Enrichment of an Israeli ethnic food with fibres and their effects on the glycaemic and insulinaemic responses in subjects with non-insulin-dependent diabetes mellitus

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The effects of various sources of dietary fibre on the high glycaemic index of an Israeli ethnic food, melawach, were investigated in subjects with non-insulin-dependent diabetes mellitus (NIDDM). Locust-bean (*Ceratonia siliqua*) gum significantly decreased the glucose response to, and glycaemic index of, melawach in these diabetic subjects ($P < 0.05$). It also tended to decrease their insulinaemic response and insulinaemic index, but differences were not significant. Dietary fibre from lupin (*Lupinus albus*) and insoluble maize-cob fibre did not affect glucose and insulin levels in NIDDM volunteers. Subjects with a BMI < 30 kg/m^2 exhibited similar glucose, but not insulin, responses to fibre. Locust-bean gum had no significant effect on glycaemic response in NIDDM subjects with a BMI > 30 kg/m^2, whereas insulinaemic response decreased. The results indicate that foods containing the same nutrients in almost the same amounts, but differing in added dietary fibre, lead to different physiological responses in diabetic subjects. Furthermore, insulin response should be considered when fibre is incorporated into the diabetic's diet.

Dietary fibre: Glycaemic response: Insulinaemic response

Since the early 1980s, carbohydrate foods with similar nutrient compositions have been known to cause different glycaemic responses. Variations were noted in the physiological responses to carbohydrate foods that had previously been considered similar (Crapo *et al.* 1976, 1977, 1980, 1981; Jenkins *et al.* 1981, 1983). Jenkins *et al.* (1981) proposed the term 'glycaemic index' (GI) to describe a uniform system for comparing carbohydrate foods. More recently the GI of ethnic Israeli foods have been investigated (Indar-Brown *et al.* 1992). A high GI was found for melawach (made from white flour and fat, mainly butter), a popular food among Yemenite Jews. The purpose of the present research was to examine postprandial responses to melawach containing dietary fibres from different sources. Dietary fibres from lupin (*Lupinus albus*), locust bean (*Ceratonia siliqua*) and maize cob were incorporated into melawach and offered to subjects with non-insulin-dependent diabetes mellitus (NIDDM). Glucose and insulin levels and indices were evaluated.

MATERIALS AND METHODS

Subjects and meals

Fourteen NIDDM subjects volunteered for the study. Their characteristics are summarized in Table 1. Informed consent was received from all subjects. The study was approved by the Committee for the Protection of Human Subjects at Meir Hospital in Kfar-Saba, Israel.

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Table 1. *Characteristics of subjects with non-insulin-dependent diabetes mellitus who participated in the present study*

Subject	Age (years)	Sex	BMI (kg/m²)	Fasting plasma glucose (mmol/l)	Treatment
1	55	F	30	8·75	Glybetic®*
2	66	M	25	9·51	Glybetic
3	65	F	31	8·58	Glybetic
4	59	M	25	8·86	Glybetic
5	60	M	24	9·50	diet
6	57	F	24	8·25	Gluphage®†
7	59	F	34	8·36	Glybetic
8	72	F	25	8·47	Glybetic
9	70	M	24	8·30	Glybetic
10	65	F	30	8·32	diet
11	38	F	35	8·58	diet
12	66	F	30	8·20	Glybetic
13	63	M	31	8·30	Glybetic
14	68	F	35	8·58	Glybetic
Mean	61		28·8	8·7	
SE	6·7		4·3	4·1	

* Glibenclamide, Teva, Israel.
† Metformin, Abic, Israel.

The following ingredients (g) were used to prepare the ethnic food melawach: wheat flour 59, sugar 1·8, soyabean oil 0·9, margarine 8·8, salt 0·9, fibre 15 and water 43·6, making a total of 130 g. The ingredients were mixed and well kneaded. The dough was then fried.

Each subject was randomly assigned to take three iso-energetic (1·8 MJ) meals and a glucose-loading test. One meal contained only basal fibre (3·6 g), whereas the other meals contained fibre (18·6 g total) derived from locust bean, maize cob or lupin. The meals consisted of the following: melawach (130 g, or 115 g without added fibre), margarine (3 g), egg (25 g) and tomato (125 g), and sugarless tea. The composition of the meal was as follows (% energy): protein (N × 6·25) 12, fat 35 and carbohydrate 53. The glucose-loading test included a standard consisting of 50 g glucose providing 0·96 MJ. Values for melawach meals were adjusted to 50 g available carbohydrate for comparison with the standard. The meals were given in random order in the morning, after a 12 h fast and there was a 7–10 d interval between meals. The melawach containing the fibre was served as fried bread and was well accepted by the subjects.

Dietary fibre preparation

Locust-bean gum was obtained from Sigma Chemical Co. (St Louis, MO, USA). Dietary fibres from lupin and maize cob were extracted in our laboratory as follows: (a) maize cob: ears of maize were oven-dried at 100° for 8 h. Kernels were then separated from the cob. Cobs were finely ground, soaked in distilled water for about 2 h to remove sugar residues, filtered through gauze and the filtrate was dried at 50° for 12 h; (b) lupin: lupin beans (1 kg) were soaked in 10 litres distilled water containing 40 ml 5 M-NaOH, pH 7·8, for 90 min at room temperature. The material was filtered through gauze and the precipitate was soaked in 5 litres distilled water containing 0·5 ml 5 M-NaOH for 60 min. The material was again filtered through gauze and the precipitate was dried overnight at 50°. Total dietary fibre was determined using the Prosky method (Prosky *et al.* 1985) and found to be 560 g/kg for maize cob and 820 g/kg for lupin.

Experimental design

Blood samples were taken from the subjects at 0 (fasting time) 30, 60, 120 and 180 min after the post-fast meal. Samples were collected in heparinized tubes, and centrifuged for 10 min at 1300 ***g*** to separate the plasma which was then stored at $-20°$ until biochemical determinations. Plasma glucose concentration was determined using a glucose analyser (Beckman Bun 2, Fullerton, CA, USA). Plasma insulin concentration was determined by radioimmunoassay (Yalow & Berson, 1959; Desbuquois, 1971). Results were plotted as glucose and insulin curves. Glycaemic and insulinaemic indices were calculated as described previously using 50 g glucose as the standard, the GI of which was set at 100% (Jenkins *et al.* 1981; Wolever & Jenkins, 1986). The change in area under the curve was calculated as the incremental area above the fasting value.

Statistical analysis

Statistical analyses were performed in two ways. For variables exhibiting a 'normal' curve, comparison was made by multi-parameter analysis and *t* test. When variables did not clearly exhibit 'normal' curves, comparison was made by Wilcoxon test for paired samples. Statistical analyses were performed using the SAS computer program (Statistical Analysis Systems Institute Inc., Cary, NC, USA). Data were analysed for a significance level of $P = 0{\cdot}05$.

RESULTS

Melawach containing locust-bean gum significantly lowered plasma glucose levels in NIDDM subjects (Fig. 1). The glycaemic response was significantly lower than that obtained following glucose loading at 30, 60 and 120 min ($P < 0{\cdot}001$). It was also significantly lower than those of NIDDM subjects given melawach with and without dietary fibre from lupin and maize cob at 60 and 120 min ($P < 0{\cdot}001$), and melawach with and without dietary fibre from lupin at 180 min ($P < 0{\cdot}001$) (Fig. 1). Melawach containing lupin or maize-cob fibre induced glucose responses similar to that following melawach without fibre, and glucose levels were significantly lower than those following glucose loading. The glycaemic response, expressed as the area under the curve, of subjects given melawach with locust-bean gum was significantly lower ($P < 0{\cdot}05$) than that to melawach without fibre, and to those to melawach containing maize-cob or lupin fibres. The GI (Table 2) of melawach with locust-bean gum (31%) was significantly lower than those of melawach with dietary fibre from lupin and without fibre ($P < 0{\cdot}02$), and was lower, but not significantly, than that of melawach with maize-cob fibre (59%).

The insulin response to melawach with locust-bean gum tended to be lower, but this was not significant (Fig. 2). When the results were expressed as areas under the curve, insulin response bordered on significance (Table 2). The insulinaemic index (II) values of diabetic subjects who had eaten melawach with locust-bean gum tended to be lower, but were not significantly different from those of subjects given melawach with dietary fibre from lupin or maize cob or without fibre (Table 2).

Table 3 summarizes the glycaemic and insulinaemic responses in NIDDM subjects divided according to BMI. Subjects with BMI < 30 exhibited significantly lower glycaemic responses following melawach than those following glucose. Maize-cob and lupin fibres led to responses which were similar to those following melawach alone. Locust-bean gum significantly reduced the glycaemic response when compared with glucose or melawach with or without lupin or maize-cob fibre. The glycaemic responses of subjects with

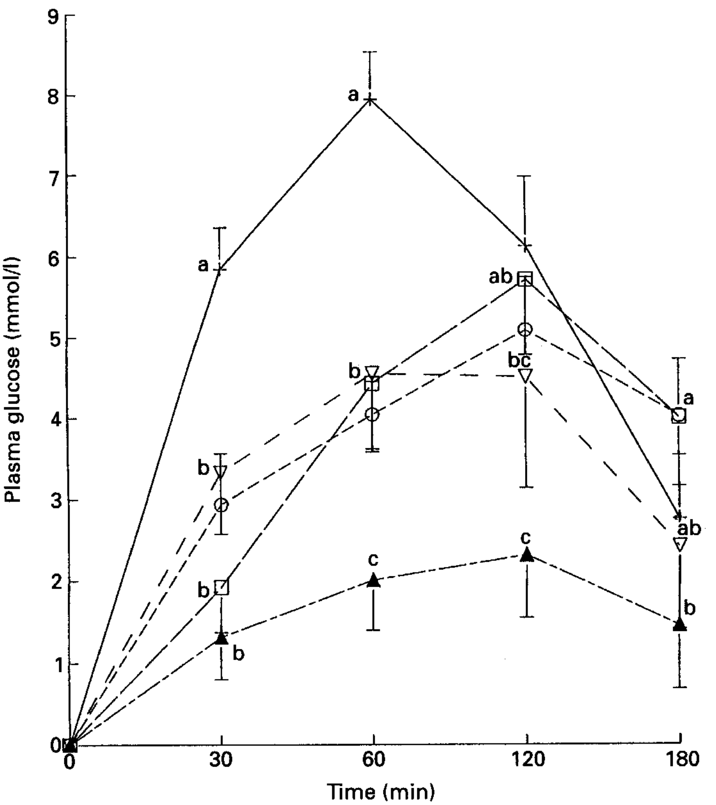

Fig. 1. Plasma glucose responses of subjects with non-insulin-dependent diabetes mellitus following meals of glucose (+ ; *n* 14), melawach (○; *n* 14), melawach + locust-bean gum (▲; *n* 9), melawach + maize-cob fibre (▽; *n* 9) and melawach + lupin fibre (□; *n* 10). For each time point, values not sharing a common letter were significantly different ($P < 0.05$). Values are means with their standard errors indicated by vertical bars.

BMI > 30 following an entire meal showed no significant differences, although the glycaemic response following melawach with locust-bean gum tended to be the lowest. Insulin levels were higher in subjects with BMI > 30 than those with BMI < 30, but the differences were statistically significant only in subjects given glucose or melawach with lupin fibre. Although locust-bean gum reduced the insulin response in both groups, the difference was only statistically significant in the BMI > 30 group.

DISCUSSION

Different glycaemic responses were obtained following the incorporation of various sources of fibre into the same basic food (melawach), as reflected by the different physiological effects of the food in NIDDM subjects (Fig. 1, Table 2). Similar results have been reported by Laine *et al.* (1987). The present study stresses the importance of calculated GI values as an additional means of establishing dietary guidelines for diabetic subjects, which include a recommendation for increased dietary fibre intake. Incorporation of locust-bean gum into melawach led to significant reductions in glucose response and GI. The lack of significance of the lower insulinaemic response and II in diabetics consuming melawach with locust-bean gum compared with the other foods tested (Figs 1 and 2) may be attributed to variations in fasting insulin concentrations. Inconsistent insulin responses (i.e. II) of NIDDM subjects have been reported previously (Indar-Brown *et al.* 1992).

Table 2. *Areas under the glucose and insulin curves, glycaemic index (GI) and insulinaemic index (II) values for subjects with non-insulin-dependent diabetes mellitus after meals of glucose, melawach, and melawach with added dietary fibre from various sources**

(Mean values with their standard errors; the number of subjects is given in parentheses)

	Area under the curve							
	Glucose (mmol/l per h)		Insulin (μU/ml per h)		GI† (%)		II† (%)	
Meal	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Glucose	988[a] (14)	102	2082[a] (13)	205	100[a] (14)	—	100[a] (14)	—
Melawach	693[b] (14)	86	2131[a] (13)	623	71[a] (14)	7	123[a] (13)	23
+Locust-bean gum	317[c] (9)	107	690[a] (9)	239	31[b] (9)	6	60[a] (9)	30
+Maize cob fibre	647[b] (9)	160	1362[a] (8)	373	59[ab] (9)	10	398[a] (8)	316
+Lupin fibre	717[b] (10)	127	2149[a] (8)	945	72[a] (10)	10	472[a] (7)	367

[a, b, c] Mean values within a column with unlike superscript letters were significantly different, $P < 0.05$.

* For details of meals and procedures, see pp. 682–683.

† Based on a 50 g carbohydrate portion; glucose (GI 100 %, II 100 %) was used as a standard.

Locust-bean gum is composed mainly of galactomannan, which may contribute to the reduction in glucose levels. A similar structure is found in guar gum extracted from the Indian cluster bean (*Cyamopsis tetragonoloba*), and fenugreek (*Trigonella foenum graecum*) (Ebelling *et al.* 1988; Madar & Shomer, 1990), which also cause a decrease in glucose level. The advantage of using locust bean rather than, for example, guar is that the former lacks the off-taste characteristic of the latter and is therefore more acceptable to the consumer. The effect of the soluble dietary fibre from locust-bean gum may stem mainly from its higher viscosity, which would cause the lower glycaemic response observed in this work. However, viscosity *in vitro* does not necessarily reflect its effect *in vivo* (Edwards *et al.* 1987; Braaten *et al.* 1991). Differences between *in vitro* and *in vivo* results stress the importance of comparing the effects of dietary fibres *in vivo* in diabetics. The addition of lupin or maize-cob dietary fibre to melawach did not decrease the glycaemic response (Fig. 1) or the GI (Table 2) in NIDDM subjects compared with melawach without dietary fibre. The lupin bean belongs to the legume family, plants of which are characteristically rich in soluble dietary fibre and antinutrients. Legumes are known to have slower rates of digestion than other starchy foods, resulting in low glycaemic responses in healthy, as well as diabetic subjects (Jenkins *et al.* 1988). However, the dietary fibre in lupin bean consists mainly of pectic materials (Samish *et al.* 1990). These pectic materials are probably not effective in lowering glucose level, as has been noted with some other pectins in diabetics (Mahalko *et al.* 1983). The low glycaemic response to legumes is also attributed to the amylose:amylopectin ratio. Legumes contain starch granules which are rich in amylose. These granules have a resistant structure and are therefore more slowly hydrolysed by the intestinal digestive enzymes (Krezowski *et al.* 1987). However, lupin dietary fibre is low in amylose and may therefore have a different effect. Maize cob is rich in insoluble fibre (Madar *et al.* 1993). Other insoluble fibres, such as wheat bran and maize bran, contain cellulose, lignin and several types of hemicellulose (Dreher, 1987), and are known not to

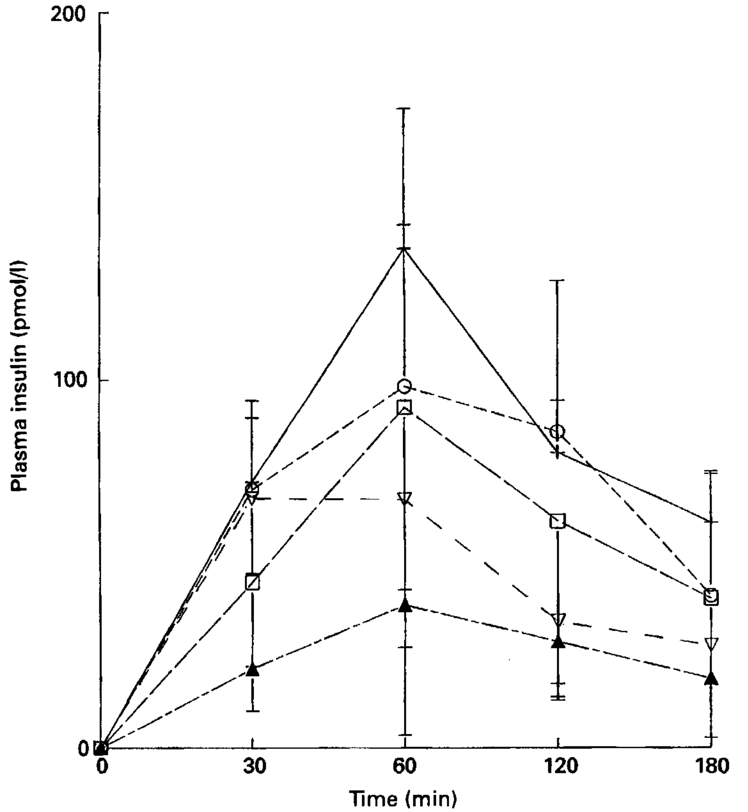

Fig. 2. Plasma insulin responses of subjects with non-insulin-dependent diabetes mellitus following meals of glucose (+ ; *n* 13), melawach (○; *n* 13), melawach + locust-bean gum (▲; *n* 9), melawach + maize-cob fibre (▽; *n* 8) and melawach + lupin fibre (□; *n* 8). Values are means with their standard errors represented by vertical bars. Differences were not statistically significant.

affect glycaemic responses in diabetics (Mahalko *et al.* 1983; Jenkins & Jenkins, 1984). In this work as well, maize-cob fibre did not change glucose or insulin levels in NIDDM subjects. Insoluble fibres are known to retain water, causing an increase in faecal volume and preventing constipation. Thus insoluble fibres may have a long-term effect on glucose and insulin levels (Jenkins & Jenkins, 1984), beyond the scope of the present study. It should be noted that during the preparation of lupin and maize-cob dietary fibres, antinutrients known to reduce glucose levels in the blood (Wolever, 1990) were removed. Another factor to bear in mind is that the percentage of insoluble fibre may have increased during the cooking of the melawach, and the interactions between the various food components may have been affected. Both of these factors may have caused the lack of influence noted with these sources.

The present study demonstrates a significant influence of BMI on glycaemic and insulinaemic responses in NIDDM subjects. Diabetic subjects with BMI higher than 30 kg/m^2 might be more resistant than diabetic subjects with BMI lower than 30 kg/m^2. Therefore, their response to food consumption with or without fibre will be different (Wolever *et al.* 1994). Locust-bean gum significantly decreased glucose levels, but not insulin levels, in patients with BMI $<$ 30 kg/m^2 (Table 3). On the other hand, glucose decreased non-significantly in subjects with BMI $>$ 30 kg/m^2. This may be dependent on

Table 3. *Glycaemic and insulinaemic responses of subjects with non-insulin-dependent diabetes mellitus and BMI values either less than or greater than 30 kg/m² to meals of glucose, melawach and melawach with added dietary fibre from various sources*†

(Mean values with their standard errors; the number of subjects is given in parentheses)

	Glucose (mmol/l per h)				Insulin (μU/ml per h)			
	BMI < 30		BMI > 30		BMI < 30		BMI > 30	
Meal	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Glucose	1078[a] (6)	134	906[a] (8)	149	1036[a] (6)	319	2979[a]* (7)	495
Melawach	660[b] (6)	102	717[a] (8)	136	1418[a] (6)	815	2741[a] (7)	911
+Locust-bean gum	267[c] (4)	62	356[a] (5)	194	662[a] (4)	442	713[b] (5)	298
+Maize cob fibre	586[b] (5)	113	723[a] (4)	358	1275[a] (4)	600	1448[ab] (4)	534
+Lupin fibre	582[b] (5)	61	851[a] (5)	244	893[a] (4)	390	3405[a]* (4)	664

a, b, c Mean values within a column with unlike superscript letters were significantly different, $P < 0.05$.
* Mean values were significantly different from those for BMI < 30 kg/m², $P < 0.05$.
† For details of meals and procedures, see pp. 682–683.

BMI, on degree of insulin resistance and their relationship with glycaemic response following meal consumption.

In summary, the soluble dietary fibre from locust bean decreased glucose and insulin levels in NIDDM subjects, and resulted in better control of glucose level. Dietary fibres from lupin and maize cob did not significantly affect glucose and insulin levels in these subjects. The results indicate that foods containing the same nutrients in almost the same amounts, differing only in added dietary fibre, may cause different physiological responses in diabetics. Dietary fibre, particularly locust-bean gum, may benefit diabetic subjects with BMI < 30 kg/m² more than those with BMI > 30 kg/m².

REFERENCES

Braaten, T., Wood, P. J., Scott, F. W., Riedel, K. D., Poste, C. M. & Collins, M. W. (1991). Oat gum lowers glucose and insulin after an oral glucose load. *American Journal of Clinical Nutrition* **53**, 1425–1430.

Crapo, P. A., Insel, J., Sperling, M. & Kolterman, O. G. (1981). Comparison of serum glucose, insulin and glucagon responses to different types of complex carbohydrates in non-insulin-dependent diabetic patients. *American Journal of Clinical Nutrition* **34**, 184–190.

Crapo, P. A., Kolterman, O. G., Waldeck, N., Reaven, G. & Olefsky, J. (1980). Postprandial hormonal responses to different types of complex carbohydrates in individuals with impaired glucose tolerance. *American Journal of Clinical Nutrition* **33**, 1723–1728.

Crapo, P. A., Reaven, G. & Olefsky, J. (1976). Plasma glucose and insulin responses to orally administered simple and complex carbohydrates. *Diabetes* **25**, 741–747.

Crapo, P. A., Reaven, G. & Olefsky, J. (1977). Postprandial plasma glucose and insulin responses to different complex carbohydrates. *Diabetes* **26**, 1178–1183.

Desbuquois, R. (1971). Use of polyethylene glycol to separate free and antibody-bound peptide hormones in radioimmunoassay. *Journal of Clinical Endocrinology* **33**, 732–738.

Dreher, M. L. (1987). Dietary fiber. In *Handbook of Dietary Fiber*, pp. 145–246 [M. L. Dreher, editor]. New York and Basel: Marcel Dekker Inc.

Ebelling, P., Yaki-Jarvinen, H., Aro, A., Helve, E., Sinisalo, M. & Koivisto, V. A. (1988). Glucose and lipid metabolism and insulin sensitivity in type 1 diabetes: the effect of guar gum. *American Journal of Clinical Nutrition* **48**, 98–103.

Edwards, C. A., Blackburn, N. A., Craigen, P., Davidson, P., Tomlin, J., Sugden, K., Johnson, I. T. & Read, N. W. (1987). Viscosity of food gums determined in vitro related to their hypoglycemic actions. *American Journal of Clinical Nutrition* **46**, 72–77.

Indar-Brown, K., Norenberg, C. & Madar, Z. (1992). Glycemic and insulinemic responses after ingestion of ethnic foods by NIDDM and healthy subjects. *American Journal of Clinical Nutrition* **54**, 89–95.

Jenkins, A. L. & Jenkins, D. J. A. (1984). The clinical implication of dietary fiber. *Advances in Nutrition Research* **6**, 169–197.

Jenkins, D. J. A., Wolever, T. M. S. & Jenkins, A. L. (1988). Starchy foods and glycemic index. *Diabetes Care* **11**, 149–159.

Jenkins, D. J. A., Wolever, T. M. S., Taylor, R. H., Barker, H., Fielden, H., Baldwin, J. M., Bowling, A. C., Newman, H. C., Jenkins, A. L. & Biol, D. V. G. (1981). Glycemic index of foods: a physiological basis for carbohydrate exchange. *American Journal of Clinical Nutrition* **34**, 362–366.

Jenkins, D. J. A., Wolever, T. M. S., Thorne, M. J., Lee, R., Kalmusky, J., Reichert, R. & Wong, G. S. (1983). The glycemic index of foods test in diabetic patients: new basis for carbohydrate exchange favouring the use of legumes. *Diabetologia* **24**, 257–264.

Krezowski, P. A., Nuttall, F. Q., Gannon, M. C., Billington, C. J. & Parker, S. (1987). Insulin and glucose responses to various starch-containing foods in type II diabetic subjects. *Diabetes Care* **10**, 205–212.

Laine, D. C., Thomas, W., Levitt, M. D. & Bantle, J. P. (1987). Comparison of predictive capabilities of diabetic exchange lists and glycemic index of foods. *Diabetes Care* **10**, 387–394.

Madar, Z. & Shomer, I. (1990). Polysaccharide composition of a fraction derived from fenugreek and its effect on starch digestion and bile acid absorption in rats. *Journal of Agricultural and Food Chemistry* **38**, 1535–1539.

Madar, Z., Timar, B., Nyska, A. & Zusman, E. (1993). Effect of high-fiber diets on pathological changes in DMH-induced rat colon cancer. *Nutrition and Cancer* **20**, 87–96.

Mahalko, J. R., Sandstead, H. H., Johnson, L. K., Milne, D. B., Warner, R. C. & Haunz, E. A. (1983). Effect of consuming fiber from corn bran, soyhulls or apple powder on glucose tolerance and plasma lipids in type II diabetes. *American Journal of Clinical Nutrition* **39**, 25–33.

Prosky, L., Asp, N. & Furda, I. (1985). Determination of total dietary fiber in foods and food products: collaboration study. *Journal of the Association of Official Analytical Chemists International* **68**, 677–679.

Samish, S., Borges, G. & Madar, Z. (1990). Nutritional and metabolic aspects of lupine seeds and their fraction in feeding experiments with rats. In *Proceedings of Joint CEC-NECRO 89-14*, pp. 131–141 [Y. Birk, A. Dovrat, M. Waldman and H. Uzureau, editors]. Poznań, Poland.

Wolever, T. M. S. (1990). Relationship between dietary fiber content and composition in foods and the glycemic index. *American Journal of Clinical Nutrition* **51**, 72–75.

Wolever, T. M. S. & Jenkins, D. J. A. (1986). The use of the glycemic index in predicting the blood glucose response to a mixed meal. *American Journal of Clinical Nutrition* **54**, 167–172.

Wolever, T. M. S., Nguyen, P. M., Chiasson, J. L., Hunt, J. A., Josse, R. G., Palmason, C., Rodger, N. W., Ross, S. A., Ryan, E. A. & Tan, M. H. (1994). Determinants of diet glycemic index calculated retrospectively from diet records of 342 individuals with non-insulin-dependent diabetes mellitus. *American Journal of Clinical Nutrition* **59**, 1265–1269.

Yalow, R. S. & Berson, S. A. (1959). Assay of plasma insulin in human subjects by immunological methods. *Nature* **184**, 1648–1649.

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