

## Effect of Barley $\beta$ -Glucan in Durum Wheat Pasta on Human Glycemic Response

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### ABSTRACT

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High-fiber, high-carbohydrate diets, including foods with low glycemic index, have been associated with prevention and treatment of diseases such as coronary heart disease and diabetes.  $\beta$ -glucan, a soluble, viscous polymer found in oat and barley endosperm cell wall, was incorporated into pasta test meals. Five fasted adult subjects were fed test meals of a barley and durum wheat blend pasta containing 100 g of available carbohydrate, 30 g of total dietary fiber (TDF) and 12 g of  $\beta$ -glucan, or an all durum wheat pasta containing the same amount of available

carbohydrate, 5 g of TDF, and negligible  $\beta$ -glucan. The  $\beta$ -glucan and durum wheat pasta resulted in a lower glycemic response as measured by average total area and maximum increment of the blood glucose curves. Lower insulin response to the  $\beta$ -glucan and durum wheat pasta was also indicated by lower average area and increment characteristics of the insulin curves. Barley  $\beta$ -glucans may be an economical and palatable ingredient for processed food products formulated to modify glycemic and insulin response.

Soluble dietary fibers have been shown to alter the rate of absorption or digestion of carbohydrates, resulting in lowered postprandial blood glucose and insulin response (Jenkins et al 1976, 1977), and lowered serum cholesterol levels (Jenkins et al 1975, 1979). Most glycemic studies have utilized isolated fibers such as guar gum (Jenkins et al 1976, 1977, Smith et al 1982) or psyllium (Wolever 1991) as sources of soluble fiber. The use of foods containing guar in postprandial glycemic studies has been carried over into clinical applications with foods containing guar to lower the glycemic response of diabetics (Smith et al 1982, Briani et al 1987). Foods formulated with guar gum are reported to have undesirable sensory attributes and sometimes result in vomiting, increased flatulence, or diarrhea (Simons et al 1981, Smith et al 1982). When  $\beta$ -glucan, a soluble fiber, was isolated from oats or consumed as oat porridge, it was reported to reduce postprandial blood glucose (Wood et al 1990, Wood 1993). However, in another study, rolled oats or oat porridge were reported to elicit high metabolic response (Granfeldt et al 1995). Barley flour in which  $\beta$ -glucan has been concentrated 3–4 times the naturally occurring levels (Knuckles 1992) is expected to have physiological effects similar to other isolated soluble fibers and oat  $\beta$ -glucan when partially substituted for wheat flour in traditional cereal products. In sensory studies, bread, pasta, and muffins containing 1.9–8.6%  $\beta$ -glucan from enriched barley flours had acceptable sensory properties (Knuckles et al 1997), unlike guar gum products.

Pastas, in general, are considered to have low glycemic indices and, correspondingly, produce low postprandial blood glucose and insulin responses (Jenkins et al 1983, Bornet et al 1987, Granfeldt et al 1991). Such responses can be further lowered by the incorporation of  $\beta$ -glucan into pasta as will be shown in this study. Previous studies of pasta containing 20% guar gum have shown that this soluble fiber can attenuate glucose and insulin responses and

may be useful in the diets of diabetic individuals (Gatti et al 1984). In this study, postprandial glucose and insulin responses were measured in subjects fed test meals consisting of pasta containing 7.7%  $\beta$ -glucan (dwb) formulated with  $\beta$ -glucan-enriched barley flour substituted for part of the standard wheat pasta flour. Consumption of cereal food products with reduced glycemic response may be increased by availability of ingredients that are palatable, natural, and economic sources of soluble fiber, such as  $\beta$ -glucan-enriched barley or oat flours.

### MATERIALS AND METHODS

$\beta$ -glucan-enriched barley flour was prepared from the Waxbar variety by repeatedly milling and sifting through a 325-mesh sieve to remove barley starch as described earlier (Knuckles et al 1992). The other pasta ingredients, durum wheat semolina and fresh egg whites, were purchased locally. Composition of the wheat semolina and the  $\beta$ -glucan-enriched barley flour are listed in Table I. Proximate composition of flours and pasta was determined using methods 2.057, 7.056, 14.006, 14.003, and 14.004 of the AOAC (1980).  $\beta$ -glucan content was determined as glucose released by hydrolysis with  $\beta$ -glucanase ( $\beta$ -glucanase, Megazyme, (Aust) Pty. Ltd., North Rocks, N.S.W., 2151) as described by McCleary et al (1985, 1986). Total dietary fiber, insoluble fiber and soluble dietary fiber were determined by methods 985.29 and 991.42 of the AOAC (1980) and Prosky et al (1988), respectively. Total carbohydrate was calculated by difference, and available carbohydrate was determined as total carbohydrate less total dietary fiber.

Pasta was prepared using a KitchenAid K5SS Pro-Line mixer equipped with a Pasta Maker attachment, following a standard homestyle formula and method (Knuckles et al 1997). Proximate composition,  $\beta$ -glucan content, and moisture balance were followed throughout the cooking and drying process to allow calculations of cooked yield and appropriate serving sizes for the test meals. Pasta composition is listed in Table I.

Subjects for this free-living study included four male and one female, healthy, nondiabetic volunteers, aged 36–60 years, with normal weight for height (weight: 68.0–80.7 kg; BMI: 22.8–27.8). Subjects were screened by questionnaire for health status and for food frequency, usual diet, and exercise habits, to eliminate individuals consuming unusual or very restricted diets and highly physically trained individuals. Subjects also maintained a dietary history throughout the three week study period. The study protocol was approved by the Human Subjects Review Committee of

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the University of California, Davis, and the USDA-ARS Human Studies Committee.

The day before the test, subjects consumed no food or beverage except water after 9:00 p.m., and test meals were served at approximately 9:00 a.m. the next day. The meals were served in a non-random order, the plain pasta meal was administered first, and the barley pasta meal was administered approximately one week later. Each test meal consisted of freshly cooked pasta, supplying 100 g of available carbohydrate, with 300 mL of distilled water to drink. A small amount (5 g) of butter was added to the pasta to improve palatability, and subjects were allowed to add a variety of dry seasonings, such as salt, pepper, herbs, and spices.

Prior to feeding the test meal, an indwelling catheter was inserted into the forearm vein and a fasting blood sample (20 mL) was taken. The subjects were then given the test meal (time 0) and consumed it within 15 min. Blood samples (10 mL) were drawn at 30, 60, 120, and 180 min from time 0. Blood was mixed with ethylenediaminetetraacetic acid (EDTA) and spun at 2,000 rpm for 20 min. Plasma was removed, divided into appropriate aliquots, and stored at  $-18$  or  $-70^{\circ}\text{C}$  until analyzed. Plasma glucose was determined by the hexokinase method (procedure 16-UV, Sigma Chemical Co., St. Louis, MO). Plasma insulin was determined by a modified radioimmunoassay using phosphate buffer containing human serum albumin (Yalow et al 1960), with precipitation by polyethylene glycol to separate free and antibody-bound insulin (Desquibus et al 1971).

Data and statistical analyses were based on the curves obtained by plotting blood glucose or insulin concentrations over time. Total area under the curve (mmol/L·hr or pmol/L·hr), incremental area (area under the curve but above the baseline initial levels), maximum increment (difference between baseline level and peak concentration), and time to reach peak concentration of glucose and insulin were calculated for each subject. Data was analyzed using the Statview computer program (Abacus Concepts, Berkeley, CA). Differences between treatments for each individual subject were tested by paired comparisons (two-tailed *t*-test), and were considered significant at  $P < 0.05$ .

**TABLE I**  
Flour and Cooked Pasta Composition (% dwb)<sup>a</sup>

	Wheat Semolina	Enriched Barley Flour	Wheat Pasta	Barley Pasta
Moisture	14.0	9.3	10.8	6.4
Protein (N × 6.25)	16.5	12.1	18.1	18.5
Fat	1.0	3.8	0.1	1.0
Total dietary fiber <sup>b</sup>	3.8 ± 0.2	32.4 ± 2.0	4.1 ± 0.1	17.4 ± 0.5
Soluble dietary fiber	...	14.0	...	5.3
β-Glucan	0.2	20.1	0.2	7.7
Carbohydrate, total	81.4	80.2	80.8	78.7
Ash	1.1	4.0	1.1	1.8

<sup>a</sup> Carbohydrate by difference. Available carbohydrate = total carbohydrate minus total dietary fiber. Proximate analyses are the mean of duplicate measurements with <1% RSD. Total and soluble dietary fiber results are the mean of six replicates with <10% RSD. β-Glucans results are the mean of three replicates with <10% RSD.

<sup>b</sup> Sum of soluble and insoluble dietary fiber.

**TABLE II**  
Plasma Glucose and Insulin of Subjects Consuming Barley or Plain Wheat Pastas<sup>a</sup>

	Glucose (mol/L·hr)		Insulin (pmol/L·hr)	
	Plain	Barley	Plain	Barley
Total area	18.4 ± 3.7	16.3 ± 2.9*	870 ± 570	475 ± 200
Incremental area	3.3 ± 2.1	1.6 ± 0.6	740 ± 500	330 ± 120
Max. increment <sup>b</sup>	2.7 ± 1.0	1.0 ± 0.5**	400 ± 245	185 ± 70*
Time to peak, min	42 ± 16	78 ± 40*	60 ± 37	78 ± 40

<sup>a</sup> Mean ± standard deviation responses of five subjects to plain vs. barley pasta meals. \* =  $P \leq 0.05$ , \*\* =  $P \leq 0.001$  in paired *t*-test.

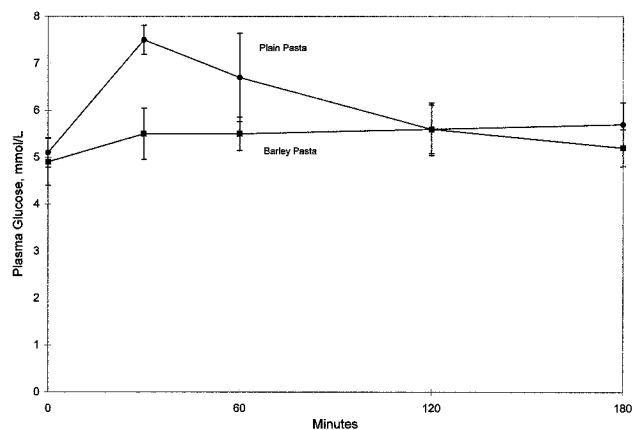
<sup>b</sup> Peak level minus baseline.

## RESULTS

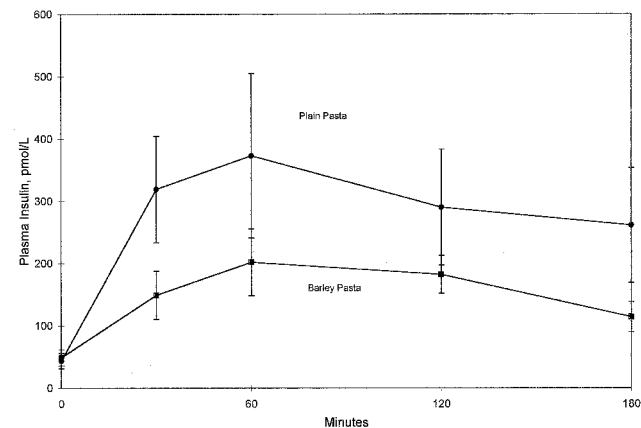
The glucose responses of subjects fed plain durum wheat pasta (plain pasta) and pasta containing 40% β-glucan-enriched barley flour (barley pasta) are shown in Fig. 1 and Table II. Initial plasma glucose levels were consistent between the two test meals for all subjects, except for one subject whose initial plasma glucose level was 1.1 mmol/L lower for the barley pasta test compared to the plain pasta test.

The maximum increment in glucose is significantly lower for barley pasta than for plain wheat pasta, ( $P \leq 0.001$ ). Total area under the plasma glucose curves of the barley pasta are significantly lower than the plasma glucose curves for the wheat pasta ( $P \leq 0.05$ ). The average time-to-peak of the plasma glucose curves for the barley pasta is significantly delayed compared to the wheat pasta, ( $P \leq 0.05$ ).

The insulin responses to the plain and barley pasta meals are shown in Fig. 2 and Table II. A reduced insulin response resulted from the barley pasta meal compared to the plain pasta meal. Average total and incremental areas under the insulin curves for the barley pasta were lower than plain pasta. Although these differences only approached statistical significance ( $P \leq 0.08$ ) with this small sample size, these results suggest that potential physiological differences do exist. However, maximum increment be-



**Fig. 1.** Plasma glucose measurements (mean ± standard error of the means) of fasted subjects ( $n = 5$ ) after consumption of plain pasta (●) containing durum wheat flour that had negligible β-glucan content and of barley pasta (■) containing a blend of β-glucan-enriched barley flour and durum wheat flour.



**Fig. 2.** Plasma insulin measurements (mean ± standard error of the means) of fasted subjects ( $n = 5$ ) after consumption of plain pasta (●) containing durum wheat flour that had negligible β-glucan content and after consumption of barley pasta (■) containing a blend of β-glucan-enriched barley flour and durum wheat flour.

tween peak and baseline was significantly lower ( $P \leq 0.05$ ) for the barley pasta. The time-to-peak insulin response was greater following the barley pasta meal than the plain pasta, but this increase was not significant, in contrast to the significantly different time-to-peak for plasma glucose. The insulin response of one subject was much higher than the response of other subjects. Averaged insulin response of the remaining four subjects at all time points was still higher for the plain pasta than for the barley pasta.

## DISCUSSION

In this study, barley flour enriched in  $\beta$ -glucan and total dietary fiber, rather than purified food gums, has been used to replace a part of the wheat flour in pasta. This enriched pasta gave indications that it may be effective in reducing postprandial plasma glucose and insulin levels. Processed cereal products such as bread, bakery products, breakfast cereals, and pasta are convenience products and are consumed regularly in the United States. Unlike many processed cereal products, commercial durum wheat pasta has been found to be low in glycemic index (Jenkins et al 1983, Bornet et al 1987). In vitro digestibility of various cereal products by  $\alpha$ -amylase parallels glycemic response and suggests that rate of digestibility, rather than decreased diffusion, is rate limiting (Bornet et al 1989, Colonna et al 1990). On the other hand, glycemic studies of homogeneous solutions of soluble fiber and glucose show an inverse relationship between viscosity and plasma glucose level (Jenkins et al 1978, Wood et al 1990).

Our results parallel the findings of Gatti et al (1984), who reported that the addition of 20% guar gum to pasta resulted in a reduced glycemic response in normal and diabetic subjects when compared to pasta without added guar gum. They showed that postprandial plasma glucose levels of five normoglycemic subjects fed pasta containing guar gum were significantly lower at 30 and 60 min than subjects fed pasta without guar gum, but the levels were the same at 120 min and higher at 180 min. Postprandial plasma glucose levels in the present study appeared not to rise steadily as in the guar pasta study, but remained flat throughout the 180-min sampling period, as characterized by a significantly lower maximum increment of 0.95 mmol/L (Table II). Subjects in the guar gum pasta study consumed 66 g of carbohydrate, 11 g of protein (from pasta and cheese), and 11 g of fat (from butter and cheese) compared to 100 g of available carbohydrate, 25–30 g of protein (from wheat and barley), and 5 g of fat (from butter) in this study. Fat and protein are known to elevate insulin levels, which will affect plasma glucose (Bornet et al 1987). Gatti et al did not report insulin response for this part of the study, but showed that insulin response was moderated when guar gum pasta was consumed as a part of a mixed meal.

The reduced glycemic response to pasta with guar or  $\beta$ -glucan compared to plain pasta without guar or  $\beta$ -glucan is probably due to delayed gastric emptying (Leclere et al 1994) or to slower absorption due to viscosity-related effects at the intestinal surface (Briani et al 1987) rather than further reductions in rate of digestion. Rates of digestion were also related to surface area and sometimes ingredient differences (Colonna et al 1990), which were not variables in this study.

In conclusion, the incorporation of cereal  $\beta$ -glucan into pasta can further reduce the glycemic and insulinemic responses of a food product already low in glycemic properties.  $\beta$ -glucan from enriched barley flour seems to be at least as effective, if not more effective, at 6.4% of ingredients than higher amounts of guar gum. Many studies utilizing guar gum have noted the adverse sensory and physiological response to guar.  $\beta$ -glucans on the other hand seem to be acceptable in pasta, bread, and muffins. The substitution of  $\beta$ -glucan-enriched barley flour for some wheat flour in foods that contain a large proportion of wheat flour may be a practical means of controlling postprandial glycemic and insulin response.

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