Mechanisms of the Effects of Grains on Insulin and Glucose Responses

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Consumption of a number of grains and grain extracts has been reported to control or improve glucose tolerance and reduce insulin resistance. The inability of the body to maintain normal glucose levels or to require excessive levels of insulin to do so has been called glucose intolerance, impaired glucose tolerance and insulin resistance. These conditions are associated with obesity and may be preliminary steps in the progression to type 2 diabetes mellitus. Although dietary goals recommend the consumption of three servings of whole grains per day, average consumption in the United States is less than one serving per day. There are a number of mechanisms by which grains may improve glucose metabolism and delay or prevent the progression of impaired glucose tolerance to insulin resistance and diabetes. These mechanisms are related to the physical properties and structure of grains. The composition of the grain, including particle size, amount and type of fiber, viscosity, amylose and amylopectin content all affect the metabolism of carbohydrates from grains. Increasing whole grain intake in the population can result in improved glucose metabolism and delay or reduce the risk of developing type 2 diabetes mellitus. Whole grains can provide a substantial contribution to the improvement of the diets of Americans. A number of whole grain foods and grain fiber sources are beneficial in reduction of insulin resistance and improvement in glucose tolerance. Form, amount and method of cooking of these foods as well as the health characteristics, age and gender of the group of subjects studied are all important factors in the effectiveness of the foods in altering these responses. Dietary recommendations of health organizations suggest consumption of three servings a day of whole grain foods; however, Americans generally fall below this standard. Recent research using various grains and grain products effective in improving insulin resistance or lowering glycemic index will be discussed below by possible mechanisms of action.

GLYCEMIC INDEX

Glycemic index (Table 1) is the area under the curve of the glucose responses to a carbohydrate-containing food compared to either a specific glucose dose or a specific amount of white bread [1–2]. The inability of the body to control blood glucose with normal levels of insulin is associated with obesity and may be an early step in the development of noninsulin-dependent diabetes mellitus [3]. Reducing the level of insulin required to maintain normal blood glucose is an indication of improvement in insulin resistance or greater insulin sensitivity [4]. While there are time-consuming invasive techniques such as glycemic clamps [5] and Bergman's minimal model [6], insulin resistance also may be measured by calculating the area under the curve of insulin responses after a carbohydrate-containing food [7]. The insulin index is measured against a standard of either the response to a glucose solution as is given in a standard glucose tolerance test or, especially in the case of diabetic subjects, a standard of a comparable amount of white bread [8]. Areas are calculated as described above for the insulin index. There is a much more extensive data base for the glycemic index of foods than for the insulin index [9]. Consumption of

Table 1. Factors Affecting Glycemic Index of Foods

Soluble fiber
Amylose content
Particle size
Method of preparation

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diets high in foods with high glycemic indices promote insulin resistance, obesity and, in susceptible segments of the population, noninsulin-dependent diabetes mellitus [10].

VISCOSITY AND SOLUBILITY

The gel-forming property of soluble fiber sources such as oats and barley has been proposed as the mechanism by which these grains reduce both cholesterol and glucose and insulin responses. Over 20 years ago, Jenkins *et al.* [11] reported that oat gum reduced glucose and insulin responses of healthy adults when added to a glucose solution. The high viscosity of the solution containing oat gum was concluded to be the property which delays gastric emptying and/or intestinal absorption resulting in these lower responses [12]. Braaten *et al.* [13] also tested responses to glucose and glucose with oat gum and found reductions in glucose and insulin when the nine healthy subjects consumed solutions to which oat gum had been added. Granfeldt *et al.* [14] tested responses of nine older men to raw rolled oats, boiled rolled oats, boiled intact oat kernels and white bread. Only consumption of boiled intact oat kernels resulted in glucose and insulin response reductions below the responses to white bread. In our own research, we have found highly viscous oat extracts to lower glucose and insulin responses of middle-aged men and women [15], whether consumed uncooked, boiled or baked [16]. Preliminary data using rolled oats or oat flour indicate reductions of glucose response of 15% to 30% in moderately overweight women [17]. Barley is also high in soluble fiber and has the potential to improve insulin sensitivity and glucose metabolism; however, little barley is consumed by Americans. Yokoyama *et al.* [18] compared responses of five subjects to pastas containing wheat or wheat and 12 g beta glucans from barley. Consumption of barley-containing pasta resulted in lower glycemic and insulin indices. Bourdon *et al.* [19] compared glucose and insulin responses of 11 healthy men (28 to 42 years of age). Subjects consumed traditional wheat pasta or a pasta in which 40% of the wheat flour had been replaced with either a highly viscous barley cultivar (Prowashonupana) which naturally has about 15% soluble beta glucan or Waxbar barley enriched in soluble fiber by repeated milling. Insulin responses were lower after the barley pastas than after the traditional wheat pasta during the first hour. Though the glucose areas did not differ, the decline in glucose after barley pastas was more gradual than after the wheat pasta. Substantial reductions in insulin and glucose responses were found in seven young subjects after varying amounts of boiled barley compared to white bread [20]. Breads made with 10% whole barley or 15% pearled barley lowered glucose responses of 15 diabetics compared to responses to white bread [21]. Another study of diabetics compared long-term (24-week) effects of barley bread to white bread in 11 NIDDM men [22]. The glycemic index was reduced, but insulin responses were increased when the men consumed the barley bread. Since drug regimen was changed in some subjects during the study, these results are difficult to assess. Comparison of barley and oat foods to white bread in nine healthy subjects [23] found no effect of porridges, but consumption of high fiber barley breads resulted in glycemic indices of 57% to 72% of white bread and insulin indices of 42% to 72% of index of white bread. Whole kernels of wheat, rye, and barley added to breads resulted in glycemic indices lower than those of white bread, but adding whole oat kernels to the bread had no effect on responses of ten healthy subjects [24]. Insulin indices for all breads to which boiled kernels had been added, however, were lower than for white bread. Preliminary data from our laboratory indicate that both flakes and flour of the high soluble fiber barley (Prowashonupana) lowers glucose and insulin in moderately overweight middle-aged women [17]. In diabetics and controls, Braaten *et al.* [25] found both oat gum and oat bran added to farina to reduce glucose and insulin responses below those of farina alone. An oat-based soup was used as a means of weight reduction in 31 subjects [26]. After 23 weeks, subjects lost an average of 6 kg, and both glucose and insulin declined; however, it is difficult to separate the effects of the soup from the weight loss caused by reduced energy intake. Glucose and insulin responses of 24 hypercholesterolemic men to wheat, rice and oat brans were not significantly different [27]. A smaller study of six men found no differences among glucose and insulin responses to 10 g of fiber from oat bran, wheat bran, wheat fiber or wheat germ [28]. These sources of fiber, however, are predominantly insoluble and would not result in highly viscous intestinal contents. The test subjects in these studies were also relatively young lean subjects.

Rye also is relatively high in soluble fiber, but there are few human studies reporting responses to rye consumption. Whole kernel rye has been tested in a few groups of diabetics [24,29–30]. Compared to white bread, glycemic index of whole kernel rye bread was 42–56 in diabetics, both insulin- and noninsulin-dependent diabetics. Rye crisp breads, which are often refined, however, have glycemic indices very similar to white bread. Comparison of responses to dark rye bread and white bread in 14 young diabetics reported no differences in the glucose indices [31].

Wood *et al.* [32] concluded that the great majority of the reductions in plasma glucose and insulin (79% to 96%) resulting from consumption of oat gum are due to its viscosity. Granfeldt *et al.* [14] however, found neither degree of gelatinization nor viscosity to affect glucose levels. It is clear from these results that those grains which are high in soluble fiber and which result in foods which are highly viscous can be effective in lowering blood glucose and insulin responses. These effects are most likely to be found in subjects for whom lowering glucose and insulin is an improvement, that is, hypercholesterolemic, older, less slim and NIDDM subjects. Effects are less significant if subjects are young, fit and have normal glucose and insulin responses. The component and form of the foods is also important. Though barley and oats, which are high in soluble fiber, may be effective, if only the more insoluble fiber components such as the bran or finely ground flour are consumed, then reductions of glucose and insulin are less substantial than if the whole kernel or the soluble fiber components are consumed.

STARCH STRUCTURE

The structure of the starch of grains can have a profound effect on the glucose and insulin responses resulting from consumption. Starch is composed of long chains of glucose (amylose) and highly branched chains of glucose (amylopectin). Hydrolysis of amylose would therefore result in fewer glucose molecules' being freed at once than the hydrolysis of the highly branched amylopectin chains. Thus, high amylose content grains result in lower glucose responses than those which have a high content of amylopectin. These differences have been most frequently studied in corn products because the range of amylose varies from 30% to 70% of the starch. Corn and corn products have a wide range in glucose and insulin responses, depending on cultivar, form, processing and level of amylose and amylopectin. Cornflakes, by prediction and actual measurement, have higher glycemic and insulin indexes than white bread (139 and 149, respectively) when determined in eight nondiabetic university students [33] and 14 diabetic children [31]. Wheeler *et al.* [34] compared responses of 16 young diabetics (14 to 25 years of age) to cornflakes, sweetened corn flakes, glucose and sucrose. Finding no differences between sweetened and unsweetened cornflakes and either cornflakes and glucose or cornflakes and sucrose, the authors conclude that cornflakes, whether sweetened or unsweetened, are not detrimental to these patients. Since cornflakes have such a high glycemic index and there are so many cereals with lower indices, this conclusion seems unwarranted. Boiled sweet corn and popcorn, however, have glycemic indices of about 80 as compared to white bread (100%). A study in our laboratory [35] reported insulin responses of 12 women and 13 men to be significantly lower after consuming corn crackers containing 70% amylose compared to 70% amylopectin. Peak glucose responses were also lower after high amylose. High amylose corn was produced from amylose extender variety back-crossed with common dent corn. The high amylopectin corn was waxy maize variety back-crossed with straight waxy variety. A long-term study [36] found lower glucose and insulin responses to corn crackers in 12 men after they consumed a variety of foods high in amylose or amylopectin for five weeks each. A similar study found hyperinsulinemic men to be more responsive to beneficial effects of high amylose than controls [37]. These studies measured glucose and insulin responses after chronic rather than acute consumption of various types of starch and reflect an adaptation to the starch. Other researches have reported beneficial effects of high amylose corn products. Weststrate and van Amelsvoort [38] found reduced glucose and insulin responses after high amylose lunches, but only reduced insulin responses after high amylose breakfasts. Granfeldt *et al.* [39] and Semprun-Fereira *et al.* [50] tested 'arepas' (cornbread made from precooked cornmeal) in healthy subjects made with standard or high amylose corn flour and found conflicting results. High amylose arepas had lower glycemic and insulin indices than ordinary cornmeal arepas (71.5 as compared to glucose or similar indices to white bread), but addition of cheese and margarine increased the glycemic index to 140. Usually, one would expect cheese and margarine to reduce glycemic index. Responses of healthy and diabetic South Africans to refined maize, rice and bread found the glucose response to maize to be almost twice that of bread and similar to glucose, but the insulin response to maize was about 2/3rds the response to bread [41]. Some Native American corn products have much lower glycemic indices than white bread such as tortillas (54%) and hominy (57%) [9]. Maize porridge, whether refined or unrefined, and taco shells, however, have glycemic indices comparable to that of white bread [42].

Rice products have a wide range of glycemic indices and rice is considered to be either a high or low glycemic index food based on cultivar, cooking method, form of food and subject group studied [43]. Rice, as corn, can vary substantially in amylose content. Comparison of responses to three rice varieties with varying amylose content, brown rice, puffed rice cakes, rice pasta and rice bran found only high amylose varieties to lower glucose and insulin responses. Rice bran tested from this study is reported to have a glycemic index compared to bread of 27 [9]. Holt and Miller [44] compared standard and quick-cooking rice and high and low amylose rice puffs and found responses to quick-cooking rice to be 60% higher than to standard rice. Low amylose rice resulted in a 50% higher glucose response than high amylose rice. Paniasigui *et al.* [45], however, conclude, after testing three high amylose varieties of rice, that amylose content alone can not predict the glycemic response and that gelatinization is also a factor. Addition of 10 g rice bran to a meal did not lower glucose or insulin responses of six healthy males [28]. The South African study found responses to refined rice to be higher than glucose and insulin responses to white bread [42]. Comparison of brown rice and barley responses in ten healthy subjects resulted in 30% lower responses to the barley meal than to the rice [46]. The higher level of fermentation of the barley as measured by hydrogen expiration was concluded to be the mechanism by which barley improved glucose response. Rasmussen *et al.* [47] compared responses of seven diabetics to 25 and 50 g carbohydrate from white rice and white bread and found significantly lower glucose and insulin responses after the 50 g rice compared to 50 g white bread, but no differences in the responses to 25 g of carbohydrate, indicating that amount of food consumed affects glucose and insulin responses. Similar reductions were found in responses to 100 g of rice compared to white bread in men and women [48]. Results for rice are very inconsistent, but many foods appear to have higher glycemic indices than white bread, and brown rice may have a lower glycemic index than white rice [9]. Instant and parboiled rice appear to be less likely to reduce glucose and insulin responses than standard rice, and a higher level of amylose is beneficial.

These results show that amylose content of the corn or rice cultivar, level of processing and form and method of cooking have a great influence on the responses to corn- and rice-containing foods. Corn and rice products can have either a beneficial or detrimental effect on glucose and insulin responses when compared to either glucose or white bread.

PARTICLE SIZE

White wheat bread, which is low in fiber content and uses finely ground flour, is often used as the standard by which glycemic and insulin indices are measured and is, therefore, not considered a low glycemic index food. It is important to remember, however, that when compared to glucose, white bread has a glycemic index of 70, substantially lower than many other foods including cornflakes, some rice foods, potatoes, cookies, soft drinks and fruits. When compared to white bread, consumption of whole wheat bread which contains boiled kernels elicits lower blood glucose and insulin responses [13]. Porridge containing wheat farina [38] and ready to eat breakfast cereal do not have glycemic indices different from white bread [9]. McIntosh *et al.* [49] compared responses to consumption of wheat and barley foods for four weeks each of 21 mildly hypercholesterolemic men. Although cholesterol levels were significantly lowered by barley, there was no difference in glucose responses to either wheat or barley. Total dietary fiber in this study was significantly increased from 21 to 38 g/day during both periods, a circumstance which could account for the lack of difference. Comparison of four types of wheat—whole grain, cracked grain, coarse and fine wholemeal flour—in ten healthy subjects resulted in glucose responses to whole grain of approximately one-third the response of the fine flour. Insulin responses were similar. We also have compared breads made with different particle sizes [50]. Consumption of white, standard and ultra fine ground wholewheat flour breads by middle-aged men and women resulted in lower glycemic indices compared to glucose, but glycemic indices of wholewheat breads, although lower than white bread, were not different. The standard wholewheat bread had relatively small particle size compared to the whole grain and cracked grains used by Holt and Miller [51]. Holm and Bjorck [52] compared responses of healthy subjects to white bread and coarse wheat breads, and breads with intact kernels. Consumption of breads with intact kernels resulted in lower responses and higher satiety scores. These results indicate that not only particle size, but their composition can affect glucose and insulin responses. Boiled whole kernels and larger particle sizes are associated with lower glucose and insulin responses for a variety of grain sources.

These results show that the current method of carbohydrate exchange, which assumes that all carbohydrates are equal, can be a dangerous recommendation for the control of glucose in noninsulin-dependent diabetics. Many factors can affect the glucose and insulin responses resulting from consumption of grain-based carbohydrate-containing foods.

CONCLUSION

There are a variety of grains and grain products which can be beneficial in lowering glucose and insulin responses. Although this review is not by any means a complete presentation of the research conducted in humans testing various grain products, a number of generalities can be expressed. The greater the particle size, the lower the glucose and insulin response. The greater the level of processing and refining, the higher the response. Grains with high levels of soluble beta glucans such as oats, rye and barley are generally more effective in improving insulin sensitivity than wheat, which contains predominantly insoluble dietary fiber. The high viscosity of these soluble fibers is partially responsible for these beneficial effects. Corn and rice can have either high or low glycemic indices because their amylose and amylopectin contents vary. Higher amylose content results in lower glucose and insulin responses. The amount of carbohydrate tested is an important determinant in the level of response. The type and characteristics of the subjects to be tested is important in determining the level of reduction which can be achieved. Therefore, older, less slim, more glucose intolerant subjects have the capacity for greater improvement in glucose and insulin responses than do young, fit, slim subjects. Nevertheless, the present American diet has great room for improvement by increasing the amount of daily whole grain servings from less than one to the recommended three servings a day. Replacing low fiber grain foods such as cornflakes or white bread with whole grain higher fiber or higher amylose content products will reduce risk of developing insulin resistance and obesity and improve the health of the American population.

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