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The Effect of Cellulose Supplementation of Diets on Gastrointestinal Tract Function of Humans

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ABSTRACT

The objective was to determine the cellulase activity of the gastrointestinal tract and the effect of cellulose supplementation of a nutritionally complete diet on cellulose digestion in human adults. All the subjects were given ordinary, low fibre and high fibre (3 × 12g wheat bran/subject/day) controlled diets. The cellulose digestion and the cellulase activity of the samples taken of the stomach and small intestine contents were found to be significant. Blood sugar content also tended to increase when dietary fibre was administered to the patients. No correlations have been found between the age or sex of patients and cellulase activity; however, higher values were found for male patients. The quantities of sugars released from dietary fibre can be relevant in the case of diabetes mellitus.

INTRODUCTION

According to latest data in the literature, dietary fibre supplementation of certain processed foods seems to be advisable (Kay & Strasberg, 1978; Spiller & Kay, 1980; Jenkins *et al.*, 1983; Kies *et al.*, 1984). With some exceptions (Wahlqvist *et al.*, 1979; Tredger *et al.*, 1981; Ullrich & Albrink, 1982), most of the studies have reported beneficial effects. A great variety of

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commercial products of high fibre content is available on the market. The addition of fibre to the diet was found to lower postprandial glucose levels by adsorption in normal subjects (Goulder *et al.*, 1978) as well as in patients with type II diabetes (Anderson, 1980). In spite of these findings, an elevated fibre content in the diet might give rise to glucose formation, e.g. by the action of cellulases. No information is available on the cellulase activity of the gastrointestinal tract in human adults.

The objective of this work was to investigate whether there was any activity in the gastrointestinal tract or if such activity could be induced by cellulose supplementation of a nutritionally complete diet. A second point was to investigate the effect of such a diet on cellulose digestion and blood sugar content.

METHODS

Determination of cellulase activity of human digestive tract

Six adult men and seven women, aged 50–70, served as subjects. All the subjects were given ordinary, low fiber and high fiber (3 × 12 g of wheat bran) controlled diets. The 12-day study was divided into a 3-day adaptation period and three randomly arranged 3-day experimental periods. The day after each period, samples were taken of the stomach and small intestine contents. The cellulose digestion and the cellulase activity of the samples were determined by the reductometric method of Mandels *et al.* (1976) (Table 1). The activity values are given in International Unit/cm^3 (IU). One IU = 1 μmole glucose equivalent per minute. The C_1 activities are given in Units (U). 1 U = released glucose equivalent, as mg from 100 mg of cellulose in 24 h at pH 4·8 and 50°C.

TABLE 1
Cellulase Activity Assays

Method	*Substrate*	*Time (min)*	*Reaction product*
FPA	Filter paper (Whatman No. 1) 1 × 6 cm, 50 mg	60	Glucose Cellobiose
C_1	Cotton 100 mg	1440	Cellobiose
C_x	Carboxymethylcellulose-Na salt (CMC-Na) 1%, 0·5 cm^3 (Sigma, St. Louis)	30	Cellobiose

Blood sugar determination

Blood sugar content was determined according to Sós (1974). 1·5 ml of diluted (1:200) blood sample was boiled with 2 ml of *o*-toluidine reagent (1·5 g thiocarbamide and 60 ml of *o*-toluidine made up to 1000 ml with acetic acid). After cooling, the glucose was determined photometrically at 610–650 (635) nm. As standard glucose (1, 2, ... 6 g w/v % in 0·2% benzoic acid) was used.

$$\frac{\text{Absorbance of sample}}{\text{Absorbance of standard}} \cdot \text{concentration of standard} = \text{blood sugar content (w/v \%)}$$

Administered dietary fiber

The composition of wheat bran was determined according to Hellendoorn *et al.* (1975) (Tables 2 and 3).

RESULTS AND DISCUSSION

The results of the cellulolytic activities of the samples are shown in Figs 1 and 2. The reducing sugar content of the samples was found to be considerable. Higher values were detected after administration of wheat

TABLE 2
The Composition of Wheat Bran (Horváth, E., 1987, unpublished results)

	Water	*Fat*	*Protein*	*Carbohydrate*	*Starch*[a]
Wheat bran	13·0	4·6	14·5	53	20

The values are given in g/100 g wheat bran.
[a] Data according to Schall (1962).

TABLE 3
Dietary Fiber Content of Wheat Bran (Horváth, E., 1987, unpublished results)

	Water soluble	*Water insoluble*	*Total dietary fiber*
Wheat bran	5·6 ± 0·4	53·2 ± 0·8	58·8 ± 0·7

The values are given in g/100 g wheat bran.

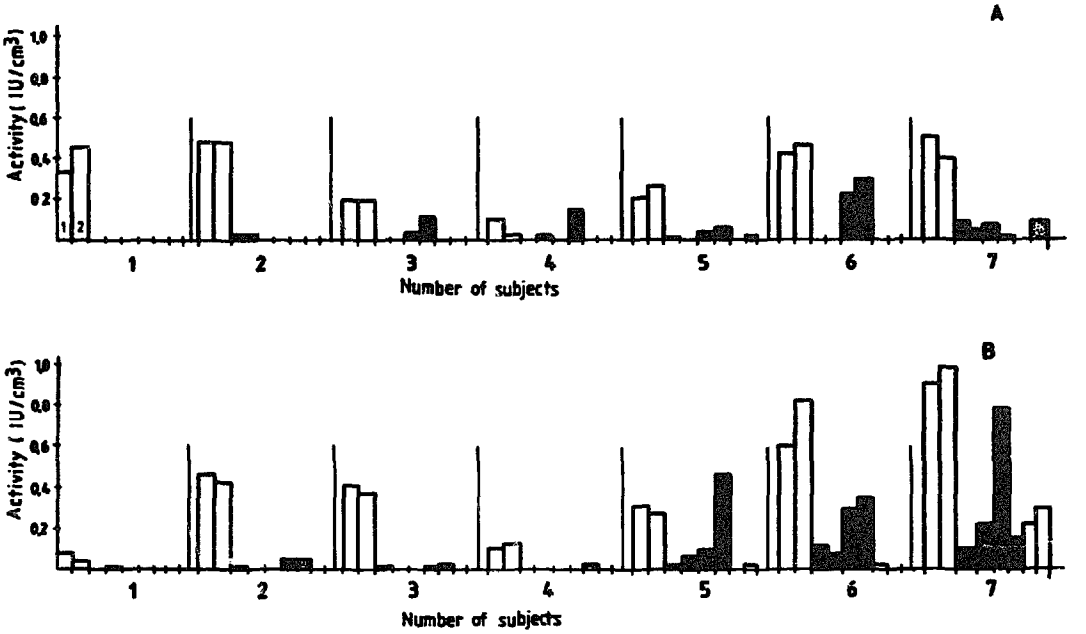

Fig. 1. Reducing sugar content and cellulase activity of female digestive tract (A) before, and (B) after administration of high fiber diet. Activity (IU/cm³): FPA ■; C_1 ▦; C_x ▨; reducing sugar content □. Pairs of columns represent data from (1) stomach and (2) small intestine.

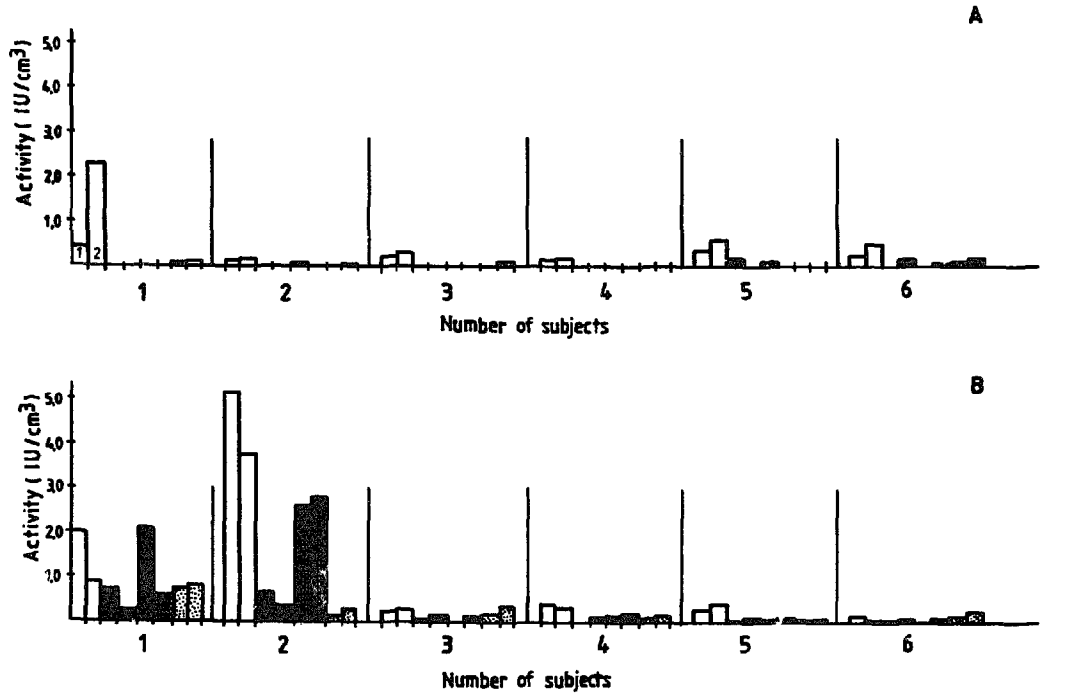

Fig. 2. Reducing sugar content and cellulase activity of male digestive tract (A) before and (B) after administration of high fiber diet. Symbols as in Fig. 1.

TABLE 4
Number of Subjects with Elevated Reducing Sugar Contents in the Stomach and Small Intestine and Induced Cellulolytic Activities after Consumption of High Fibre Diet

	I (*Female*)		*II* (*Male*)		*III* (*Induction*)				*Ratio of activity in small intestine and stomach*[a]			
					Female		*Male*		*Female*		*Male*	
	s	*i*	*s*	*i*	*s*	*i*	*s*	*i*	*Before administration*	*After of high fibre diet*	*Before administration*	*After of high fibre diet*
Reducing sugar	2	2	2	2	4	4	4	2	5	3	6	2
FPA-activity	2	1	2	4	4	3	4	5	1	2	1	4
C_1-activity	3	3	3	5	3	4	5	6	3	2	0	4
C_x-activity	1	1	5	5	5	2	6	6	0	1	3	6

In columns I, II and III, the figures in the body of the table mean: $>0{\cdot}5$ mg/cm^3 reducing sugar; $>0{\cdot}10$ IU/cm^3 FPA-activity; $>0{\cdot}10$ U/cm^3 C_1-activity; $>0{\cdot}10$ IU/cm^3 C_x-activity.
s = Stomach sample; i = small intestine sample.
[a] In many cases cannot be evaluated, because the initial value was 0.

bran. For the small intestine the increase was significant for all the males and, with one exception, for the females, too (Table 4). For the stomach, the increase was significant for the great majority of the subjects. (Tables 5 and 6). Since the free reducing sugar content of the wheat bran was insignificant, the high sugar content of the samples can be explained by the enzymic degradation of the starch content of the wheat bran. Acidic breakdown in the stomach can also lead to the release of reducing sugars. No digestive disorders were observed when dietary fiber was administered to the patients. No correlations have been found between the age of subjects and cellulase activity. In some instances, however, higher values were found for male subjects (Figs 1 and 2).

Female subjects

In the case of females, no or only small quantities (subjects 2, 4, 5, 7) of FPA activity could be detected in the subjects before administration of wheat bran. The FPA activity was found to be significantly inducible in the stomach and small intestine of subjects 6 and 5, 6, 7, respectively. In 50% of the cases, higher FPA activity was found in the stomach than in the small intestine, which might be due to additional reducing sugar formation caused by the acidic breakdown of the filter paper in the extremely acidic medium in the stomach. In subjects 3 and 4 the C_1 activity was found to be lost after

TABLE 5
Reducing Sugar Content and Cellulase Activity of Female Digestive Tract

Sign of subject	*Reducing sugar content (mg glucose equivalent/cm³)*			*FPA*			C_1			C_x		
	A	*B*	*t*	*A*	*B*	*t*	*A*	*B*	*t*	*A*	*B*	*t*
						Female stomach						
1	0·34 ± 0·01	0·08 ± 0·01	31·84***	0	0	0	0	0	0	0	0	0
2	0·48 ± 0·02	0·46 ± 0·02	1·66	0·03 ± 0·01	0·01 ± 0·0	3·46	0	0	0	0	0·06 ± 0·01	10·39**
3	0·20 ± 0·01	0·42 ± 0·01	26·94**	0	0·02 ± 0·0	0	0·04 ± 0·01	0	6·93*	0	0·03 ± 0·02	2·60
4	0·10 ± 0·01	0·10 ± 0·01	0	0	0	0	0	0	0	0	0·02 ± 0·01	3·46
5	0·21 ± 0·01	0·31 ± 0·01	12·25**	0·01 ± 0·0	0·02 ± 0·01	1·73	0·04 ± 0·02	0·11 ± 0·01	5·42*	0	0	0
6	0·42 ± 0·01	0·60 ± 0·01	22·05**	0	0·12 ± 0·03	6·93*	0·22 ± 0·01	0·31 ± 0·01	11·02**	0	0·02 ± 0·01	38·11***
7	0·50 ± 0·01	0·90 ± 0·01	43·99***	0·09 ± 0·01	0·10 ± 0·01	1·22	0·72 ± 0·06	0·78 ± 0·02	1·64	0	0·22 ± 0·01	38·11***
						Female small intestine						
1	0·46 ± 0·02	0·04 ± 0·01	32·53***	0	0·01 ± 0·0	0	0	0	0	0	0	0
2	0·49 ± 0·01	0·42 ± 0·01	8·57*	0·03 ± 0·02	0	2·60	0	0·60 ± 0·01	10·39**	0	0	0
3	0·20 ± 0·01	0·39 ± 0·01	23·27**	0	0	0	0·12 ± 0·01	0·02 ± 0·01	12·25**	0	0	0
4	0·02 ± 0·01	0·12 ± 0·01	12·25**	0·02 ± 0·0	0	0	0·14 ± 0·01	0	23·5**	0	0	0
5	0·26 ± 0·01	0·26 ± 0·01	0	0	0·06 ± 0·01	10·39**	0·06 ± 0·02	0·46 ± 0·02	30·2**	0·02 ± 0·01	0·02 ± 0·01	0
6	0·46 ± 0·01	0·82 ± 0·01	44·09***	0	0·08 ± 0·01	13·86**	0·30 ± 0·01	0·37 ± 0·02	5·6*	0	0·01 ± 0·0	0
7	0·40 ± 0·01	0·99 ± 0·01	72·20***	0·05 ± 0·01	0·21 ± 0·01	19·60**	0·10 ± 0·01	0·15 ± 0·01	8·5*	0·09 ± 0·02	0·30 ± 0·02	12·86**

A: Reducing sugar content and cellulase activity before administration of high fiber diet. Mean values of three replicates.
B: Reducing sugar content and cellulase activity after administration of high fiber diet. Mean values of three replicates. A and B values pertaining to a given subject and parameter were compared by the *t*-test.
t: critical value of *t*-test.
Values with asterisk superscripts indicate significant differences between the respective A and B values: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

TABLE 6
Reducing Sugar Content and Cellulase Activity of Male Digestive Tract

Sign of subject	*Reducing sugar content (mg glucose equivalent/cm³)*			*FPA*			*C_1*			*C_x*		
	A	*B*	*t*	*A*	*B*	*t*	*A*	*B*	*t*	*A*	*B*	
						Male stomach						
1	0·46 ± 0·01	1·99 ± 0·01	187·39***	0	0·71 ± 0·02	61·49***	0	2·08 ± 0·02	180·13***	0·04 ± 0·01	0·75 ± 0·01	86·96***
2	0·14 ± 0·01	5·18 ± 0·02	390·40***	0	0·65 ± 0·01	112·58***	0·2 ± 0·01	2·59 ± 0·01	314·76***	0	0·11 ± 0·01	19·05**
3	0·20 ± 0·01	0·21 ± 0·01	1·22	0	0·07 ± 0·01	12·12**	0	0·02 ± 0·01	3·46	0·02 ± 0·01	0·13 ± 0·01	13·47**
4	0·12 ± 0·01	0·39 ± 0·01	33·07***	0·02 ± 0·01	0·01 ± 0·0	1·73	0	0·15 ± 0·01	25·98**	0	0·12 ± 0·01	20·51**
5	0·36 ± 0·01	0·26 ± 0·01	12·25**	0·07 ± 0·01	0·02 ± 0·01	6·12*	0·04 ± 0·01	0·05 ± 0·01	1·22	0	0·05 ± 0·01	8·66*
6	0·24 ± 0·01	0·14 ± 0·01	12·25**	0	0·03 ± 0·01	5·20*	0	0	0	0·05 ± 0·01	0·17 ± 0·01	14·70**
						Male small intestine						
1	2·29 ± 0·01	0·79 ± 0·01	183·71***	0	0·22 ± 0·01	38·11***	0	0·59 ± 0·01	102·19***	0·07 ± 0·01	0·81 ± 0·01	90·63***
2	0·16 ± 0·03	3·72 ± 0·04	123·32***	0	0·31 ± 0·01	53·69***	0	2·78 ± 0·02	240·76***	0·01 ± 0·0	0·27 ± 0·01	45·03***
3	0·32 ± 0·03	0·29 ± 0·01	4·98*	0	0·15 ± 0·01	25·98**	0	0·12 ± 0·01	20·51**	0·10 ± 0·01	0·34 ± 0·02	18·59**
4	0·15 ± 0·01	0·31 ± 0·03	8·76*	0·02 ± 0·01	0·10 ± 0·01	9·80*	0	0·19 ± 0·01	32·91***	0	0·15 ± 0·02	12·99**
5	0·52 ± 0·01	0·45 ± 0·01	8·57*	0	0·08 ± 0·01	13·86**	0	0·11 ± 0·01	19·05**	0	0·08 ± 0·01	13·86**
6	0·50 ± 0·02	0·08 ± 0·01	32·53***	0·15 ± 0·01	0·07 ± 0·01	9·80*	0·04 ± 0·01	0·08 ± 0·02	3·10	0·17 ± 0·01	0·25 ± 0·01	9·80*

A: Reducing sugar content and cellulase activity before adminstration of high fiber diet. Mean values of three replicates.
B: Reducing sugar content and cellulase activity after administration of high fiber diet. A and B values pertaining to a given subject and parameter were compared by the *t*-test.
t: critical value of *t*-test.
Values with asterisk superscripts indicate significant differences between the respective A and B values: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

wheat bran administration. This may be due to the adsorption of the enzyme on the cotton surface.

In subjects 5, 6, 7 considerable C_1-activity was induced by wheat bran. With the exception of subject 7, higher activity values were found in the small intestine. Very low quantities of C_x activity could be detected in the subjects. However, this activity was also found to be inducible, mainly in the stomach (Fig. 1). (The increase was significant for stomachs of subjects 2, 6 and 7.)

Male subjects

In the majority of cases higher activity values were found for the male subjects (Fig. 2). In subjects 1 and 2 the FPA activity of the stomach was induced to a considerable extent after wheat bran administration. However, the increases were significant for subjects 3, 5 and 6 as well (Tables 5 and 6). The highest C_1 and C_x activities were detected also in subjects 1 and 2, although the induced C_x activities were significantly higher for all the subjects.

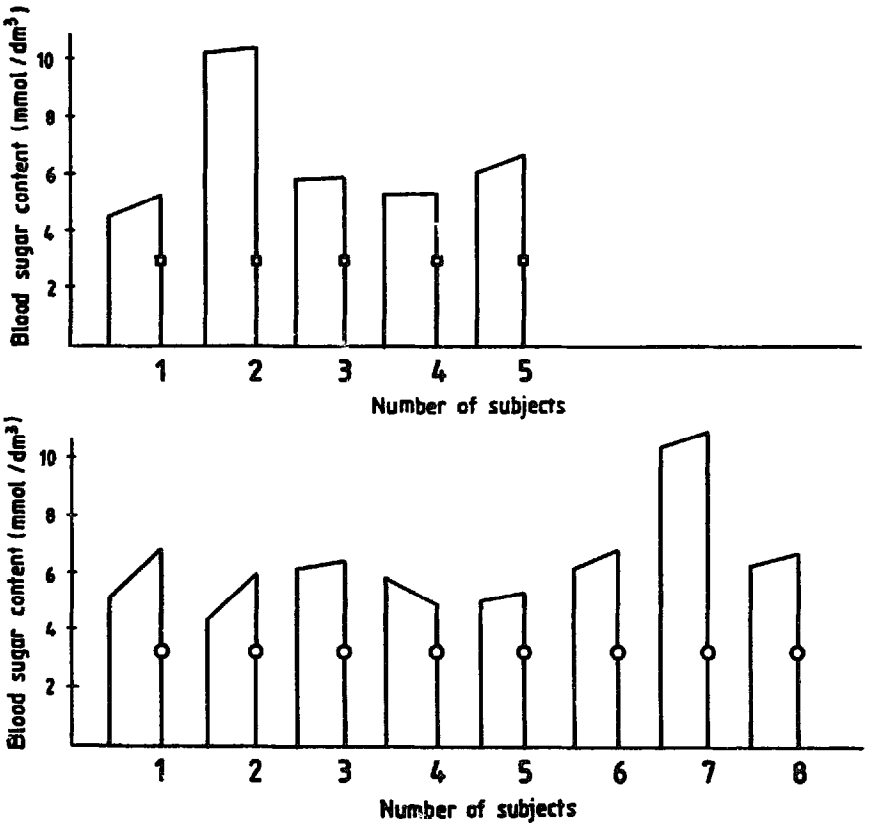

Fig. 3. Blood sugar content before and after administration of high fiber diet. Empty stomach (——); 0·5 h sample (—□—); 1 h sample (—○—).

TABLE 7
Blood Sugar Content before and after Administration of High Fiber Diet

Sign of subject	*Blood sugar content of 0·5 h samples (mol/dm³)*			*Sign of subject*	*Blood sugar content of 1 h samples (mol/dm³)*		
	A	*B*	*t*		*A*	*B*	*t*
1	4·37 ± 0·15	5·23 ± 0·06	9·22*	1	5·40 ± 0·10	6·63 ± 0·15	11·82**
2	10·2 ± 0·10	10·33 ± 0·06	1·93	2	4·50 ± 0·10	5·97 ± 0·06	21·83**
3	5·8 ± 0·10	5·87 ± 0·06	1·18	3	6·17 ± 0·06	6·50 ± 0·2	2·74
4	5·3 ± 0·20	5·33 ± 0·06	0·25	4	5·77 ± 0·06	5·03 ± 0·55	2·32
5	6·03 ± 0·15	6·33 ± 0·06	3·22	5	5·17 ± 0·06	5·27 ± 0·06	2·04
				6	6·27 ± 0·06	6·83 ± 0·06	11·43**
				7	10·63 ± 0·12	10·93 ± 0·06	3·87
				8	6·27 ± 0·06	6·8 ± 0·10	7·87*

A: Blood sugar content before administration of high fiber diet. Mean values of three replicates.
B: Blood sugar content after administration of high fiber diet. Mean values of three replicates.
A and B values pertaining to a given subject and parameter were compared by the *t*-test.
t: critical value of *t*-test.
Values with asterisk superscripts indicate significant differences between the respective A and B values: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Induced activities were found in the other male subjects as well. With the exception of subjects 1 and 2 the small intestine activities were found to be always higher than those found in the stomach fluid (Table 4). All the induced activities were significantly higher than the control values, except for the C_1 activity in subject 6.

No or only slight increase was detected in the blood sugar content 30 min after wheat bran administration (Fig. 3). In the 1 h samples the increase was significant in 50% of the samples. (Table 7).

CONCLUSION

The results of this study indicated that dietary fiber was enzymatically digested in the human gastrointestinal tract. Of the substrates applied for the determination of the cellulolytic activity only glucose and/or cellobiose can be generated by the enzyme. The wheat bran contains hemicelluloses which are preferentially hydrolysed already at the beginning of the process. However, the blood sugar (glucose) content increases after administration of wheat bran in 50% of the cases. To our knowledge no evidence can be found

in the literature for the conversion of pentoses (e.g. xylose) into glucose by microorganisms; we must therefore assume that the β-bonds of the oligomers are split into glucose by cellulases.

The digestion of the starch content of the wheat bran starts already in the mouth tract due to α-amylase. The glucose liberated from the starch is resorbed in the mouth. No differences would be found in the glucose production if it were due exclusively to the hydrolysis of starch.

In the case of microbial contamination there would be no difference in glucose production before and after administration of wheat bran.

The cellulolytic activities were found to be inducible by the addition of dietary fiber. This is particularly well supported by the results obtained with male subjects (for the stomach and the small intestine, respectively, out of 18 data each only 4 and 1 were non-significant). The quantity of the sugars thus released might be relevant for sufferers with diabetes mellitus. In the majority of the subjects investigated, considerable cellulolytic activities were found even without administration of wheat bran. This might be related to eating habits.

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REFERENCES

Anderson, J. W. (1980). The role of dietary carbohydrate and fiber in the control of diabetes. In *Advances in Internal Medicine*, Vol. 26, ed G. H. Stollernan, Yearbook Medical Publishers, Chicago.

Goulder, T. J., Alberti, K. G. M. M. & Jenkins, D. A. (1978). Effects of added fiber on the glucose and metabolic response to a mixed meal in normal and diabetic subjects. *Diabetes Care*, **1**, 351–5.

Hellendoorn, E. W., Noordhoff, M. G. & Slogman, J. (1975). Enzymatic determination of the indigestible residue (dietary fiber) content of human food. *J. Sci. Food Agric.*, **26**, 1461–8.

Jenkins, D. J. A., Wolever, T. M. S., Jenkins, A. L., Lee, R. Wong, G. S. & Josse, R. (1983). Glycemic response to wheat products: Reduced response to pasta but no effect to fiber. *Diabetes Care*, **6**, 155–9.

Kay, R. N. & Strasberg, S. N. (1978). Origin, chemistry, physiological effects and clinical importance of dietary fiber. *Clin. Invest. Med.*, **1**, 9–24.

Kies, C., Sanchez, V. E. & Fox, H. M. (1984). Cellulose supplementation of a nutritionally complete, liquid formula diet: Effect on gastrointestinal tract function of humans and fecal fiber recovery. *J. Food Sci.*, **49**, (3), 815–16.

Mandels, M., Andreotti, R. & Roche, C. (1976). Measurement of saccharifying cellulase. In *Enzymatic Conversion of Cellulosic Materials: Technology and Applications*, ed by E. L. Gaden, M. H. Mandels, E. T. Reese & L. A. Spano, J. Wiley, New York, pp. 21–33.

Sós, J. (ed.) (1974). Determination of blood sugar content. In: *Laboratory Diagnostics*. Medicina, Budapest, p. 176.

Spiller, C. A. & Kay, R. M. (Ed.) (1980). *Medical Aspects of Dietary Fiber*, Plenum Press, New York.

Schall, H. (1962). *Nahrungsmitteltabelle*, Johann Ambrosius Barth Verlag, Leipzig.

Tredger, J., Sheard, C., & Marks, V. (1981). Blood glucose and insulin levels in normal subjects following a meal with and without added sugar beet pulp. *Diabetes Metab.*, 7, 169–72.

Ullrich, I. H. & Albrink, M. J. (1982). Lack of effect of dietary fiber on serum lipids, glucose, and insulin in healthy young men fed high starch diets. *Am. J. Clin. Nutr.*, 36, 1–9.

Wahlqvist, M. L., Morris, M. J., Littlejohn, G. O., Bond, A. & Jakson, R. V. J. (1979). The effect of dietary fiber on glucose tolerance in healthy males. *Aust. NZ J. Med.*, 9, 154–8.