it is not clear whether or not these non-starch polysaccharides are analysed using this method, and if so, in which fraction they are supposed to appear.

Other alternatives for fibre are the methods of Prosky et al. (1985) determining total dietary fibre (TDF), and in a second step insoluble and soluble fibre (Prosky et al., 1992), and the method of Englyst and Cummings (1988) analysing total fibre, and also in a second step insoluble and soluble fibre. Both are rather expensive and time-consuming.

There are usually good reasons for the choice of a particular method by different laboratories; ranging from legislation for labelling of pet foods to cost-effectiveness. To make an informed decision which method to choose for a certain research purpose or to compare results from different methods, it is helpful to have systematic comparisons between methods for prepared dog and cat foods. The present study, therefore, evaluates data from previous experiments on starch digestibility (de-Oliveira et al., 2008; Carciofi et al., 2008). In the current study, CF, NDF and ADF (as aNDFom and AD$m$Fom) and TDF were analysed in food and faeces, which made it possible to compare these methods of fibre analyses under the conditions given by the previous experiments. Because the results suggested material from non-food origin in the faeces, and hair was visible in faeces, a few hair samples of dogs and cats were also analysed for fibre.

Materials and methods

Study design

Six dry dog foods and six dry cat foods were investigated. Every dog and cat food, respectively, contained one of the following carbohydrate sources: maize, broken rice, sorghum, peas, lentils or cassava flour. Food composition is reported in Table 1, and details of food formulation are published elsewhere (Carciofi et al., 2008; de-Oliveira et al., 2008). Foods were formulated in accordance with the nutrient guide for dogs and cats of American Association of Food Control Officials (AAFCO, 2003) and balanced to meet maintenance requirements.

Thirty-six beagle dogs (mean ± SE: 12.5 ± 1.2 kg BW; 3.0 ± 1.5 years old) and 36 mixed-breed cats (4.3 ± 0.8 kg BW; 4.9 ± 0.7 years old) were used in digestibility tests. The animals were kept in the Laboratory of Research on Nutrition and Nutritional Diseases of Dogs and Cats at Sao Paulo State University (Jaboticabal, Brazil). During the digestibility experiments, the animals were individually housed in stainless steel metabolic cages. Water was available ad libitum throughout the duration of the experiment. The Ethics Committee for Animal Well Being at the College of Agrarian and Veterinarian Sciences, Sao Paulo State University, approved all experimental procedures.

The digestibility trial was carried out through the marker method for dogs (Carciofi et al., 2007) and the quantitative collection of faeces for cats,
according to AAFCO (2003) guidelines. Five days test-diet adaptation phase preceded a 5-days (for dogs) or a 10-days (for cats) collection of faeces. The quantity of diet provided was calculated using standard equations determining energy requirements for cat or dog maintenance (ME, kJ = 293·kg BW for cats; ME, kJ = 552·BW\(^{0.75}\) for dogs), in accordance with NRC (1985, 1986). Each day, food was weighed and divided into two equal portions, fed at 9 am and 5 pm in stainless steel bowls. Bowls were removed before the next meal, and any remaining food was weighed and recorded. On the first day of faecal collection, all faeces were removed from the cages before 8 am. Faecal output was collected from this point on for the next 5 (dogs) or 10 days (cats) at each mealtime. Samples were pooled for every individual animal and frozen at \(-15^\circ\text{C}\) until laboratory analysis. Details are described earlier (Carciofi et al., 2008; de-Oliveira et al., 2008).

**Analytical methods**

Dog foods (\(n = 6\)), cat foods (\(n = 6\)), dog’s faeces (\(n = 36\)) and cat’s faeces (\(n = 36\)) were analysed for crude protein (method 954.01), acid-hydrolysed fat (method 954.02), ash (method 942.05), CF and dry matter (DM; method 934.01) according to the Association of Official Analytical Chemists (AOAC guidelines (1995), TDF as described by Prosky et al. (1992) and total amount of starch according to the guidelines set out by Miller (1959) and Hendrix (1993). Acid detergent fibre and NDF (Goering and Van Soest, 1970) were also determined in dog food and faeces, both analyses were performed non-sequentially. Acid detergent fibre was expressed exclusive of residual ash (ADFom; Udén et al., 2005), and NDF analysis included a pretreatment of the sample with heat-stable alpha amylase and was expressed exclusive of residual ash (aNDFom; Udén et al., 2005). All analyses were carried out in duplicate. Analyses were repeated if more than 5% of difference was observed between duplicates. Faeces contained visible amount of hair. To evaluate the possible effect of swallowed hair in faecal fibre analysis, four hair samples of dogs were analysed for aNDFom, ADFom and CF and three hair samples of cats for CF.

**Calculations and statistical analyses**

Nitrogen-free extract (NIE) was calculated using the fibre amounts recorded in each analytical method (CF, aNDFom, ADFom and TDF) according to the following equation for NIE and analogue:

\[
\text{NIE}_{\text{CF}} = 100 - (\text{moisture} + \text{crude protein} + \text{ash} + \text{fat} + \text{CF})
\]

\[
\text{NIE}_{\text{ADF}} = 100 - (\text{moisture} + \text{crude protein} + \text{ash} + \text{fat} + \text{ADFom})
\]
Methods of fibre analysis in pet food

L. D. de-Oliveira et al.

\[
\text{NfEADF} = 100 - (\text{moisture} + \text{crude protein} + \text{ash} + \text{fat} + \text{ADFom})
\]

\[
\text{NfTDf} = 100 - (\text{moisture} + \text{crude protein} + \text{ash} + \text{fat} + \text{TDF})
\]

Apparent digestibility (%) was calculated as follows: collection method: (intake of nutrient from food – excretion of nutrient by faeces)/intake of nutrient from food × 100; marker method: 100 – (indicator in food/indicator in faeces × nutrient in faeces/nutrient in food × 100). A modified form of the test for digestive uniformity by Lucas et al. (1961) was used. In the original Lucas test, a linear regression between the nutrient intake (independent variable) and the apparently digested nutrient intake (dependent variable; Lucas et al., 1961) is calculated. If these variables correlate, this points to a digestive uniformity of the component. The slope of the regression line multiplied by 100 represents true digestibility in %, and the negative intercept the endogenous losses. For nutrients with a low digestibility such as fibre, this test was modified: A linear regression between nutrient intake (independent variable) and faecal nutrient excretion (dependent variable) was calculated. In this modified form of the test, 1 minus the slope of the regression line multiplied by 100 represents true digestibility, and the intercept the endogenous losses, or in case of fibre material from non-food origin. Linear regressions were calculated between fibre intake (independent variable) and fibre excretion (dependent variable) as described earlier, with both parameters expressed on a body weight basis. Literature data were compared with current data. Therefore, literature data were calculated using the mean nutrient intake values, mean nutrient digestibility values and mean body weight, as published for each study, and data were plotted together with data from this study. When necessary, data were analysed using the general linear model functions of SAS (Version 8; SAS Institute, Cary, NC, USA). The model sums of squares were separated into treatment (diet) and animal effects. Where significant differences were detected in ANOVA’s F-test, multiple comparisons of means were made using Tukey’s test. A p-value of ≤0.05 was considered as significant. All data were found to comply with the assumptions of ANOVA models.

Results

The concentration of fibre of the experimental diets varied according to the composition of the carbohydrate source (Table 1). Crude fibre analyses gave the lowest values for fibre, and TDF the highest. ADFom and aNDFom were in between. Variation between diets was lowest in CF and highest in TDF. Total dietary fibre, aNDFom and ADom content in dog foods correlated significantly with each other (r ≥ 0.88; p = 0.02). Crude fibre content did not correlate with any other method in dog food (r ≤ 0.1). In cat food, there was a trend to higher TDF values in foods with higher CF values (r = 0.79), which was, however, not significant (p = 0.06). In dog foods, NfETDF was closest to the starch content followed by NfETDF. There was a considerable gap between NfECF, NfAADF and starch content. In contrast to dog food, however, in cat food, there was a considerable gap between starch and NfETDF.

Faecal CF content was lower than aNDFom, ADom and TDF amounts (Table 2). There was a negative correlation between CF and TDF in % dry matter in dog faeces (r = –0.66; p < 0.01) and a positive correlation in cat faeces (r = 0.63; p < 0.01). No other correlation between the fibre fractions was significant. Nitrogen-free extract calculated with crude fibre (NfECF) content was higher than the NfETDF and starch content in dog and cat faeces. In dogs, NfECF was also higher compared with NfAADF and NfNDF. Faecal starch content was considerably lower than all NfE analogues.

Dry matter, fibre, NIE, starch intake and faecal excretion per kilogram BW are presented in Table 3. There were only small differences in dry matter intake. Differences in fibre, starch and NIE intake reflected differences in diet composition. Faecal starch excretion was higher in cats than in dogs. Faecal excretion of NfECF was higher than NfAADF, NfNDF and NfTDf. Crude fibre excretion was usually lower than the excretion of other fibres. Faecal TDF excretion tended to be highest.

Crude fibre had in general the lowest apparent digestibility, followed by ADFom (Table 4). Total dietary fibre and aNDFom apparent digestibilities were higher. Even though the apparent digestibilities of different fibre fractions differed considerably, they were positively correlated in dogs (r > 0.84). By contrast, there was no relationship between apparent digestibility of CF and TDF in cats (p > 0.05). The NIE digestibility was lowest for NfECF and highest for NfETDF in most diets, and the latter was closest to starch digestibility. Cats presented lower NIE digestibility than dogs, although these data were not compared statistically.

For all fibre analyses, there was a significant correlation between fibre intake and faecal fibre excretion (r ≥ 0.87; p < 0.01; Table 5). The relationship...
between fibre intake and faecal fibre excretion, considering the own data plotted together with literature data, is presented on Figs 1–5. 'True digestibility' (i.e. the regression slope) was close to zero for CF, with a high uniformity in both species. There was very little material of non-food origin appearing as CF in dogs or cats. The regression slope was higher for ADFom, TDF and aNDFom in dogs, respectively, 26.5%, 37.7% and 53.1%. For all these three fibre analyses, material of non-food origin appeared in the faeces (i.e. the intercept), ranging from 0.12 g/kg BW/day for ADFom to 0.33 g/kg BW/day for aNDFom. True TDF digestibility, and also the amount of material from non-food origin in faeces, was very similar in dogs and cats.

Four hair samples of dogs had a mean ± SE content of 91.1 ± 1.4% aNDFom, 87.6 ± 1.41% ADFom and 2.5 ± 0.4% CF. Crude fibre in feline hair amounted to 8.6 ± 1.5%.

Discussion

Fibre analyses of food agreed well with previous data on dog food (Opitz et al., 1998; Kienzle et al., 2001b). The absence of a correlation between CF and the other methods of fibre analyses suggests that CF quantifies a variable part of the real fibre content. There was a good agreement between NfETDF and starch content in dog food. Small differences are possibly because of small amounts of sugars, including oligosaccharides, and soluble fibre, which are not analysed by starch determinations or by TDF. In cat foods, NfETDF overestimates starch in all foods (6.8% units on average). Similar ingredients in all foods were analysed by starch, whereas NfETDF was analysed by starch determinations or by TDF in cat food. 

For CF, ADF, NDF and TDF, means in a column not sharing an uppercase superscript differ (p < 0.05). For NfE and starch results, means in columns not sharing a lowercase superscript differ (p < 0.05). CF, crude fibre; ADF, acid detergent fibre; NDF, neutral detergent fibre; TDF, total dietary fibre; NfECF, nitrogen-free extract calculated with crude fibre; NfEADF, nitrogen-free extract calculated with acid detergent fibre; NfENDF, nitrogen-free extract calculated with neutral detergent fibre; NfETDF, nitrogen-free extract calculated with total dietary fibre. nd, not determined.

### Table 2

<table>
<thead>
<tr>
<th>Item</th>
<th>Cassava flour-based diet</th>
<th>Maize-based diet</th>
<th>Sorghum-based diet</th>
<th>Broken rice-based diet</th>
<th>Lentil-based diet</th>
<th>Pea-based diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faeces, % (DM basis)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CF</td>
<td>13.3 ± 0.1</td>
<td>10.8 ± 0.4</td>
<td>14.8 ± 0.3</td>
<td>10.1 ± 0.1</td>
<td>13.0 ± 0.1</td>
<td>9.4 ± 0.1</td>
</tr>
<tr>
<td>ADF</td>
<td>24.9 ± 0.9</td>
<td>nd</td>
<td>21.3 ± 0.8</td>
<td>nd</td>
<td>28.9 ± 0.4</td>
<td>nd</td>
</tr>
<tr>
<td>NDF</td>
<td>33.4 ± 0.4</td>
<td>nd</td>
<td>27.8 ± 0.7</td>
<td>nd</td>
<td>42.2 ± 0.5</td>
<td>32.9 ± 0.8</td>
</tr>
<tr>
<td>TDF</td>
<td>22.1 ± 0.2</td>
<td>30.7 ± 2.2</td>
<td>38.0 ± 0.6</td>
<td>34.4 ± 1.2</td>
<td>19.9 ± 0.2</td>
<td>27.0 ± 3.1</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>NfECF</td>
<td>23.1 ± 1.3</td>
<td>27.5 ± 0.6</td>
<td>27.1 ± 1.0</td>
<td>32.9 ± 0.6</td>
<td>32.6 ± 0.6</td>
<td>40.1 ± 1.5</td>
</tr>
<tr>
<td>NfEADF</td>
<td>11.5 ± 1.2</td>
<td>nd</td>
<td>20.7 ± 1.5</td>
<td>nd</td>
<td>16.7 ± 0.7</td>
<td>32.6 ± 1.5</td>
</tr>
<tr>
<td>NfENDF</td>
<td>3.0 ± 1.0</td>
<td>14.2 ± 1.4</td>
<td>4.0 ± 0.9</td>
<td>8.6 ± 1.4</td>
<td>3.3 ± 0.1</td>
<td>16.5 ± 1.8</td>
</tr>
<tr>
<td>NfETDF</td>
<td>14.3 ± 1.2</td>
<td>7.6 ± 1.9</td>
<td>1.6 ± 0.1</td>
<td>3.9 ± 0.6</td>
<td>1.7 ± 0.1</td>
<td>9.7 ± 1.0</td>
</tr>
<tr>
<td>Starch</td>
<td>1.6 ± 0.1</td>
<td>3.7 ± 0.5</td>
<td>1.6 ± 0.1</td>
<td>3.9 ± 0.6</td>
<td>1.5 ± 0.1</td>
<td>3.2 ± 1.0</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Starch</td>
<td>1.6 ± 0.1</td>
<td>3.7 ± 0.5</td>
<td>1.6 ± 0.1</td>
<td>3.9 ± 0.6</td>
<td>1.5 ± 0.1</td>
<td>3.2 ± 1.0</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
difference for some diets, indicating that possibly some fibre compounds could be turned more soluble because of microbial degradation, releasing small oligosaccharides or sugars, which will not precipitate because of microbial degradation, releasing small oligosaccharides or sugars, which will not precipitate and possibly some small amounts of lignin, although it is well known that only approximately 50–90% of cellulose is analysed as CF (Cummings, 1976; Kienzle et al., 2001a). Apparent digestibility of CF was very low in the present study as well as in other studies (Fahey et al., 1990a; Kienzle et al., 2001b; Prola et al., 2006; Kempe and Saastamoimen, 2007) and showed a high coefficient of variation. Given the rather close correlation between intake and faecal excretion, the high coefficient of variation is unlikely to be due to differences in bacterial fermentation of CF. It is more likely to be caused by the stronger mathematical effects of experimental and analytical errors on the calculation of apparent digestibility in case of low digestibility.

For ADFom, there was also a close correlation between intake and faecal excretion. As shown in Fig. 2, data from Fahey et al. (1990b) behave similarly, whereas data from Fahey et al. (1990a) are
<table>
<thead>
<tr>
<th>Item</th>
<th>Cassava flour-based diet</th>
<th>Maize-based diet</th>
<th>Sorghum-based diet</th>
<th>Broken rice-based diet</th>
<th>Lentil-based diet</th>
<th>Pea-based diet</th>
</tr>
</thead>
</table>

Methods of fibre analysis in pet food production © 2011 Blackwell Verlag GmbH

Table 4. Apparent total tract digestibilities of foods based on different carbohydrates sources by dogs and cats (mean ± SEM, n = 6 animals per diet). For CF, ADF, NDF and TDF, means in a column not sharing an uppercase superscript differ (p < 0.05). For NFE and starch results, means in a column not sharing a lowercase superscript differ (p < 0.05). CF, crude fibre; ADF, acid detergent fibre; NDF, neutral detergent fibre; TDF, total dietary fibre; NFE_{CF}, nitrogen-free extract calculated with crude fibre; NFE_{ADF}, nitrogen-free extract calculated with acid detergent fibre; NFE_{NDF}, nitrogen-free extract calculated with neutral detergent fibre; NFE_{TDF}, nitrogen-free extract calculated with total dietary fibre. nd, not determined.
Table 5 Correlations between fibre intake and faecal fibre excretion for various methods of fibre analysis in dogs and cats

<table>
<thead>
<tr>
<th>Specie</th>
<th>X-axis (fibre intake, g/kg BW/day)</th>
<th>Y-axis (faecal fibre excretion, g/kg BW/day)</th>
<th>Equation</th>
<th>95% confidence interval</th>
<th>(R^2)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dogs</td>
<td>CF</td>
<td>CF</td>
<td>(Y = 0.9494X + 0.0068)</td>
<td>0.470–0.882</td>
<td>0.89</td>
<td>0.0001</td>
</tr>
<tr>
<td>Dogs</td>
<td>TDF</td>
<td>TDF</td>
<td>(Y = 0.6239X + 0.1888)</td>
<td>0.974–1.208</td>
<td>0.93</td>
<td>0.0001</td>
</tr>
<tr>
<td>Dogs</td>
<td>NDF</td>
<td>NDF</td>
<td>(Y = 0.4686X + 0.3334)</td>
<td>0.913–1.124</td>
<td>0.86</td>
<td>0.0001</td>
</tr>
<tr>
<td>Dogs</td>
<td>ADF</td>
<td>ADF</td>
<td>(Y = 0.7349X + 0.1213)</td>
<td>0.840–1.042</td>
<td>0.94</td>
<td>0.0001</td>
</tr>
<tr>
<td>Cats</td>
<td>CF</td>
<td>CF</td>
<td>(Y = 0.9982X - 0.0630)</td>
<td>0.377–0.512</td>
<td>0.84</td>
<td>0.0001</td>
</tr>
<tr>
<td>Cats</td>
<td>TDF</td>
<td>TDF</td>
<td>(Y = 0.6917X + 0.1793)</td>
<td>1.124–1.452</td>
<td>0.76</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

CF, crude fibre; ADF, acid detergent fibre; NDF, neutral detergent fibre; TDF, total dietary fibre.

Fig. 1 Relationship between crude fibre (CF) intake \(x\); g/kg BW/day and faecal CF excretion \(y\); g/kg BW/day in dogs (own data plotted together with literature data) and regression line according to the equation: \(Y = 0.9494X + 0.0068\), \(r^2 = 0.89\) as presented in Table 5.

Fig. 2 Relationship between acid detergent fibre (ADF) intake \(x\); g/kg BW/day and fecal ADF excretion \(y\); g/kg BW/day in dogs (own data plotted together with literature data) and regression line according to the equation: \(Y = 0.7349X + 0.1213\), \(r^2 = 0.94\) as presented in Table 5.

Fig. 3 Relationship between neutral detergent fibre (NDF) intake \(x\); g/kg BW/day and fecal NDF excretion \(y\); g/kg BW/day in dogs (own data plotted together with literature data) and regression line according to the equation: \(Y = 0.4686X + 0.3334\), \(r^2 = 0.86\) as presented in Table 5.

Fig. 4 Relationship between total dietary fibre (TDF) intake \(x\); g/kg BW/day and fecal TDF excretion \(y\); g/kg BW/day in dogs (own data plotted together with literature data) and regression line according to the equation: \(Y = 0.6239X + 0.1888\), \(r^2 = 0.93\) as presented in Table 5.
outliers from the regression line. In the latter study, sugar beet pulp was used as a fibre source. A major component of sugar beet pulp fibre is pectin, which is highly soluble and fermentable, and according to Schrag (1999), pectin may appear as ADF in some cases. In our own study, apparent ADFom digestibility varied between 8.5% and 20.5% and the mean true digestibility was 26.5%. As, according to Sunvold et al. (1994a,b), cellulose is not fermented in the canine and feline intestine, ADFom must also measure fermentable non-starch polysaccharides like pectin. The intercept of the equation describing intake and digested ADFom (0.1213 g/kg BW/day; p < 0.01) also indicated that this method quantified some other compounds as fibre, possibly including bacterial cell wall or swallowed hair.

aNDFom intake and faecal aNDFom excretion (0.3334 g/kg BW/day) indicated that in faeces, this method quantified some other compounds as fibre, possibly including bacterial polysaccharides or swallowed hair. However, theoretically microbial cell wall is soluble in neutral detergent.

The results of TDF intake and faecal TDF excretion from the present investigation are in agreement with data from previous studies in dogs or cats (Fahey et al., 1990a,b, 1992; Sunvold et al., 1995a,b; Muir et al., 1996; Cole et al., 1999; Murray et al., 1999; Burkhalter et al., 2001; Middelbos et al., 2007), as shown in Figs 4 and 5. An average true digestibility of TDF of approximately 38% for dogs and 31% for cats was estimated (Table 5), but a large variation was found between diets and experiments, characterizing a fraction of low digestive uniformity. Total dietary fibre quantifies most non-starch polysaccharides as suggested by the good agreement between NfETDF and starch. Both fermentable and non-fermentable compounds are recovered (Prosky et al., 1992), making it difficult to predict the apparent digestibility of TDF, which varies according to the percentages of fermentable and non-fermentable fibre in the food. It is remarkable that the estimated ‘true digestibility’ of TDF is lower than that for aNDFom in dogs. Possible explanations could include interference of the high starch and high fat content of the extruded diets on the food aNDFom analysis and the quantification of the carbohydrate–lipid and carbohydrate–amino acid compounds formed during the extrusion process, which could lead to an overestimation of aNDFom intake; solubilisation of some fibre compounds in the gut during the passage of the digesta leading to an underestimation of faecal fibre (aNDFom) excretion.

In relation to fibre analyses, the most important differences between the faeces and food compositions are the compounds of microbial origin. For instance, gram-positive bacterial cell wall is a dense peptidoglycan layer, composed of N-acetyl-muramic acid, N-acetyl-glucosamine and teichoic acid (Hölting, 2004), which might be included in the TDF measurement. There are, however, no scientific studies confirming or excluding whether such bacterial cell wall compounds are measured as TDF. As carnivores do not have very strong hindgut fermentation, such compounds are not likely to contribute with large amounts to faecal TDF excretion. Such a contribution would lead to underestimation of TDF apparent digestibility and is supported by the intercept found in the regression between TDF intake and faecal TDF excretion (for dogs $b = 0.1888$ g/kg BW/day; for cats $b = 0.1793$ g/kg BW/day).
questions may be resolved when TDF is differenti-
ated into soluble and insoluble fibre.

The fibre analysis of hair samples revealed that the
detergent extraction methods did not solubilise hair,
which is quantified as fibre. In the TDF method, the
insoluble residue retained during the filtration pro-
cess is submitted to nitrogen quantification, and
the residual protein subtracted during the calculation
process, so it is very unlikely that the hair may
contaminate the analysis. Thus, speculating that
some hair can be quantified as fibre in ADom and
aNDom analysis, it justifies the higher intercept val-
ues of the regression between fibre intake and faecal
fibre excretion (Figs 2 and 3) of these compounds as
compared to those for TDF, and probably the inter-
cept observed in the regression between TDF intake
and faecal excretion may correspond, at least in some part, to faecal bacterial cell wall excretion. 

Analysing CF, starch and possibly sugar appears to
give relevant information for many purposes. Crude
fibre represents an indigestible fibre fraction, and
NIE^CF minus starch and sugar would represent other
non-starch polysaccharides, which may or may not
be fermentable. On the other hand, from all fibre
analyses, TDF is most appropriate to analyse directly
the non-starch polysaccharide fraction of the food
and faeces. Combining TDF for analysing all non-
starch polysaccharides and CF for analysing unfer-
metable fibre may be a cost-efficient solution for
fibre analysis in pet food. In fact, if the difference
between TDF and CF is calculated and the intake of
this fibre fraction is plotted against its faecal excre-
tion using data from dogs and cats, there was a close correlation \( r = 0.91 \). The regression coefficient
amounted to 0.83 \( (Y = 0.590X + 0.136; CI = 0.736–0.935) \). Therefore, the true digestibility (i.e. ferment-
ability) of this fibre fraction amounts to 41%. Thus,
CF analyses and TDF analyses appear to differentiate
between totally unfermentable fibre (CF) and partly
fermentable fibre compounds (TDF – CF) in pet
food, but this approach does not resolve the problem
of predicting the fermentability of the more ferment-
able fibre fraction (TDF-CF). At present, this can
only be measured by in vivo trial or by the in vitro
fermentation technique using dog or cat faecal inoc-
ula to evaluate organic matter disappearance and gas
production (Bosch et al., 2008).

Acknowledgements

Grant supported by CAPES Foundation (Brazilian
Federal Agency for Support and Evaluation of Grad-
uate Education) from 1st July to 30th October,
2007, in Ludwig Maximilians University Munich,
Germany (process BEX 0336/07-6).

References

AAFPCO, 2003: Official Publication. Association of Amer-
ican Feed Control Officials, Atlanta, Georgia.
AOAC, 1995: Official Methods of Analysis, 15th edn. Associ-
ation of Official Analytical Chemists, Arlington, VA.
Armbrust, L. J.; Milliken, G. A., 2003: Gastric emptying
in cats using foods varying in fiber content and kibble
Bednar, G. E.; Platil, A. R.; Murray, S. M.; Grieshop, C.
M.; Merchen, N. R.; Fahey, G. C. Jr. 2000: Starch and
fiber fractions in selected food and feed ingredients
affect their small intestinal digestibility and ferment-
ability and their large bowel fermentability in vitro
Bosch, G.; Pellikaan, W. F.; Rutten, P. G. P.; van der
Poel, A. F. B.; Verstegen, M. W. A., 2008: Comparative
in vitro fermentation activity in the canine distal gastro-
intestinal tract and fermentation kinetics of fibre
Burkhalter, T. M.; Merchen, N. R.; Bauer, L. L.; Murray,
S. M.; Platil, A. R.; Brent, J. L. Jr; Fabey, G. C. Jr,
2001: The ratio of insoluble to soluble fiber
components in soybean hulls affects ileal and
total-tract nutrient digestibilities and faecal characteris-
Burrows, C. F.; Kronfeld, D. S.; Banta, C. A.; Merritt, A.
M., 1982: Effects of fiber on digestibility and transit
Campbell, J. M.; Flickinger, E. A.; Fahey, G. C. Jr, 1997:
A comparative study of dietary fiber methodologies
using pulsed electrochemical detection of monosaccha-
ride constituents. Seminary in Food Analysis 2, 43–53.
Carciofi, A. C.; Vasconcellos, R. S.; de-Oliveira, L. D.;
Brunetto, M. A.; Valério, A. G.; Bazolli, R. S.; Carrilho,
E. N. V. M.; Prada, F., 2007: Chromic oxide as a
digestibility marker for dogs – a comparison of methods
of analysis. Animal Feed Science and Technology 134,
273–282.
Carciofi, A. C.; Takakura, F. S.; de-Oliveira, L. D.;
Teshima, E.; Jeremias, J. T.; Brunetto, M. A.; Prada, F.,
2008: Effects of six carbohydrate sources on dog diet
digestibility and postprandial glucose and insulin
response. Journal of Animal Physiology and Animal
Nourishment 98, 326–336.
Murray, S. M.; Hussein, H. S.; Brent, J. L. Jr, 1999:
Soybean hulls as a dietary fiber source for dogs. Journal
of Animal Science 77, 917–924.
A., Ronald (eds), Fiber in Human Nutrition. Plenum


Schrag, I., 1999: Untersuchungen zur Bruttoenergiebestimmung an isolierten Einzelfuttermitteln sowie an kommerziellen Futtermitteln für Hund und Katze [Investigations on the determination of gross energy in isolated substances and commercial dog and cat food]. Thesis, Ludwig Maximilians University Munich, Munich, Germany, p. 138.

Schuster, S., 2003: Wirkung verschiedener Cellulosen im Vergleich zu Guarmeal auf Nährstoff- und Bruttoenergieverdaulichkeiten sowie Kotqualität beim Hund [Influence of different celluloses compared to guar gum on nutrient and energy digestibilities and faeces quality at dogs]. Thesis, Ludwig Maximilians University Munich, Munich, Germany, p. 128.


Udén, P.; Robinson, P. H.; Wiseman, J., 2005: Use of detergent system terminology and criteria for submission of manuscripts on new, or revised, analytical methods as well as descriptive information on feed analysis and/or variability. *Animal Feed Science and Technology* **118**, 181–186.

