

Physiological Responses of Men and Women to Barley and Oat Extracts (Nu-trimX). II. Comparison of Glucose and Insulin Responses

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ABSTRACT

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This study was designed to compare the glucose, insulin, and glucagon responses to consumption of high-soluble β -glucan compounds from oats and barley. After an initial medical evaluation that included blood and urine testing, 11 men and 11 women, nondiabetics, 35–57 years, were selected. Subjects consumed a controlled diet for three days. On the third day of five successive periods, subjects consumed 1 g/kg of body weight of carbohydrate as glucose or 0.66 g/kg of body weight pudding (predominantly sucrose) and 0.33 g/kg of body weight as oat bran, barley flour, oat or barley extract (Nu-trimX) in a Latin square design. Order of treatment was randomly assigned. Glycemic responses were calculated

using the trapezoid method. Data were analyzed using mixed procedure analysis of variance program. Glucose responses to oats, barley, and both extracts, and areas under the curve were significantly lower than responses to the glucose solution ($P < 0.0001$). Insulin responses for the barley extract were lowest and were significantly lower than for glucose solution. Oat and barley extracts retain the beneficial effects of the grains from which they are extracted. High-soluble fiber barley is more effective than standard oats. Oat and barley carbohydrate-based fat substitutes can provide a useful addition to menus to control plasma glucose responses.

Cereal fibers have beneficial effects on glucose metabolism (Jenkins et al 1978; Yokoyama et al 1997; Hallfrisch and Behall 2000), blood lipids (Akerberg et al 1998), risk of colon cancer (McIntosh 1993). Soluble fibers are one of the effective components in glucose and lipid control (Wood et al 1989; Braaten et al 1991). Oats and barley are both high in soluble fibers (Lee et al 1992) and are effective in lowering blood cholesterol in humans (McIntosh et al 1995). Oat foods have also been used to help to control postprandial glucose and insulin levels in diabetes mellitus patients (Golay et al 1992). Glycemic index has been used to calculate glycemic load in epidemiological studies and related to beneficial health outcomes including reduced risk of type 2 diabetes mellitus (Hu et al 2001) and coronary heart disease (Liu et al 2000). Health claims for oats indicate that oats are effective in lowering blood cholesterol levels. (FDA 2001). However, the recommended effective level of consumption is four servings per day, each containing at least 0.75 g of soluble fiber. Hallfrisch et al (1995) have shown that a high soluble fiber extract developed from oat starch (Oatrim) (Carriere and Inglett 1998) reduces glucose responses and insulin levels in men and women. This extract can be added to a variety of foods without significantly affecting the palatability of the menus (Hallfrisch and Behall 1997).

A new procedure to produce fat substitutes from a variety of grains has been developed by Inglett (2000). Called Nu-trimX (NUTrient Technical Research Involving Metabolism--bran eXtracted), this process extracts solubilized β -glucans from oats or barley endosperm while reducing the cellulose components. This wet extraction process removed the bran fiber components from cooked grains and processed flours, resulting in hydrocolloids that can be used as substitutes for cream, coconut cream, and other high-fat components of baked goods, frozen desserts, meats, and salad dressings (Inglett 2001). Use of foods containing these extracts can result in substantial reductions of fat, saturated fat, and energy intake, but it has not yet been determined whether or not these extracts retain the beneficial health effects of oats and barley. The barley used, Prowashonupana, is a high-soluble fiber cultivar that contains $\approx 2\times$ times the amount of soluble fiber found in the oat bran used.

This study compared the plasma glucose, insulin, and glucagon responses in nondiabetic adults to oat bran, barley, and extracts (Nu-trimX) produced from them compared with responses to oral glucose as a control.

MATERIALS AND METHODS

The study was approved by the Institutional Review Boards of the United States Department of Agriculture and Johns Hopkins University School of Public Health before the study. Medical evaluation and blood and urine screen were conducted by Karen Herrmann, M.D., Johns Hopkins School of Public Health. Subjects were excluded for abnormal fasting glucose, hyperlipidemia, urinary tract infections, and the use of medications affecting glucose metabolism. Eleven nondiabetic men and 11 nondiabetic women were selected for the study (Table I). Men and women initially were paired for age and body mass index (BMI). Two of the men did not complete the study. One moved out of state and the other had difficulty consuming all of the test meals. The final group of men was slightly older and heavier, but mean age and BMI of the remaining men and the women were similar.

Study design and regimen were elaborated in a companion report (Hallfrisch and Behall 2003). Another of the sample menus is included in Table II. On the third day of controlled feeding, a tolerance test (1 g of carbohydrate/kg of body weight) as glucose or 0.66 g/kg of body weight pudding (predominantly sucrose) + 0.33 g/kg of body weight oat bran, barley flour, or oat or barley extract (Nu-trimX) in a Latin square design. Mean macronutrient amounts of test meals are reported separately (Hallfrisch and Behall 2003). Subjects were asked to consume test meals within 10 min. Order of treatment was assigned randomly to age and BMI matched pairs. There was an 11 day washout period between each treatment. Water was added to the barley and oat treatments to equalize the volume consumed during the glucose tolerance test. Blood samples were drawn at fasting, 0.5, 1, 2, and 3 hr after consumption of the treatment by a licensed phlebotomist.

Plasma glucose levels were analyzed with a kit (#15910, Trace-America, Allentown, PA) that uses an automated enzymatic method (CentrifChem System 500, Union Carbide, Trace-America, Miami, FL). Plasma insulin levels were analyzed by radioimmunoassay (RIA) using the RSL ¹²⁵I Insulin kit #07-160102 (ICN Biomedicals, Diagnostic Division, Irvine, CA). Plasma glucagon levels were measured using a similar procedure, specific for glucagon (double antibody ¹²⁵I RIA #KGND1 Diagnostic Products, Los Angeles, CA). The samples were counted in a gamma counter (Auto-Gamma 5000 series, Packard Instrument, Downers Grove, IL).

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Glucose, insulin, and glucagon data were analyzed using the mixed procedure analysis of variance (ANOVA) using SAS v. 6.12. Areas under the curve for glucose and insulin were calculated using the trapezoid formula (Gannon and Nutall 1987). A value of $P < 0.05$ was considered statistically significant. Mean separation of significant terms was conducted using least significant difference range test.

RESULTS

Only data from the nine men and 11 women who completed the study are included in the analyses. Plasma glucose responses were affected by time ($P < 0.0001$) and the interactions of test meal time \times ($P < 0.03$), and sex \times time ($P < 0.02$). (Fig. 1) Fasting values were similar for men and women. At 30 min, plasma glucose was significantly higher after glucose than after barley extract. At 60 min, both barley meals and the oat bran were lower than levels after glucose. Glucose levels at 120 min were similar regardless of test meal, but at 180 min, glucose levels after oat bran and barley flour were higher than after glucose or either extract. Both the highest (30 min) and lowest (120 min) mean values occurred after glucose. Though men and women did not respond differently to the different meals, their patterns of response were different (sex \times time). The value at 30 min was higher for men than for women. For men, the lowest mean glucose level occurred at 120 min, while for women the decline in glucose at 30–180 min was more gradual.

Area under the 120-min glucose curve (AUC) was lower for all test meals than for glucose at 57–62% of the AUC for glucose (Table III). The lowest area was for the barley extract. Areas under the 120-min insulin curves were also significantly lower than the area after glucose at 68–83% of the area for glucose.

Plasma insulin values were converted to logarithms before statistical analysis due to nonhomogeneity of variance. However, Mean plasma values (pmol/L) are reported (Fig. 2). Insulin responses were affected by test meal ($P < 0.02$); test meal \times time ($P < 0.0001$); sex \times time ($P < 0.01$). All test meals $<$ glucose. Plasma insulin responses were lower after all barley and oat treatments than after the glucose tolerance test. Fasting, 30-min, and 180-min values were similar. At 60 min, insulin values after oat bran and barley extract were lower than after glucose and insulin values after barley flour and oat extract were intermediate (test meal \times time, $P < 0.0003$). At 120 min, insulin values after all four test meals were lower than after glucose. Similarly to the glucose responses, mean insulin responses of men and women did not differ according to test meal

but their patterns of response were different (sex \times time, $P < 0.03$). Fasting, 30-min, and 60-min values were not significantly different for men and women but peak levels were somewhat lower in women and the decline was slower with significantly higher levels at 120 and 180 min for women. Plasma glucagon responses were significantly affected only by time ($P < 0.0001$, data not shown).

DISCUSSION

The glycemic index is the area under the curve of the 2-hr glucose response to a carbohydrate food compared with either a specific glucose dose (usually 50 g) or a specific amount of white bread (Wolever 1991). The response to white bread is usually $\approx 70\%$ of the glucose area under the curve. Diets that have low glycemic loads, calculated from epidemiological data using the glycemic indices of individual foods, have been related to a number of beneficial health outcomes including lower risk of coronary heart disease (Hu and Willett 2001; Liu et al 2000) and type 2 diabetes mellitus (Brand Miller 1994; Hu et al 2001).

The amount of carbohydrate consumed has an effect on the level of glycemic response (Wolever and Bolognesi 1996). Most studies of glycemic index use 50 g of available carbohydrate as the standard dose. In view of the difficulty of determining availability of carbohydrate due to unknown amounts of resistant starch (Botham et al 1997) and actual amount of soluble fiber that can be classified as available (Wisker et al 1992), we have used equal amounts of total carbohydrate for our test meals. Because we have tested men, women, old, young, thin, and fat, we have attempted to standardize our studies by adjusting the meal to the size of the subject and always using the same control. Our studies use glucose as the control and we use 1 g/kg of body weight of total carbohydrate as our meal size. For the present study, and a previous study testing methods of cooking on effectiveness of Oatrim (van der Sluijs et al 1999), our test meals contained 0.33 g/kg of test food (oat bran, barley flour, and oat and barley extracts) and 0.66 g of vanilla instant pudding, which was predominantly sucrose. We did not feel that it would be possible for subjects to consume 1 g/kg of the barley or oat extracts. We do realize that this may make interpretation of results somewhat problematic, but our goal was to determine whether the extracts retained the beneficial effects on glucose and insulin responses that previously were demonstrated for oat bran and barley (Braaten et al 1991; Wolever and Bolognesi

TABLE I
Initial Characteristics of Subjects^a

	Men	Women	Final Men
<i>n</i>	11	11	9
Age	44.6 \pm 5.1	44.2 \pm 6.8	45.8 \pm 4.7
Weight	81.0 \pm 11.2	67.7 \pm 9.9 ^b	83.5 \pm 9.5
Body mass index	25.0 \pm 2.9	25.0 \pm 3.5	25.6 \pm 2.5

^a Values are mean \pm standard deviation.

^b Different from corresponding value for men ($P < 0.05$).

TABLE II
Sample Menu

Breakfast	Lunch	Dinner
Rice cereal	Turkey breast	Roast beef
Milk, lactose-free	Lettuce	Gravy
Orange juice	Tomato	Mashed potatoes
Blueberry muffin	Roll	Corn muffin
Margarine	Celery sticks	Tossed salad
	Ranch dressing	French dressing
	Chocolate chip cookies	Cherries
	Milk, lactose-free	Margarine

TABLE III
Areas Under the Curve for Glucose and Insulin Responses of Men and Women^a

Test Meal	Glucose	Oats	Oat Extract	Barley	Barley Extract
Glucose	141a	90b	97b	92b	81b
Men	148a	89b	93b	91b	91b
Women	134a	90b	100b	93b	70b
Insulin	31,838a	23,009b	26,548b	23,678b	21,807b
Men	35,574a	23,277b	29,109b	22,836b	23,884b
Women	28,101a	22,739b	23,989b	24,519b	19,731b

^a Values are areas under the curve for 120 min of plasma glucose and insulin levels. ANOVA for glucose test meal ($P < 0.0003$); standard error 22. Values followed by the same letter in the same row are not significantly different ($P < 0.05$). ANOVA for insulin test meal ($P < 0.002$); standard error 2,615. No significant effect of gender for either glucose or insulin.

1996). We realize that part of the reduction is due to the presence of both sucrose and unavailable carbohydrate in the test meals. But many foods for which glycemic indices are published, such as ice cream and numerous baked goods, also suffer from these limitations. The important factor is that the glucose response is blunted when these foods are consumed. Glycemic indices for our test meals were 64 and 65 for oat bran and barley, 69 and 57 for oat and barley extracts, respectively. There were no significant differences between the test grains and their extracts.

Numerous studies have examined the effects of oat foods on glucose responses but few have studied the effects of barley in humans. In a study similar to the present study, Braaten et al (1991) compared acute responses of nine subjects to glucose alone or to a pudding containing glucose plus oat gum or guar gum. Both gums reduced glucose and insulin responses, but subjects rated the oat gum as more palatable than guar gum. Hallfrisch et al (1995) found significant declines in glucose and insulin responses to carbohydrate loads in subjects after chronic consumption of oat extracts produced from oat starch. That study incorporated the extracts in menus for five weeks. In the present study, oat bran and oat extract were given as an acute tolerance test, thus there was no intestinal adaptation to the chronic consumption of oats. Both of these studies, however, found decreases in glucose responses after consumption of oat extracts. There have been a few studies where oat foods have been fed in which glucose and insulin have not been significantly lowered (Kestin et al 1990; Cara et al 1992; and Liljeberg et al 1996). Kestin et al 1990 compared responses of 24 mildly hypercholesterolemic men to 12 g of wheat, rice, or oat bran for four weeks but found

no differences in glucose or insulin responses. The subjects were younger than those in the present study. The acute dose given in our study was approximately twice the amount given daily in the Kestin study (22 g for women, 28 g for men). Cara et al (1992) compared 10 g of oat bran, wheat bran, or wheat fiber or 4 g of fiber as wheat germ added to a standard low-fiber meal in six normolipidemic men 22–41 years. These men were younger than our subjects and the meals contained 70 g of fat which could overwhelm the differences in responses from just 4–10 g of fiber. Liljeberg et al (1996) found glucose and insulin responses of nine healthy subjects to oat porridge to be almost identical to their responses to white bread. The total amount of carbohydrate in the meals fed by Liljeberg et al (1996) was $\approx 30\text{--}35$ g, while all of our test meals are standardized to a total of 1 g/kg of body weight. Though the amount of oats was similar, the total dose of carbohydrate was much greater in our subjects and would be expected to elicit a higher response.

The number of studies reporting effects of barley on glucose and insulin responses is more limited than reports of oats. Liljeberg et al (1996) also fed barley test meals. Barley porridge did not lower glucose and insulin responses compared with white bread, but high-fiber porridge and breads made using the Prowashonupana barley did lower responses. Yokoyama et al (1997) fed five adults pasta made with either durum wheat or high β -glucan barley from the Waxbar cultivar. The content of soluble fiber was concentrated by repeated milling and sifting to remove starch. Subjects received 100 g of carbohydrate and the barley contained 12 g of β -glucan. Insulin and glucose responses to the barley were lower than for the wheat pasta. These subjects received significantly more fiber and carbohydrate than our subjects but results are similar.

A number of other viscous fibers have been reported to improve glucose and insulin responses. There have been various theories suggested for these effects (Eastwood and Kay 1979; Daniel et al 1997). The design of our study does not allow for confirmation of these theories but it does support them. French and Read (1994) showed that soluble fibers in combination with a high-fat meal not only slowed gastric emptying but also slowed absorption, prolonging contact of nutrients with intestinal chemoreceptors which was instrumental in prolonging satiety and intestinal feedback. Wood et al (1989) showed that soluble fiber from oats induced a significant reduction in postprandial insulinemia, which appeared to be dose-dependent. Lupton et al (1993) found barley bran flour increased intestinal transit time, thus reducing the time available for intestinal absorption. Viscosity of the soluble fibers may also be responsible for reductions in the glucose and insulin responses (Wood et al 1989; Danielson et al 1997). Wisker et al (1992) suggest that the addition of barley to human diets reduces available energy.

CONCLUSIONS

Our study demonstrates that addition of oat and barley foods whether from bran, flour, or extracted components reduces glucose and insulin responses. These results demonstrate that hydrocolloids extracted from oats and barley retain the beneficial effects of the whole grains and suggest that increasing the oat and barley content of the American diet might lower risk factors for type 2 diabetes. These extracts can be added to a variety of foods to reduce fat and to increase soluble fiber content of diets. Long-term studies are necessary to determine whether these extracts retain the beneficial effects on blood lipids seen with other oat and barley foods.

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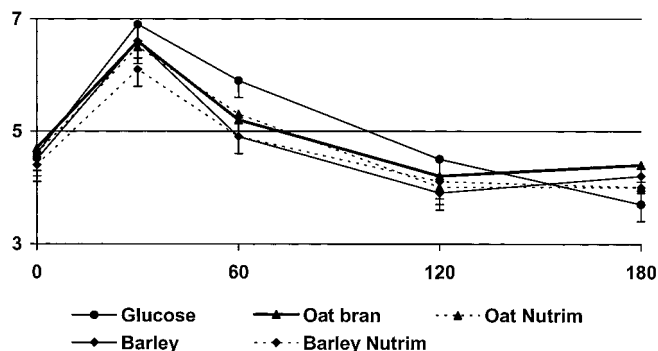


Fig. 1. Plasma glucose levels of men and women combined (mmol/L). Mixed procedure ANOVA: Time ($P < 0.0001$); time \times test meal ($P < 0.03$); sex \times time ($P < 0.02$). Barley extract mean $<$ glucose mean; at 30 min: barley extract $<$ glucose; at 60 min: oat bran, barley, and barley extract $<$ glucose; at 180 min: oat bran and barley extract $>$ glucose; at 30 min: men $>$ women.

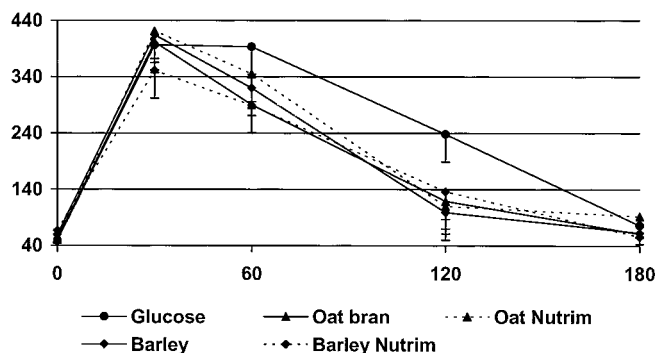


Fig. 2. Insulin responses of men and women combined ($n = 20$). Mixed procedure ANOVA on log-transformed values: Treatment ($P < 0.006$); treatment \times time ($P < 0.0003$); sex \times time ($P < 0.03$). Means of all test meals $<$ mean of glucose; at 60 min: oat bran and barley extract $<$ glucose; at 120 min: all test meals $<$ glucose; 30 min and 180 min not significant; women $>$ men at 120 and 180 min.

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