Digestibilities of Energy, Protein, Fat and Nonstarch Polysaccharides in a Low Fiber Diet and Diets Containing Coarse or Fine Whole Meal Rye Are Comparable in Rats and Humans

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ABSTRACT The apparent digestibility of energy, protein, fat and nonstarch polysaccharides (NSP) of a low fiber diet and two high fiber diets containing coarse or fine whole meal rye bread was studied in experiments with humans and rats. Human subjects consumed the experimental diets for 3 wk each in a 3 × 3 cross over design. For the rat diets, duplicate portions of the foods consumed by the human subjects were mixed together, freeze dried and ground. There was a good agreement in the digestibility of energy (humans: 94.7 ± 0.9, 91.2 ± 1.2 and 91.6 ± 1.4%; rats: 95.0 ± 0.8, 92.5 ± 1.4 and 91.7 ± 1.8%) and fat (humans: 95.2 ± 1.5, 94.4 ± 1.0 and 94.8 ± 2.5%, rats: 95.4 ± 0.9, 94.0 ± 0.4 and 94.0 ± 0.4%) for the low fiber diet and the diets containing coarse or fine whole meal bread, respectively. Apparent and true digestibility of protein was consistently lower (P < 0.0001) in humans (apparent digestibility: 90.6 ± 1.5, 86.2 ± 1.4 and 86.3 ± 2.3%; true digestibility: 95.1 ± 1.5, 90.7 ± 1.4 and 90.8 ± 2.2%) than in rats (apparent digestibility: 92.3 ± 1.1, 89.4 ± 0.9 and 88.9 ± 1.0%; true digestibility: 98.3 ± 1.1, 94.9 ± 0.9 and 94.2 ± 1.0%) for all three diets. The digestibility of NSP tended to be lower (P < 0.066) in rats than in humans for the diet containing fine whole meal bread (rats: 59.6 ± 8.0%, humans: 68.0 ± 5.2%) and the low fiber diet (rats: 72.1 ± 10.8%; humans: 80.5 ± 7.1%), whereas it was similar in both species for the diet containing the coarse whole meal bread (rats: 66.1 ± 6.0%; humans: 65.8 ± 9.3%). In spite of some differences in digestibility values, our results suggest that the rat is a suitable model for humans to predict digestibility of nutrients in mixed diets containing cereal fiber sources. J. Nutr. 126: 481–488, 1996.

INDEXING KEY WORDS:
• digestibility • nutrients • dietary fiber • humans • rats

The need for appropriate animal models when studying questions in human nutrition is very great because studies with humans are generally complicated, time-consuming and expensive. The rat is the most frequently used animal model to predict protein digestibility (FAO/WHO 1991). The similar capacity of humans and rats to digest protein resulted in a joint FAO/WHO expert committee recommending the use of the rat balance method for predicting protein digestibility in humans (FAO/WHO 1991). One major advantage with rats is that they are omnivorous, thus allowing studies on a wide variety of diets and single foods. However, there are dramatic differences in the anatomy of the digestive tract of humans and rats (Björnhag 1992). In spite of these differences available data from humans and rats fed identical diets indicate that the rat model can be used to predict protein as well as energy digestibility in humans with relatively high precision (Jungvid et al. 1992). However, our current knowledge of how the rat compares with humans in terms of digestibility of other nutrients is rather limited.

In an earlier study, Bach Knudsen et al. (1994) demonstrated that the digestibility of nonstarch polysaccharides [NSP] and most of its monosaccharide residues was higher in humans than in rats, whereas the digestibility values for protein, energy and fat in general were very similar for the two species. Van Soest et al. (1982)

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2 To whom reprint requests should be addressed.
3 Abbreviations used: DM, dry matter; NSP, nonstarch polysaccharides.
also observed that the fermentation of dietary fiber was higher in humans than in rats but lower than in pigs. These findings are not in agreement with results of Nyman et al. (1986) who found a good agreement between humans and rats in the digestibility of fiber residues isolated from carrots, cabbage, apple, guar gum and wheat bran.

Cereals in various processed forms are an important dietary contributor of protein and energy worldwide (Pedersen et al. 1989) and the foremost important fiber source in northern Europe accounting for ~60% of the total dietary fiber intake of ~20 g/d in Scandinavia and Germany (Cummings 1993). Dietary guidelines recommend increasing the intake of whole meal bread and whole grain cereals as part of a healthy diet [e.g., Deutsche Gesellschaft für Ernährung 1991]. At present, however, there are no data available that evaluate the rat as a model for humans when studying diets containing relatively large amounts of cereal foods. Studies on a variety of material are needed to avoid similarities between humans and rats by coincidence.

The aim of the present investigation was to compare the digestibility in humans and rats of energy, protein, fat and NSP of a low fiber control diet and two high fiber diets containing either coarse or fine whole meal rye bread.

**MATERIALS AND METHODS**

The studies with human subjects took place at Christian-Albrechts-University of Kiel, Germany, whereas the rat studies were performed at Research Centre Foulum, Denmark.

**Human experiments.** Seven healthy, free-living female students 23–31 y old took part in the balance experiments. Subjects gave written consent. The studies were approved by the Ethical Committee of the Medical Faculty of the University of Kiel. Normal energy intake of each subject was calculated from a 7-d prestudy record using a German food table (Deutsche Forschungsanstalt für Lebensmittelchemie 1990). During the studies, subjects had a controlled food intake that maintained their body weight in a range of ±1 kg of their starting weight. Subjects had lunch together in the institute kitchen; foods for all other meals were prepackaged and consumed at home. During lunch, contact was made with the nutritionist involved with the study [E. W.] to ensure that compliance was maintained. Subjects participating in this study were highly motivated students in nutritional sciences who were interested in the objectives of the study.

**Study design.** The study comprised three experimental periods of 21 d each, separated from each other by 3 wk. Subjects consumed the low fiber diet and the two high fiber diets containing coarse or fine whole meal rye bread, respectively, in a 3 × 3 cross over design. During the last 7 d of each experimental period, balances were performed as described in a previous work (Wisker and Feldheim 1990). In brief, during the balance week duplicate samples of all foods and total feces were collected for analysis. Acid-brilliant green (E 142, H. Schulz, Dragoco, Holzminden, Germany) was given as fecal marker at the beginning and the end of the balance periods.

**Diets.** All subjects consumed the same amount of fiber-containing foods. The basal diet consisted of two 1-d menus that were consumed in rotation throughout the study. The foods ingestec as the basal diet are given in Table 1. In addition to these foods, subjects consumed daily either 350 g coarse or 377 g fine whole meal rye bread [high fiber diets] or 200 g wheat mixed bread and 75 g cake [low fiber diet]. The basal diet and bread provided ~8 MJ/d. A fixed combination of fiber-free foods [honey, 20 g, pudding, 50 g, cheese, 5 g, fresh cheese, 10 g, sausage, 5 g] was added incrementally to meet the individual energy requirements. Each increment provided 630 kJ. With the exception of breads, all food consumed during the experiments was prepared in the institute kitchen. Whole meal bread was prepared from one single batch of rye that was milled to two different particle sizes [coarse bread: 50% of particles >2 mm, 90% >1 mm; fine bread: 99% of particles <0.5 mm] [W. Seibel and J. Brümmer, Federal Centre for Cereal, Potato and Lipid Research, Detmold and Münster, Germany]. All foods consumed were weighed to the nearest gram.

Protein, fat and available carbohydrate contributed 19, 36 and 45% to the metabolizable energy of the low fiber diet. When the high fiber diets were consumed, 18, 35 and 47% of the energy was delivered by protein, fat and carbohydrate, respectively. The NSP intake increased from 16.7 g/d during the low fiber diet to 38.2 and 37.7 g/d when the diets containing coarse and fine whole meal rye bread, respectively, were consumed.

| Table 1: Foods consumed by human subjects as the basal diet¹ |
|---------------------|---------------------|
| Food                | Intake (g/d)        |
|                     |                     |
| Potatoes (boiled)   | 100                 |
| Iceberg lettuce/cucumber² | 60/150             |
| Orange/strawberries² | 150/150            |
| Marmalade/honey²    | 40/20              |
| Margarine           | 40                 |
| Meatballs           | 75                 |
| Sausage             | 37                 |
| Cheese              | 72                 |
| Soft cheese         | 60                 |
| Pudding³            | 150                |

¹ Each subject consumed the same amount of these foods daily during each experimental period of the study. Additional amounts of fiber-free foods were eaten to meet individual energy requirements. 
² Foods were consumed in rotation.
³ Pudding was prepared from milk, sugar, starch, eggs and vanilla.

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**Rat experiments**

**Study design.** The general experimental procedure has been described by Eggum (1973). The protocol was approved by the Danish Animal Experiments Inspectorate, Copenhagen, Denmark. Groups of five or six Wistar male rats (Møllgard Breeding Centre Ltd., Lille Ejengved, Denmark) housed individually in metabolic cages were used per diet. They weighed ~65 g when the experiment started. A preliminary period of 17 d and a balance period of 5 d were used. The rats gained ~135 g in this period. The animals had free access to food and water. Diet formulation was the same as for the human studies.

**Diets.** During the balance periods of the study in humans, foods for the rat diets were collected. For the diet containing fine whole meal bread and the low fiber diet, respectively, duplicate samples of the foods consumed by the individual subjects were collected, mixed together, homogenized, lyophilized and ground to pass a 0.5-mm mesh screen. For the diet containing coarse whole meal bread, bread was dried separately from the other foods and matted by hand to a particle size resembling that of the coarse meal. Bread and the other freeze dried ground foods (0.5 mm) were mixed together before they were used as diets for the rats. A preliminary study was conducted to determine whether the rats would selectively eat these diets. This was not the case. Thus, the rat diets corresponded to the average food and nutrient intake of the human subjects. However, the diets fed to the rats were fortified with micro-nutrients as described by Eggum (1973). All diets were kept frozen at ~20°C until used. The chemical composition of the diets is given in Table 2.

**Chemical analyses.** Dry matter (DM) content of food and feces was determined by drying the freeze dried samples at 105°C for 8 h. Gross energy was determined in the freeze-dried samples of foods and feces by adiabatic bomb calorimetry using an IKA calorimeter C 4000 (Janke & Kunkel, IKA-Werk, Heltersheim, Germany) in the human studies and a LECO AC 300 automated calorimeter system 789-500 (LECO, St. Joseph, MI) in the rat studies. Nitrogen was determined by a micro-Kjeldahl method in human studies and in the rat experiments by the Kjeldahl method using a Kjell-Foss 16200 autoanalyzer (Foss Electric A/S, Hillerød, Denmark). Protein was calculated as N × 6.25. Fat was determined after acid hydrolysis by extraction with petroleum ether in human studies and with diethyl ether in rat studies (Stoldt 1952). α-Glucose was determined by the modification of the enzymatic method of Bach Knudsen et al. (1987) as described by Bach Knudsen et al. (1993). Ash was determined in a muffle furnace at 550°C. Because the studies were carried out at two different institutions, for the analysis of NSP in diets and feces the procedures used normally at the two departments were applied. Total NSP and their constituent sugars in diets and feces were determined as alditol acetates by gas-liquid chromatography for neutral sugars using the Uppsala procedure C (Theander and Westerlund 1986) in human studies and a modification of the Uppsala procedure (Theander and Westerlund 1986) and the Englyst (Englyst et al. 1982) procedure in rat studies as described by Bach Knudsen et al. (1993) and by a colorimetric method for uronic acids (Englyst et al. 1982). In principle, the determination of NSP in human and rat studies differed in the concentration of the sulfuric acid and in time and temperature used for the hydrolysis of the polysaccharides. Details of the NSP determination at both institutes have been described previously (Bach Knudsen et al. 1994). The procedures for measuring NSP residues, although slightly different at the two institutes, gave comparable results for the diets. This indicates that estimates of digestibility, which depend also on fecal NSP determination, are unlikely to be influenced by analytical errors. Klasen lignin was measured gravimetrically as the residue resistant to 12 mol/l sulfuric acid (Theander and Westerlund 1986).

**Calculations and statistical analysis**

The content of polysaccharide residues in food and feces was calculated as anhydrosugars, and all digestibilities (apparent digestibility of energy, protein, fat and NSP) were calculated as the difference of the recorded quantitative intake and excretion in feces, expressed as percentage of intake. For true protein digestibility fecal nitrogen losses were corrected for endogenous losses. For human subjects, estimates of endogenous fecal nitrogen losses were calculated as 12

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**Table 2**

| Chemical composition of the experimental diets consumed by human subjects and by rats |
|--------------------------------------|---------------|---------------|---------------|
| Diet                                | Low fiber     | High fiber coarse bread | High fiber fine bread |
|                                      | g·kg⁻¹ dry matter | g·kg⁻¹ dry matter | g·kg⁻¹ dry matter |
| Gross energy                        | 21.8          | 21.2           | 21.1          |
| Protein (N × 6.25)                  | 21.6          | 21.0           | 20.1          |
| Fat                                 | 18.2          | 16.2           | 16.4          |
| NSP                                 |               |                |               |
| Arabinose                           | 6             | 14             | 14            |
| Xylose                              | 7             | 23             | 24            |
| Mannose                             | 2             | 2              | 3             |
| Galactose                           | 3             | 4              | 5             |
| Glucose                             | 13            | 24             | 22            |
| Uronic acid                         | 6             | 6              | 6             |
| Total NSP                           | 37            | 73             | 74            |

NSP = nonstarch polysaccharides.
mg nitrogen/kg body weight [FAO/WHO/UNO 1985]. For rats endogenous fecal nitrogen losses were estimated according to Eggum (1973).

The fecal bulking capacity and its composition due to the increase in fiber from whole meal bread were calculated as the increase in fecal DM, protein, fat, NSP, α-glucose and residues per gram increase in ingested NSP. The results were examined by a two-way analysis of variance model [Snedecor and Cochran 1973]:

\[ X_{iik} = \mu + \alpha_i + \beta_j + (\alpha \beta)_{ij} + \epsilon_{iik} \]

where \( X_{iik} \) is the dependent variable (e.g., digestibility of NSP), \( \mu \) is the overall mean, \( \alpha \) is the effect of diet, \( \beta \) is the effect of species [humans or rat] and \( \epsilon_{iik} \) is a normally distributed random variable. Significant species differences within each dietary group were identified by linear contrast. All statistical calculations were done by General Linear Modeling using a SuperANOVA package (ABACUS Concepts, Berkely, CA).

RESULTS

The apparent digestibilities of energy, protein, fat and NSP and the true protein digestibility in the human subjects and the rats are given in Table 3. The apparent digestibilities during the consumption of the two high fiber diets were for all measured variables except fat, NSPxylose and NSPglucose significantly lower than those of the low fiber control diet. For all three diets the apparent digestibility of protein was lower in human subjects \( (P < 0.0001) \) with the most dramatic difference between the two species found for the high fiber diet containing coarse whole meal bread. True protein digestibility was also significantly lower in humans than in rats \( (P < 0.0001) \) for all experimental diets. Digestibility of fat was the same in both species for all three diets.

Although digestibility of total NSP was in general significantly lower in rats than in humans \( (P < 0.04) \), there were no significant species differences for the single diets. It was only for the low fiber diet and the high fiber diet containing fine bread that the difference approached significance \( (P < 0.066) \). This was especially due to a lower digestibility in rats of xylose in the low fiber \( (P < 0.001) \) and the high fiber diet containing the fine whole meal bread \( (P < 0.004) \) and of uronic acids in the high fiber diet containing the fine whole meal bread \( (P < 0.029) \). In the diet containing coarse whole meal bread, the digestibilities of total NSP and NSP residues were similar in rats and humans.

Table 3 shows the percentage composition of human and rat fecal DM. There was no species difference in the percentage of protein, but when all experimental diets were consumed, rat feces contained a small, but significantly higher percentage of fat \( (P < 0.02) \) and a significantly higher percentage of α-glucose \( (P < 0.007) \), NSP \( (P < 0.0001) \), Klason lignin \( (P < 0.0007) \) and a lower percentage of ash \( (P < 0.0001) \). When human subjects consumed the low fiber diet and the diets containing coarse and fine whole meal rye bread, 94.3 \( \pm 1.9 \), 96.2 \( \pm 3.2 \), 92.9 \( \pm 2.3 \) g/100 g of fecal dry weight, respectively, could be attributed to the components analyzed. The corresponding data for the rats were 97.2

### Table 3

<table>
<thead>
<tr>
<th></th>
<th>Low fiber control diet</th>
<th>High fiber diet containing coarse whole meal bread</th>
<th>High fiber diet containing fine whole meal bread</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Humans ((n = 7))</td>
<td>Rats ((n = 6))</td>
<td>Humans ((n = 7))</td>
<td>Rats ((n = 6))</td>
</tr>
<tr>
<td>Energy</td>
<td>94.7 ± 0.9</td>
<td>95.0 ± 0.8</td>
<td>91.2 ± 1.2</td>
<td>92.5 ± 1.4</td>
</tr>
<tr>
<td>Protein</td>
<td>90.6 ± 1.5</td>
<td>92.3 ± 1.1</td>
<td>86.2 ± 1.4</td>
<td>89.4 ± 0.9</td>
</tr>
<tr>
<td>(NSP)</td>
<td></td>
<td></td>
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<tr>
<td>Protein (true</td>
<td></td>
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<tr>
<td>digestibility)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat</td>
<td>95.2 ± 1.5</td>
<td>95.4 ± 0.9</td>
<td>94.8 ± 1.0</td>
<td>94.1 ± 0.4</td>
</tr>
<tr>
<td>NSP residues</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arabinose</td>
<td>79.8 ± 3.9</td>
<td>75.2 ± 5.9</td>
<td>59.7 ± 3.1</td>
<td>63.4 ± 4.7</td>
</tr>
<tr>
<td>Xylose</td>
<td>80.2 ± 3.1</td>
<td>65.4 ± 9.2</td>
<td>71.3 ± 7.3</td>
<td>68.4 ± 6.2</td>
</tr>
<tr>
<td>Mannose</td>
<td>85.9 ± 5.1</td>
<td>80.5 ± 10.9</td>
<td>76.6 ± 9.4</td>
<td>78.2 ± 6.0</td>
</tr>
<tr>
<td>Galactose</td>
<td>74.2 ± 6.7</td>
<td>75.9 ± 7.2</td>
<td>58.9 ± 3.1</td>
<td>59.3 ± 6.7</td>
</tr>
<tr>
<td>Glucose</td>
<td>75.8 ± 13.4</td>
<td>66.8 ± 17.0</td>
<td>59.1 ± 19.7</td>
<td>62.0 ± 7.5</td>
</tr>
<tr>
<td>Uronic acid</td>
<td>90.4 ± 5.6</td>
<td>84.5 ± 9.5</td>
<td>82.4 ± 5.7</td>
<td>80.7 ± 7.3</td>
</tr>
<tr>
<td>Total NSP</td>
<td>80.5 ± 7.1</td>
<td>72.1 ± 10.8</td>
<td>65.8 ± 9.3</td>
<td>66.1 ± 6.0</td>
</tr>
</tbody>
</table>

1 Values are means ± SD. Within each diet, values with different superscripts show significant differences between humans and rats. NSP = nonstarch polysaccharides.
TABLE 4
Composition of fecal dry matter in human subjects and in rats fed the low fiber diet and the high fiber diets containing coarse or fine whole meal bread

<table>
<thead>
<tr>
<th></th>
<th>Low fiber control diet</th>
<th>High fiber diet containing coarse whole meal rye bread</th>
<th>High fiber diet containing fine whole meal rye bread</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>g/100 g fecal dry matter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein (N \times 6.25)</td>
<td>36.0 ± 1.5</td>
<td>35.7 ± 1.6</td>
<td>29.6 ± 2.6</td>
<td>30.6 ± 2.7</td>
</tr>
<tr>
<td>Fat</td>
<td>15.6 ± 3.6</td>
<td>17.7 ± 2.9</td>
<td>9.9 ± 1.7</td>
<td>9.5 ± 3.9</td>
</tr>
<tr>
<td>α-Glucose</td>
<td>1.0 ± 0.7</td>
<td>2.2 ± 1.0</td>
<td>2.8 ± 2.5</td>
<td>4.0 ± 1.2</td>
</tr>
<tr>
<td>NSP (total)</td>
<td>13.3± 3.8</td>
<td>23.0± 5.3</td>
<td>35.0± 3.4</td>
<td>33.0± 3.5</td>
</tr>
<tr>
<td>Klason lignin</td>
<td>9.9± 2.0</td>
<td>15.1± 2.2</td>
<td>10.0± 2.2</td>
<td>10.4± 2.5</td>
</tr>
<tr>
<td>Ash</td>
<td>18.6± 3.0</td>
<td>3.4± 0.4</td>
<td>14.1± 1.8</td>
<td>14.0± 2.0</td>
</tr>
<tr>
<td>Sum of components analyzed</td>
<td>94.3± 1.9</td>
<td>97.2± 5.2</td>
<td>96.2± 3.2</td>
<td>94.1± 3.0</td>
</tr>
</tbody>
</table>

1 Values are means ± SD. Within each diet, values with different superscripts show significant differences between humans and rats. NSP = nonstarch polysaccharides.

± 5.2, 94.1 ± 3.0 and 96.9 ± 1.9 g/100 g fecal dry weight, respectively.

The fecal DM increase per gram of additional NSP from coarse or fine whole meal bread, respectively, was higher in humans than in rats. This was due primarily to a higher excretion of fecal protein, whereas for the other components there were no species differences (Table 5). The particle size of the breads did not affect fecal DM increase in humans and rats, but a higher excretion of α-glucose was seen with both species [P < 0.02] when the breads with the coarse particles were fed. There were no differences between humans and rats in additional fecal losses of fat, NSP, α-glucose and residues due to the additional intake of fiber from coarse or fine whole meal bread.

DISCUSSION

One of the physiological consequences of the high energy requirement per unit of body mass of small animals like rats is a higher feed intake and, consequently, a faster passage rate through the gastrointestinal tract. Coprophagy may be one mechanism for the rat to overcome the negative effects of a low retention time on nutrient utilization. Microbial cells resulting from the fermentation of dietary residues, which are lost for humans, may become available by coprophagy for rats. However, when rats are fed nutritionally adequate diets, little coprophagy has been observed (Mathers and Dawson 1991). The diets studied in the present work had relatively high contents of energy and protein and less dietary fiber, calculated on DM basis, than diets used in other studies (Bach Knudsen et al. 1991, 1993). Under these conditions, coprophagy is probably without importance.

For most of the digestibilities measured in the present study, there was a good agreement between humans and rats. Digestibility of energy was the same in both species for all three experimental diets studied. This is consistent with the results obtained by Bach Knudsen et al. (1994) for similar low fiber diets as used in the present study as well as for high fiber diets con-
taining barley fiber at two levels of protein intake. In
the same study, however, digestibility of energy mea-
sured for two high fiber diets containing fruits and vege-
tables or a citrus fiber concentrate was significantly
higher in humans than in rats. These differences were
related mainly to the much higher fermentation of NSP
from these diets in humans relative to rats (Bach Knud-
sen et al. 1994).

Highly fermentable fiber sources generally have a
smaller effect on fecal DM excretion and thereby on
cecal energy losses than have poorly fermentable fiber
sources (Wisker and Feldheim 1992). In the study of
Bach Knudsen et al. (1994), the much higher fermenta-
tion of NSP from fruits, vegetables and citrus fiber in
humans resulted in a significantly lower excretion of
organic material in humans than in rats. In the present
work, there were no or only small differences between
the species in the fermentation of NSP, and the differ-
ences between the two species in the increase in fecal
DM during consumption of the high fiber diets could
be attributed to a higher excretion of fecal protein in
humans than in rats. This explains the good agreement
between humans and rats in the digestibility of energy.

The microbial degradation of NSP affects nitrogen
metabolism in the large intestine. A more intensive
microbial fermentation of dietary residues stimulates
the synthesis of bacterial mass, which is followed by a
higher excretion of microbial nitrogenous material in
the feces (Mason and Palmer 1973, Stephen and Cum-
ings 1980) and a lower apparent protein digestibility.
In agreement with this and previous findings (Bach
Knudsen et al. 1994), we found a generally higher di-
gestibility of NSP and a consistently lower apparent
protein digestibility (1.7−3.2%) in humans than in rats.
However, for the diet with coarse whole meal bread,
there was a significant species difference in protein di-
gestibility, despite comparable NSP digestibilities.
This is presumably due to the fact that the intact cell
structures of the coarse bread contained starch that
escaped digestion in the small intestine. A study with
ileostomy subjects has shown that the physical form
of barley grain affected the digestion of starch by pan-
creatic amylase. With flaked barley, 17% of the in-
gested starch resisted the intestinal digestion compared
with only 2% with finely milled barley flakes (Livesey
et al. 1995). Earlier studies (Macfarlane and Englyst
1986) showed that nearly all the starch reaching the
large intestine will be fermented by the colon mi-
croflora and thus stimulate bacterial protein synthesis.
Consistent with these findings, only very small
amounts of α-glucans were excreted in both humans
and rats. However, we can only speculate if the percent-
age of ingested starch reaching the colon will be the
same for humans and rats. Probably the difference in
protein digestibility on the coarse bread diet indicates
that comparatively more starch was undigested in the
human than in the rat small intestine.

True protein digestibility was also lower (3.2−4.2%)
in humans than in rats, but absolute differences be-
tween species were higher compared with those in ap-
parent protein digestibility. At least in part this may
have been due to the fact that in rats endogenous fecal
nitrogen losses were measured, whereas in humans
they were estimated on the basis of literature data
(FAO/WHO/UNO 1985). Such calculations may be
connected with some errors, because studies, on endog-
enous fecal nitrogen do not always give consistent re-
results (Huang et al. 1972, Scrimshaw et al. 1972). A
problem that applies to both species is that endogenous
losses may depend on the amount and type of dietary
fiber in the diet. Even when concentrations and types
of dietary fiber in the diet are the same for both species,
as was the case in the present study, it is unknown
whether a possible effect of fiber on endogenous nitro-
gen losses will be the same in humans and rats.

There are anatomical differences between humans
and rats with respect to the digestion of fat; the rat
has no gallbladder, cannot concentrate bile and has a
nearly constant flow of diluted bile into the duodenum
(Björnhag, 1992). Rats may therefore be unable to
eмуlise large meals of fat sufficiently, which poten-
tially may lead to a lower fat absorption. Despite these
differences and the relatively high dietary fat levels
(162−182 g/kg) compared with standard rat diets (30−
g/kg) (Eggum 1973), there was an excellent agreement
in the digestibility of fat between humans and rats.
Similar results were found in a previously published
work of our group (Bach Knudsen et al. 1994), where
the fat content of diets varied between 131 and 195 g/
kg. The reason for this excellent agreement is presum-
ably the experimental design because dietary factors
known to affect fat absorption, such as the amount
and type of fat (Appgar et al. 1987, Walker et al. 1973)
dietary fiber (Vahouny and Cassidy 1987) were the
same for both species.

The digestibility of NSP in the two species was
about the same for the diet containing coarse whole
meal bread, whereas for the other two diets the diges-
tibility of NSP was ~8% lower in rats than in humans.
The difference in the digestibility of NSP between hu-
mans and rats was much smaller than found in a previ-
ous experiment (Bach Knudsen et al. 1994) where the
digestibility of NSP was from 7.7 to 36.8% lower in
rats than in humans. However, it is noticeable that the
digestibility of NSP was lower for 9 of the 10 investi-
gated diets in the two experiments, thus supporting the
conclusion (Bach Knudsen et al. 1994) that rats have a
lower capacity to digest NSP than humans. This is also
supported by the finding that the relative contribution
of NSP to fecal DM was higher in rats than in humans.
In this aspect our results are in disagreement with the
study of Nyman et al. (1986). These authors found a
high correlation and a good agreement between hu-
mans and rats in the degradation of NSP from various
isolated fiber sources. However, in that study there
were marked differences in the basal diets ingested by
the human subjects and the rats and also in the analytical methods used for determination of NSP in the human and the rat experiments, respectively.

The retention time in the large intestine is an important factor influencing the digestibility of NSP in all animal species including humans (Van Soest et al. 1982). From the data available it seems that whole gut transit times are longer in humans than in rats (Bach Knudsen et al. 1991, Cummings et al. 1976, Raczynski et al. 1982) and that an increased intake of dietary fiber lowers transit time (Bach Knudsen et al. 1991, Cummings et al. 1976). A decrease in the transit time in the large intestine is also correlated with a lower degradation of dietary fiber in humans (Cummings 1982) and in rats (Bach Knudsen et al. 1991). In humans, transit time is inversely related to the stool weight (Spiller et al. 1986). In the present work, the ingestion of fiber from the whole meal breads had a greater effect on fecal wet weight in the human subjects (6.8 and 4.9 g/g of additional NSP from coarse and fine bread, respectively) [Wisker E., Daniel M., Feldheim, W., unpublished results] than the fiber sources used in the earlier studies of Bach Knudsen et al. (1994). The greater bulking capacity of the fiber from whole meal bread in the present study probably led to a more rapid passage of the fiber residues through the gut, especially in the case of the coarse bread, which affected stool weight more than the fine bread. Therefore, transit time in humans may have come closer to that of the rats, resulting in a similar degree of NSP digestibility.

In conclusion, the results of the present study support our earlier findings that despite anatomical differences in the digestive tract between humans and rats, the relatively good numerical agreement between the species in the digestibilities of most nutrients suggests that the rat is a suitable model for humans to predict digestibilities of nutrients in mixed diets containing cereal fiber sources.

LITERATURE CITED


