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Digestibility of dietary fiber components in vegetarian men

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Abstract. Digestibility of fiber components namely neutral detergent fiber (total content of cellwall) cellulose, hemicellulose and lignin are estimated in 14 healthy vegetarian men during adlibitum feeding and at 3 energy levels namely 2526, 2868 and 3290 kcals/day. Values of digestibility for adlibitum experiments were 34.17 ± 2.3 for neutral detergent fiber (NDF), 30.1 ± 3.9 for cellulose and 53.4 ± 3.0 for hemicellulose and 8.1 ± 2.6 for lignin. There was a considerable variability in digestibility of fiber components between individuals.

Introduction

Dietary fiber by definition is the cellulosic material not digested by human pancreatic or intestinal enzymes. However, it is known that the polysaccharides of the plant cell wall are broken down to some extent during passage due to fermentation by gut microflora. Digestibility of fiber is decided by its physicochemical and structural properties [1]. These properties are dependent upon the type of foods, as well as food processing [2, 3]. For example vegetable cell walls are highly fermented in human subjects as compared to cereal brans [4]. These physicochemical properties influence the residence time of the fiber in the intestine.

The longer a fiber is exposed to the degradative conditions of the large intestine, the greater is its digestibility. Dietary fiber serves as a substrate for microbial gastrointestinal fermentation. It is through this mechanism that energy in carbohydrates having β linkages which are resistant to human digestive enzymes become available for metabolism. Dietary fiber when digested may not only contribute to the energy but fiber digestion may affect nutrient interactions [5]. There is a need to study the digestibility of fiber in populations consuming high fiber diets.

Since energy is derived from bacterial fermentation of fiber and the population of bacteria depends on level and type of fiber, person needs to be adapted to this level of fiber. If so, digestibility of fiber may be different for populations accepting vegetarian foods as their lifestyle. The information about the digestibility of fiber in vegetarians is limited. Habitual intakes of dietary fiber in Indians were in the range of 30–40 g/day [6]. The purpose of this study was (1) to estimate the digestibility of dietary fiber components in vegetarian subjects

during adlibitum feeding, and (2) to examine the effect of marginal underfeeding and overfeeding on digestibility of fiber components.

Materials and methods

Experimental design. Subjects were observed during pre-experimental period of 14 days each for their habitual levels of energy intake. Based on these observations they were served six diets during each of the experiments of 28 days duration at three energy levels 2526, 2868 and 3290 kcals respectively which represent 90% (experiment 1, 2), 100% (experiment 3, 4) and 110% (experiment 5, 6) of habitual levels as shown in Table 2.

During adlib experiments the subjects consumed foods according to their preference and there was no restriction on the amount of food consumed. For each of the three energy levels, two isocaloric diets were formed. The two isocaloric diets differed in their contents and types of vegetables and pulses used while the cereal type and content was identical. Study design was approved by the ethical committee of the institute.

Fourteen young healthy adult male volunteers in the age group of 18–25 years participated in the study. The subjects mean weight was 51 ± 4.2 kg and mean height was 166.1 ± 6.9 cm. Subjects were informed about the experiment and had undergone thorough medical examination to ensure that they were healthy. They were under strict supervision and lived in the metabolic unit throughout the study. The formula diets were based on the food items consumed during adlib experiments and consisted of traditional Indian foods such as rice, dal (Red gram curry), chapatti, leafy vegetables, milk etc. These foods represent those commonly consumed in India and the subjects were accustomed to these food items. The desired calories and proteins in the formula diets were prepared considering the subjects choice for the amount and type of food ingredients. Feces were collected daily in plastic containers.

Analytical techniques. Daily samples of composite diets during adlib experiment were analysed for its fat by Soxlet method and protein by the Kjeldahl method and energy calculated by the application of Atwaters factors, [7]. The Neutral detergent fiber, Acid detergent fiber and lignin were analysed by using the modified detergent method using alpha amylase for reducing the interference of starch [8]. Hemicellulose and cellulose were both calculated by difference:

Neutral detergent fiber – Acid detergent fiber = hemicellulose

Acid detergent fiber – lignin = cellulose

Formula diets were cooked prior to the experiment and analysed for the same in duplicate. Fecal samples were pooled and analysed for proximate principles and fiber components in duplicate.

Statistical methods. Paired t test and analysis of variance with hierarchial model was used in data evaluation for cellulose, hemicellulose and lignin

separately, when between experiment variances are computed considering between replicate within person as error component.

Typical formula diet of one subject

Item	Wheat g	Rice g	Red gram g/day	Vege-table g	Pulses (Other) g	Sugar g	Oil g	Fruit g	Milk ml
Amount	250	80	80	275	35	55	52	70	140

Results

Table 1 shows the mean intake, fecal excretion as well as digestibility of neutral detergent fiber (NDF), cellulose, hemicellulose and lignin during adlib experiments. Cellulose contributed to 48% of total fiber intake, while hemicellulose and lignin contributed 34 and 17.8%, respectively.

Table 2 shows the mean intake, fecal excretion and digestibility of cellulose, hemicellulose and lignin during 3 fixed intake experiments. The order of digestibility of fiber components was hemicellulose > cellulose > lignin.

Comparison of Table 1 and 2 indicates that the intake of cellulose, hemicellulose and lignin were comparable during both adlib and fixed intake experiments as indicated by paired t test ($p > 0.1$). One way classification of analysis of variance indicates that cellulose digestibility between fixed experiments at 3 energy levels was significant ($F = 6.0$, $p > 0.1$) as compared to between subject within experiment.

The coefficient of variation for digestibility of fiber components was 24.7% for cellulose, 15.24% for hemicellulose, and 45.64% for lignin. This indicates that each individual has a varying ability to digest the components of dietary fiber. Further, this variation is larger for lignin than cellulose and hemicellulose.

Table 1. Digestibility (%) of NDF, cellulose, hemicellulose and lignin during adlib experiments

Fiber components	NDF	Cellulose	Hemicellulose	Lignin
Intake (g/day)	37.73 ± 5.81	18.22 ± 3.25	12.83 ± 1.97	6.71 ± 1.19
Fecal (g/day)	24.88 ± 4.13	12.71 ± 2.40	5.97 ± 1.02	6.19 ± 1.22
Digestibility (%)	34.17 ± 2.30	30.06 ± 3.90	53.43 ± 3.02	8.07 ± 2.60

Table 2. Digestibility (%) of cellulose, hemicellulose and lignin during fixed intake experiments

	Experiment No.					
	1	2	3	4	5	6
Intake	2526 kcals/day		2868 kcals/day		3290 kcals/day	
Cellulose (g/day)	19.41 ± 4.90	17.92 ± 3.27	22.83 ± 3.70	21.85 ± 2.42	22.65 ± 3.13	21.32 ± 3.70
Hemicellulose (g/day)	13.13 ± 2.35	14.19 ± 3.16	14.58 ± 1.91	16.10 ± 2.20	15.93 ± 2.02	16.76 ± 2.40
Lignin (g/day)	6.16 ± 1.69	6.30 ± 1.99	7.64 ± 1.49	7.05 ± 1.34	8.00 ± 1.38	6.90 ± 1.78
Fecal						
Cellulose (g/day)	14.55 ± 3.37	12.62 ± 2.20	18.54 ± 2.54	14.96 ± 3.40	17.61 ± 4.40	14.51 ± 3.40
Hemicellulose (g/day)	6.21 ± 1.73	7.25 ± 1.06	7.10 ± 0.94	8.11 ± 2.12	6.71 ± 0.74	7.68 ± 1.70
Lignin (g/day)	6.82 ± 0.94	6.25 ± 1.85	7.68 ± 1.12	6.86 ± 1.02	7.20 ± 1.12	6.48 ± 1.21
Digestibility %						
Cellulose (g/day)	34.00 ± 6.45	33.79 ± 5.50	24.41 ± 3.90	32.28 ± 10.40	24.06 ± 6.19	31.21 ± 3.40
Hemicellulose (g/day)	55.30 ± 13.63	52.23 ± 5.18	53.24 ± 7.50	51.77 ± 7.33	54.15 ± 4.60	57.38 ± 6.78
Lignin (g/day)	8.30 ± 3.75	11.44 ± 4.98	8.45 ± 3.42	9.73 ± 5.03	8.66 ± 3.16	6.74 ± 2.82

Values represent average for all the subjects for the experiment and SD represents interindividual variation.

Discussion

The estimates of cellulose, hemicellulose and lignin intakes have indicated that our subjects habitual intakes are much higher than the intakes of Western subjects. Moreover, these figures are even higher than the levels of high fiber diets used for studies on fiber as has been reported by Kelsay et al. [9] and Van Soest [10]. The order for contribution to dietary fiber from each of the food types was found to be cereals > pulses > vegetables in our study.

Kelsay et al. [9] found the digestibility of cellulose to be 41.6+9.1, hemicellulose 88.0+2.4 and lignin 18.4+6.6. The digestibility of different components of dietary fiber in the present study was found to be lower than those observed on Western subjects. This may be due to the higher intakes of fiber components and the difference in types of fiber consumed.

In both adlib and fixed intake experiments we found a greater digestibility of hemicellulose than cellulose. Results indicated that each of the three fiber components were digested to varying extent. The finding of greater digestibility of hemicellulose, than cellulose is consistant with other reports [11–13]. Lignin is considered to be resistant to hydrolysis by colonic bacteria [14]. Our results also indicated that as compared to cellulose and hemicellulose, lignin was resistant to hydrolysis and was less digestable. The differences in fiber digestion may be related to its difference in the chemical composition and structural properties such as chain length, degree of branching and crystallinity.

Dietary fiber when broken down by the microflora of the large intestine result in short chain organic acids (SCOA) (acetate, propionate, butyrate), various gases and heat. These SCOAs produced in the colon can be excreted in feces [15, 16] or they can be quantitatively absorbed in the human colon [17, 18] and will be available for energy metabolism. Thus dietary fiber if degraded can be considered to have a caloric value. Overall digestibility of NDF was about 34 indicating that about 12 to 13 g of fiber is digested. If energy value for fiber is assumed to be 4 k cl/g, in the present study digested fiber may contribute to about 50 kcal of energy.

The present data indicates that cellulose digestibility was affected by energy levels. It was observed that digestibility of cellulose was higher at lower energy level of 2526 kcals than the other two levels. Secondly the higher variability of lignin digestibility indicates a large range in individual responses for lignin digestion. This is in concurrance with the results reported by Kelsay et al. [9].

In conclusion it was felt that the different dietary components such as cellulose, hemicellulose and lignin from Indian diets were digested to varying extent with the order hemicellulose > cellulose > lignin. The variation in digestibility may be dependent on the source of fiber as well as the host factors.

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References

1. Beams RM, Eggum BO (1981) The effect of type and level of protein, fiber and starch on nitrogen excretion patterns in rats. Br J Nutr 46: 301–3034.
2. Cummings JH, Southgate DAT, Branch WJ, Wiggens H, Houston H, Jenkins DJA, Jivaraj T, Hill MJ (1979) The digestion of pectin in the human gut and its effect on calcium absorption and large bowel function. Br J Nutr 41: 477–485.
3. Prynne CJ, Southgate DAT (1979) The effect of a supplement of dietary fiber on fecal excretion by human subjects. Br J Nutr 41: 495–503.
4. McLean Ross AH, Eastwood MA, Anderson JR, Anderson DMW (1983) A study of the effects of dietary gum arabic in humans. Am J Clin Nutr 37: 368–3754.
5. Goranzon H, Forsum E (1987) Metabolizable energy in humans in two diets containing different sources of dietary fiber: Calculation and analysis. J Nutr 117: 267–273.
6. Joshi SR, Mane ST, Agte VV (1991) Analysis of insoluble fiber components in Indian foods and habitual diets. Ind J Clin Biochem 6: 97–103.
7. AOAC (1975) Official methods of analysis, 12th ed. Washington, DC: The Association of official analytical chemists.
8. Marlett JA, Chesters JG (1985) Measuring dietary fiber in human foods. J Food Sci 50(2): 410–414.
9. Kelsay JL, Goering HK, Behall KM, Prather ES (1981) Effect of fiber from fruits and vegetables on metabolic responses of human subjects: fiber intakes, fecal excretions and apparent digestibilities. Am J Clin Nutr 34: 1849–1852.
10. Van Soest PJ (1984) Some physical characteristics of dietary fibers and their influence on the microbial ecology of the human colon. Proc Nutr Soc 43: 25–33.
11. Fetzer SG, Kies C, Fox HM (1979) Gastric disappearance of dietary fiber by adolescent boys. Cereal Chem 56: 34–37.
12. Southgate DAT, Durnin JVGA (1970) Calorie conversion factors. An experimental ressesment of the factors used in the calculation of the energy value of human diets. Br J Nutr 24: 517–535.
13. Williams RD, Olmstead WH (1936) The effect of cellulose, hemicellulose and lignin on the weight of the stool: A contribution to the study of laxation in man. J Nutr 11: 433–449.
14. Tadesse K, Eastwood MA (1978) Metabolism of dietary fiber components in man assessed by breath hydrogen and methane. Br J Nutr 40(2): 393–396.
15. Rubinstein R, Howard AV, Wrong OM (1969) In vivo dialysis of faeces as a method of stool analysis: The organic anion component. Clin Sci 37: 549–564.
16. Cummings JH, Southgate DAT, Branch WJ, Wiggins H, Houston H, Jenkins DJA, Jivaraj T, Hill MJ (1979) The digestion of pectin in the human gut and its effect on calcium absorption and large bowel function. Br J Nutr 41: 477–485.
17. Ruppin H, Bar Meir S., Soergel KH, Wood CM, Schmitt MG (1980) Absorption of short chain fatty acids by the colon. Gastroenterology 78: 1500–1507.
18. Roediger WEW (1980) Role of anaerobic bacteria in the metabolic welfare of the colonic mucosa in man. Gut 21: 793–798.