Barley Cultivar, Kernel Composition, and Processing Affect the Glycemic Index[1–3]

Ahmed Aldughpassi,[4] El-Sayed M. Abdel-Aal,[5] and Thomas M. S. Wolever[4]*

[4]Department of Nutritional Sciences, University of Toronto, Toronto, Canada; and [5]Agriculture and Agri-Food Canada, Guelph Food Research Centre, Guelph, Canada

Abstract

Barley has a low glycemic index (GI), but it is unknown whether its GI is affected by variation in carbohydrate composition in different cultivars and by food processing and food form. To examine the effect of these factors on GI, 9 barley cultivars varying in amylose and β-glucan content were studied in 3 experiments in separate groups of 10 healthy participants. In Expt. 1, 3 barley cultivars underwent 2 levels of processing: hull removal [whole-grain (WG)] and bran, germ, and crease removal [white pearled (WP)]. GI varied by cultivar (CDC Fibar vs. AC Parkhill, [mean $\pm$ SEM]: 26 $\pm$ 3 vs. 53 $\pm$ 4, respectively; $P < 0.05$) and pearling (WG vs. WP: 26 $\pm$ 4 vs. 35 $\pm$ 3, respectively; $P < 0.05$) with no cultivar $\times$ pearling interaction. In Expt. 2, the GI of 7 WG cultivars ranged from 21 $\pm$ 4 to 36 $\pm$ 8 ($P = 0.09$). In Expt. 3, WG and WP AC Parkhill and Celebrity cultivars were ground and made into wet pasta. The GI of AC Parkhill pasta (69 $\pm$ 3) was similar to that of Celebrity pasta (64 $\pm$ 4) but, unlike in Expt. 1, the GI of WP pasta (61 $\pm$ 3) was less than that of WG pasta (72 $\pm$ 4) ($P < 0.05$). Pooled data from Expts. 1 and 2 showed that GI was correlated with total fiber ($r = -0.75$, $P = 0.002$) but not with measures of starch characteristics. We conclude that the GI of barley is influenced by cultivar, processing, and food form but is not predicted by its content of amylose or other starch characteristics.   J. Nutr. 142: 1666–1671, 2012.

Introduction

The growing availability and intake of refined carbohydrates, especially those with a high glycemic index (GI)[6], combined with the rise in the obesity epidemic have contributed to an increase in cardiometabolic disorders (1). The latest reports from international studies show an unabating upward trajectory in diabetes rates, with 366 million people worldwide suffering from diabetes in 2011 (2). Type 2 diabetes is characterized by insulin resistance and reduced insulin secretion (3,4). Therefore, food products that decrease plasma glucose and insulin demands plausibly reduce the risk of type 2 diabetes (5). This has renewed interest in whole-grain (WG) cereals with intact botanical structure that are slowly digested and have a low GI. The GI, which was introduced 30 y ago, is a physiologic indicator that ranks carbohydrate-rich foods on the basis of their potential to increase blood glucose. By replacing high-GI refined carbohydrates such as white rice or white bread with low-GI WG products such as barley, consumers can meet nutrition recommendations to consume WG foods daily and reduce dietary GI, maneuvers that may slow the progression of chronic diseases. However, the consumption of barley in North America is very low, at least in part due to lack of availability of barley food products that are convenient to purchase and prepare. Recently, many new barley cultivars have been specifically produced for food use that have unique functional characteristics that improve their versatility for use as food products with enhanced health benefits such as high β-glucan and slowly digested starch (SDS) barley. The genetic and compositional diversity in barley cultivars and other factors such as the level of pearling, amylose-to-amylopectin ratio, food form, and cooking method may influence postprandial responses of barley products and alter their GI. It has been suggested that GI values do not necessarily indicate the rate and extent of carbohydrate absorption, but rather are determined by the combined effect of all the properties of the grain that influence the rate of entry and removal of glucose from the blood stream (6). Elucidation of the role of carbohydrate quality in health promotion requires a better understanding of how the physicochemical characteristics of food and processing methods such as pearling, a common commercial process in which the husk and outer layers of barley grains are removed by a friction and abrasion process, relate to their

physiologic responses. This will also provide additional insight to the concept of GI. Therefore, the objective of this study was to examine the effects of pearling, barley cultivar, physicochemical properties, and food form on the GI of 9 barley cultivars in healthy participants. This project was completed in 3 separate experiments. The purpose of Expts. 1 and 2 was to examine the effects of barley cultivar and level of pearling [e.g., WG, commercial pearled (CP), pot pearled (PP), and white pearled (WP)]. In Expt. 3 a novel in-house, wet, pasta-like product was manufactured from 100% barley flour to assess the effects of food form on the GI.

Participants and Methods

All experiments were performed with the use of protocols approved by the Research Ethics Board at the University of Toronto. All participants provided written informed consent to participate. A total of 3 experiments, each with a randomized design were performed in separate groups of 10 healthy participants in the morning after a 10–12-h overnight fast.

Barley samples. Nine Canadian barley cultivars were selected on the basis of their diversity in starch, amylose, and β-glucan content and their agronomic purpose. The selected barley cultivars included 3 two-rowed, hulled, normal barleys (AC Parkhill, Chief, and GB 992027); 3 six-rowed, hulled, normal barleys (AC Klink, Celebrity, and OAC Kawathra); 1 two-rowed hull-less, normal barley (AC Alberta); and 2 two-rowed, hull-less, waxy barleys (CDC Fibar and CDC Rattan). Kernels from 2-rowed barleys are generally larger and more uniform in size than are those from 6-rowed barleys due to crowding of spikelets in the latter. Hull-less barley are free-threshing or naked grains. Normal barley contains starch with an amylose-to-amylopectin ratio of ~1:3, whereas the starch in waxy barleys consists almost entirely of amylopectin. Characteristics of a majority of the selected barley cultivars and their grains were reported previously (7–9). All cultivars were from Canadian suppliers, and the majority were obtained from Cribit Seeds. The waxy cultivars were supplied by the University of Saskatchewan. Samples were provided in 25-kg amounts, and a 3-kg representative sample of each cultivar was obtained from the original bags for this study. Barley kernels were pearled in 100-g batches for various lengths of times to achieve the desired level of pearling by using an abrasive mill (model TM05; Satake) (**Supplemental Table 1**). Only barley fractions used in the current study are presented in **Supplemental Table 2**; the entire fractions were described in a previous study (10).

Carbohydrate analysis. The results of carbohydrate analysis have been reported previously (10) but are included briefly here for comparison with in vivo glycemic responses. Barley WG and pearled fractions were ground for chemical analysis by using a cyclone sample mill (Udy) equipped with a 0.5-mm screen and stored at 4°C prior to analysis. Moisture and total starch were determined by using American Association of Cereal Chemists approved methods 44-16 and 76-13, respectively (11). Glucose was measured by using a glucose oxidase/peroxidase reagent and a Carey 3C UV-visible spectrophotometer (Varian Techtron). Amylose and amylopectin were measured by using a commercially available method (Megazyme). Rapidly digested starch (RDS), SDS, and rapidly available glucose (RAG) were determined according to Englyst et al. (12). Resistant starch (RS) was determined by using approved method 32-40 and total, soluble, and insoluble dietary fiber were determined by using an enzymatic gravimetric procedure, approved method 32-07 (11). The barley test meals were consumed in portions containing 50 g available carbohydrate, which was defined as available starch plus free sugars (10).

Expt. 1. The participants in Expt. 1 consisted of 6 women and 4 men aged 40.6 ± 2.7 y with a BMI of 27.6 ± 1.2 kg/m^2. The objective was to determine the effect on GI of 2 extreme levels of pearling in 3 cultivars of barley varying in amylose and β-glucan content. The cultivars chosen for this experiment were AC Parkhill (high amylose, low β-glucan), Celebrity (high amylose, medium β-glucan), and CDC Fibar (low amylose, high β-glucan) (**Table 1**). The levels of pearling included WG (only the husk was

removed) and WP (all of the bran and most of the germ and crease removed).

Participants arrived at the laboratory between 0730 and 0945 on 9 separate occasions after 10–12-h overnight fasts. On each occasion, after being weighed and providing a fasting blood sample, participants consumed a test meal containing 50 g available carbohydrate within 15 min, and further fingerprick blood samples were obtained at 15, 30, 45, 60, 90, and 120 min after starting to eat. Participants were allowed to drink with the test meal a cup of water, tea, or coffee with 30 mL 2% milk and/or artificial sweetener if desired. The type of drink chosen by the participant stayed constant during the whole study. During the course of the 2-h test period, participants remained seated. Six of the test meals consumed by each participant consisted of the 3 different cultivars of barley, each pearled to 2 different levels (WG or WP); these were cooked as described below and consumed in randomly assigned order. White bread was tested as reference food by all participants. It was baked in an automatic bread maker as previously described (13).

Expt. 2. The participants in Expt. 2 consisted of 6 women and 4 men aged 46.6 ± 4.4 y with a BMI of 26.4 ± 1.1 kg/m^2. The objective was to examine the effect on GI of 6 additional barley cultivars and of 2 additional intermediate pearling levels. Seven barley cultivars were included (Table 1 and **Table 2**); 6 were studied only in the WG state, whereas one cultivar (Celebrity) was pearled to reproduce 4 fractions: WG, CP (some bran and germ were also removed), PP (all of the bran and most of the germ removed), and WP. Participants were therefore studied on 13 occasions; they consumed 10 different barley test meals in randomly assigned order and white bread 3 times using the same procedures as described for Expt. 1.

Expt. 3. The participants in Expt. 3 consisted of 8 women and 2 men aged 40.5 ± 4.7 y with a BMI of 28.3 ± 2.0 kg/m^2. The objective was to determine the effect on the GI of pasta made from barley flour by using barley cultivars shown in Expts. 1 and 2 to have different GI values (AC Parkhill and Celebrity), each pearled to different levels (WG and WP). Barley samples were milled into flour by using an analytical mill (A-10; Tekmar) and made into a wet, pasta-like product using 100% barley flour from each cultivar. Barley flour (100 g) was mixed with water (60–70 mL) to form a paste, which was extruded by using a pasta maker (PastaMatic MX700, SIMAC VETRELLA). As a control, wet durum semolina pasta (100 g) mixed with water (35 mL) was made under the same conditions by using commercial durum semolina (Robin Hood; Cargill, Inc.). All products were analyzed for dry matter and wet and dry loss. Salt (1 g), xanthan (1 g) and 85 μL of annato solution (2.8%) were added per 100 g barley flour to improve flavor, texture, and color, respectively, and overall appearance. After extruding the pasta, products were refrigerated overnight at 4C° before being cooked the next morning.

TABLE 1 The iAUC and GI of 3 barley cultivars processed (pearled) in 2 different ways: Expt. 1[1]

	iAUC			GI		
	Fraction			Fraction		
Barley cultivar	WG	WP	Mean	WG	WP	Mean
	mmol × min/L					
Celebrity	71 ± 20	88 ± 14	79 ± 16[a,b]	25 ± 4	33 ± 3	29 ± 3[a,b]
AC Parkhill	85 ± 21	109 ± 19	97 ± 19[a]	30 ± 5	41 ± 5	35 ± 4[a]
CDC Fibar	61 ± 16	78 ± 11	69 ± 13[b]	22 ± 4	30 ± 3	26 ± 3[b]
Mean of cultivars	72 ± 18	91 ± 14*	—	26 ± 4	35 ± 3*	—
White bread	—	—	189 ± 22[§]	—	—	71[§]

[1] Values are means ± SEM for $n = 10$ participants. There was a significant main effect of cultivar. Means without a common superscript letter differ, $P < 0.05$. *Significant main effect of pearling level, $P < 0.05$. [§]White bread differed from all barley test meals, $P < 0.05$. There was no significant cultivar × pearling interaction for iAUC or GI. GI, glycemic index; iAUC, incremental AUC; WG, whole-grain; WP, white pearled.

TABLE 2 The iAUC and GI of 7 barley cultivars: Expt. 2[1]

Barley cultivar[2]	iAUC	GI
	mmol × min/L	
Celebrity	48 ± 9[b]	21 ± 4[b]
Chief	65 ± 11[b]	29 ± 4[b]
Rattan	58 ± 12[b]	26 ± 6[b]
AC Klinck	71 ± 12[b]	36 ± 8[b]
Kawartha	61 ± 10[b]	28 ± 4[b]
AC Alberta	63 ± 13[b]	29 ± 7[b]
GB	52 ± 10[b]	24 ± 5[b]
White bread	163 ± 15[a]	71[a]

[1] Values are means ± SEM for *n* = 10 participants. Means without a common superscript letter differ, *P* < 0.05. GI, glycemic index; iAUC, incremental AUC.
[2] Cultivars were processed to remove the husk only (whole-grain).

Cooking procedures. On the basis of the in vitro carbohydrate analysis, samples of each barley cultivar were cooked in portions that provided 50 g available carbohydrate (Supplemental Table 2). Single portions of barley grains were rinsed with cold water, added to boiling water (1:5 barley:water; wt/v), covered and boiled for 25 min (WG and CP fractions) or 30 min (PP and WP fractions), and allowed to sit at room temperature for 10 min prior to being served to the participants . Pasta was cooked in boiling water for 5 min for the barley products and 20 min for the semolina product to obtain al dente (firm to the bite) texture. A pasta-to-water ratio of 1:8 (wt/v) was used to minimize losses of nutrients due to cooking in a large amount of water.

Blood glucose analysis. Capillary blood samples were collected into flat-bottomed 5-mL plastic tubes, with a push cap containing a small amount of sodium fluoride and potassium oxalate as an anticoagulant and preservative, and stored at −20°C prior to analysis of whole-blood glucose with an automatic analyzer (model 2300 STAT; Yellow Springs Instruments).

Statistical analysis. Results are expressed as means ± SEM. Statistical analysis was performed by using SAS version 9.3 (SAS Institute, Inc.). Incremental AUC (iAUC), ignoring the area below the baseline, were calculated by using the trapezoid rule as previously described (14). The iAUC for each test meal was expressed as a percentage of the same participant's mean iAUC after white bread consumption, and the resulting values were multiplied by 0.71 to convert to the glucose scale (i.e., the GI of glucose = 100). The mean of these values was the GI of the food. Because Expts. 1 and 3 had a partly balanced factorial design with 2 factors for the barley test meals (cultivar and level of pearling) but not for the control (white bread), the data from Expts. 1 and 2 were analyzed in 2 ways. To determine the significance of the differences in glycemic response between the barley meals and white bread, the GI and iAUC values for all of the test meals (including white bread) were analyzed by using repeated-measures ANOVA. To determine the effects of cultivar and pearling in Expts. 1 and 3, the mean iAUC and GI values of the barley test meals (not including white bread controls) were subjected to repeated-measures ANOVA to determine the main effects of cultivar and level of pearling and the cultivar × pearling interaction. Similarly, blood glucose concentrations at each time point were subjected to repeated-measures ANOVA in Expts. 1 and 3. Because Expt. 2 did not have a factorial design, the iAUC and GI values for all of the test meals were analyzed by using repeated-measures ANOVA. In all cases, after demonstration of heterogeneity by ANOVA, differences between individual means were assessed by using Tukey's test to adjust for multiple comparisons. In Expt. 1, one participant missed one test meal (Celebrity WG), and the missing result was imputed by using a procedure described by Snedecor and Cochrane (15); to account for the imputed value in the statistical analysis, the error df was reduced by 1. Pearson's correlation analysis was used to identify relationships between chemical composition and GI values of the barley products in Expts. 1 and 2 combined. The criterion used for statistical significance was 2-tailed *P* < 0.05.

Results

Expt. 1. All 6 barley test meals elicited significantly lower glycemic responses than did white bread (*P* < 0.001) (Table 1 and **Supplemental Fig. 1**). When only the barley test meals were included in the statistical analysis, there was a significant main effect of cultivar for iAUC (*P* = 0.008), with the response of CDC Fibar being significantly less than that of AC Parkhill. Pearling tended to increase mean iAUC (*P* = 0.07). However, there were main effects of both cultivar (*P* = 0.013) and pearling (*P* = 0.046) on GI; the GI of CDC Fibar was significantly less than that of AC Parkhill by 9 GI units and pearling (WP) increased GI by 9 units compared with WG. There was no significant cultivar × pearling interaction for either iAUC (*P* = 0.89) or GI (*P* = 0.87).

Expt. 2. All of the barley test meals elicited significantly lower glycemic responses than did white bread. The mean GI values of the barley cultivars processed as WG ranged from 21 to 36, but the differences between barley cultivars were not significant (Table 2). When the Celebrity cultivar was subjected to progressively greater degrees of pearling, from WG to CP, PP, and WP, mean GI values were 21 ± 4, 25 ± 3, 22 ± 3, and 32 ± 6, respectively (*P* = 0.09).

Expt 3. The glycemic responses elicited by the barley pastas did not differ significantly from those elicited by semolina pasta or white bread, and the response elicited by semolina pasta was similar to that after white bread (**Table 3** and **Supplemental Fig. 2**). When only the barley test meals were included in the statistical analysis, there was no significant main effect of cultivar for iAUC (*P* = 0.31) or GI (*P* = 0.29). In contrast to the results from Expt. 1, pearling decreased both the AUC (*P* = 0.016) and GI (*P* = 0.029) of barley pasta. There was no significant cultivar × pearling interaction for either iAUC (*P* = 0.80) or GI (*P* = 0.81).

Correlation between GI values and barley composition. There was no significant correlation between the GI values of the barley kernels tested in Expts. 1 and 2 and either the amylose, RAG, RDS, or RS contents of the test meals (**Fig. 1**). These correlations were not significant whether the results for pearled barley were included or not. The relationship between GI and SDS was not significant when only the WG test meals were included (*r* = −0.38, *n* = 9, *P* = 0.32) but approached significance when the results for pearled barley were included (Fig. 1). The only nutrient in barley to

TABLE 3 The iAUC and GI of 2 fractions of pearled barley pasta and semolina pasta: Expt. 3[1]

Barley cultivar	iAUC			GI		
	Fraction			Fraction		
	WG	WP	Mean	WG	WP	Mean
	mmol × min/L					
Celebrity pasta	137 ± 17	115 ± 17	126 ± 14	71 ± 6	58 ± 4	64 ± 4
AC Parkhill pasta	141 ± 17	127 ± 12	133 ± 13	73 ± 7	64 ± 4	69 ± 3
Mean of cultivars	139 ± 14	121 ± 13*	—	72 ± 4	61 ± 3*	—
Semolina pasta	—	—	151 ± 20	—	—	78 ± 8
White bread	—	—	142 ± 16	—	—	71

[1] Values are means ± SEM, *n* = 10 participants. Pasta was made from 2 barley cultivars pearled in 2 different ways with semolina pasta as a control. *Significant main effect of pearling level, *P* < 0.05. There was no significant main effect of cultivar and no significant cultivar × pearling interaction for iAUC or GI. GI, glycemic index; iAUC, incremental AUC; WG, whole-grain; WP, white pearled.

correlate significantly with GI was total fiber, and the correlation was significant whether or not the WP, PP, or CP test meals were included (Fig. 1) ($r = -0.81$, $n = 9$, $P = 0.008$). The correlation between GI and β-glucan ($r = -0.44$, $n = 14$, $P = 0.11$) was not as good as that between GI and total fiber ($r = -0.75$, $n = 14$, $P = 0.002$).

Discussion

The results of these experiments suggest that processing, cultivar, chemical properties, and food form are all factors that affect the GI of barley. All of the 9 barley cultivars and fractions had a low GI (GI range: 21–41) (Tables 1 and 2). This is similar to values reported previously (16). In Expt. 1, pearling resulted in a higher GI in all 3 of the cultivars tested. In addition, the cultivars differed in GI with CDC Fibar having a lower GI than did AC Parkhill. This is of interest because of all the barley cultivars tested, CDC Fibar contained the lowest amount of amylose and the highest amount of β-glucan.

Amylose [unbranched α-(1-4) linked molecules] and amylopectin (branched α-(1-4) and α-(1-6) linkages] are the 2 chief components of starch. Generally, normal barley starch has a 3:1 ratio of amylopectin to amylose, whereas waxy starch consists almost entirely of amylopectin. The normal barley cultivars examined in the study had an amylopectin-to-amylose ratio of 3.3:1 to 3.9:1, and starches in the waxy cultivars, CDC Fibar, and CDC Rattan were composed of ∼96–100% amylopectin. The branched structure of amylopectin is more susceptible to hydrolysis than the nearly linear structure of amylose, which increases the rate of digestion (17). The amylose-to-amylopectin ratio influences the rate of starch digestion and in turn dictates the concentration of RDS and SDS (18). Thus, it would be predicted that a barley cultivar with a lower percentage of amylose would have a higher GI, but this was not the case with CDC Fibar, which had the lowest content of amylose but the second-lowest GI of all the cultivars tested here. It could be speculated that the reason why CDC Fibar had a low GI, despite a low amylose content, is because of its high content of β-glucan (soluble fiber) and dietary fiber. β-Glucan extracted from oats (19,20) and barley (21,22) has been shown to reduce glycemic

responses when incorporated into foods. However, the overall evidence from this study does not support a strong role of β-glucan in determining the GI of whole and pearled barley kernels because GI was more strongly related to the total fiber content of barley rather than the β-glucan content. The results also suggest that the GI of barley is influenced by several competing factors, including starch and dietary fiber nutritional fractions and their interactions.

To further elucidate what influenced the GI of barley, we assessed starch digestibility in vitro. Some starches release glucose into the bloodstream faster than others. RDS is broken down to glucose in ≤20 min, whereas SDS is digested in 20–120 min (12). RDS content varied between cultivars, with CDC Fibar and CDC Rattan containing significantly higher amounts of RDS (26.9–33.4%) compared with other barleys (14.9–26.2%). Englyst et al (6) have suggested that the GI of cereal products can be explained by their content of slowly available glucose and RAG, with RAG being positively correlated with the GI of different cereals ($r = 0.74$, $P < 0.01$) (6). However, in our study RAG did not correlate with the GI. This suggests that the GI of foods cannot necessarily be predicted by using in vitro methods (23).

In barley the major form of RS is resistant starch type 1 (RS1), physically inaccessible starch (24). Previous studies have shown a negative correlation between RS and the GI of barley (25). However, in this study the RS content of all barley cultivars was low, ranging from 0.11 to 0.49 g/serving. In addition, degree of pearling had little impact on RS content. On the other hand, total fiber was negatively correlated with the GI of the barley cultivars ($r = -0.81$, $n = 9$, $P = 0.008$). Being high in dietary fiber is not necessarily an essential prerequisite of a low-GI food; many common cereals with naturally occurring levels of viscous fiber have a minimal impact on glycemia (26). Instead, dietary fiber as part of an intact botanical structure, as in barley, may be more significant. In this context, it is of interest that pearling reduced the total fiber content of barley to a greater extent than that of the β-glucan. This suggests that the starch in the outer layers of barley kernels that are removed by pearling is protected by fiber (not β-glucan) to a greater extent and has a lower GI than the starch in the center of the barley kernels. This
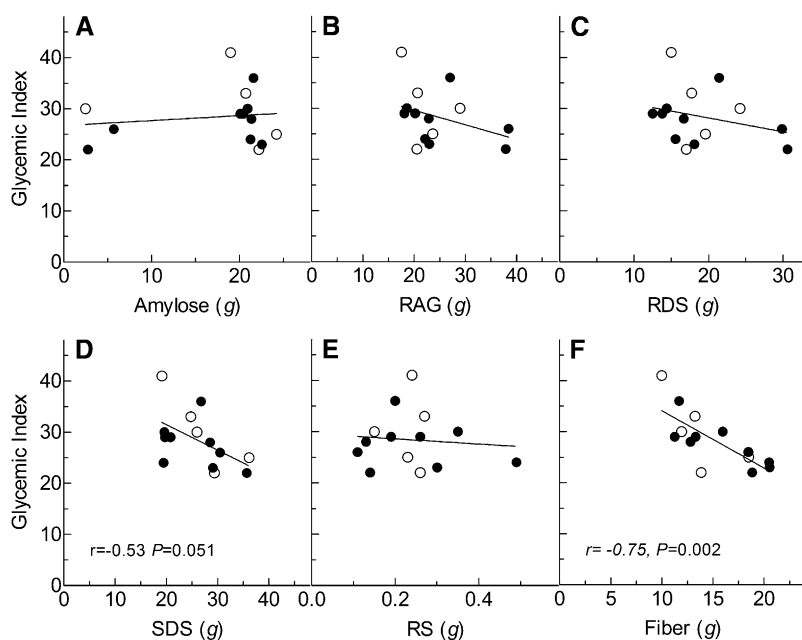

FIGURE 1 Correlations between the GI and amounts of amylose (*A*), RAG (*B*), RDS (*C*), SDS (*D*), RS (*E*), and total fiber (*F*) in whole-grain and pearled barley consumed by $n = 6$ (Expt. 1) or $n = 2$ (Expt. 2) healthy participants. *Filled circles*, whole-grain barley; *open circles*, pearled barley. GI, glycemic index; RAG, rapidly available glucose; RDS, rapidly digested starch; RS, resistant starch; SDS, slowly digested starch.

might explain why white pearling, which removes 25–30% of the starch from barley, increases the GI of barley.

In the current study, RS was directly measured in barley products, and thus its content is relatively small, and the sum of RDS, SDS, and RS contents is lower than the total starch content (Supplemental Table 2). This discrepancy is due to differences of how starch components were measured; a common practice among researchers is to estimate RS by difference (e.g. Total Starch − RDS − SDS), which is not as accurate as the direct measurement of RS used in the current study.

The results of Expt. 1 suggest that the matrix structure of barley is a more important determinant of GI than its content of RDS, SDS, RS, or β-glucan. This was also shown by the results of Expt. 3 in which disruption of the matrix structure of barley by grinding of WG barley greatly increased the GI, even though the pasta contained the same chemical constituents as the WG barley. Our barley pastas had unexpectedly relatively high GI values because pasta is considered to have a low GI. However, we believe our pasta had a high GI because we produced wet or fresh pastas, whereas pasta is usually available in dry form. The drying process could harden the matrix structure and make it less accessible to enzymes, and inactivate indigenous β-glucan–degrading enzymes, whereas wet pasta is more readily available or accessible to indigenous and external enzymes. This was supported by the high GI of the control wet pasta made from semolina flour compared with dry semolina pasta (GI $\sim$ 41) (16). It is of interest that pasta made from pearled barley had a lower GI than did WG barley pasta, whereas pearling increased the GI of intact barley kernels. We speculate that this may be because there were more particles of insoluble fiber in the WG pasta, which gave it a weaker structure and was thus more readily able to break apart and be digested.

In the latest 2010 US Dietary Guidelines (26), eating WG foods was encouraged. Although we agree with this advice because WG contain high levels of important nutrients such as dietary fiber and magnesium, the results of this study are consistent with those of previous studies that suggest that WG, which can be processed into a variety of different forms, do not necessarily have a low GI. Therefore, there is a need for improved methods of how WG are classified. Selecting a low-GI barley cultivar can help not only blunt high postprandial blood glucose levels but also reduce the overall glycemic load of a meal, a dietary maneuver that could produce enhanced public health benefits.

We did not measure insulin responses in this study because the added expense would have limited the number of different cultivars and processing methods we could have tested. In addition, previous studies have shown that barley food products with a low GI also elicit low insulin responses (27). Although we studied only normal participants, the values may apply to other populations because previous studies suggest that the GI values of starchy foods are similar in normal, hyperinsulinemic, and diabetic participants (28).

In conclusion, this study showed that barley cultivar, chemical composition, processing, and food form are all significant factors that influence the physicochemical characteristics of barley and in turn alter the GI. The chemical composition and processing appear to have the biggest impact on the quality of the carbohydrates, which may be a determining factor of variations in the GI values of cereal products.

Acknowledgments

Literature Cited

1. Barclay AW, Petocz P, McMillan-Price J, Flood VM, Prvan T, Mitchell P, Brand-Miller JC. Glycemic index, glycemic load, and chronic disease risköa meta-analysis of observational studies. Am J Clin Nutr. 2008; 87:627–37.

2. Whiting DR, Guariguata L, Weil C, Shaw J. IDF diabetes atlas: global estimates of the prevalence of diabetes for 2011 and 2030. Diabetes Res Clin Pract. 2011;94:311–21.

3. Willett W, Manson J, Liu S. Glycemic index, glycemic load, and risk of type 2 diabetes. Am J Clin Nutr. 2002;76:274S–80S.

4. Wolever TMS. Glycaemic index and disease. The glycaemic index: a physiological classification of dietary carbohydrate. UK: CABI, 2006, pp. 174–264.

5. Chiu CJ, Liu S, Willett WC, Wolever TM, Brand-Miller JC, Barclay AW, Taylor A. Informing food choices and health outcomes by use of the dietary glycemic index. Nutr Rev. 2011;69:231–42.

6. Englyst KN, Vinoy S, Englyst HN, Lang V. Glycaemic index of cereal products explained by their content of rapidly and slowly available glucose. Br J Nutr. 2003;89:329–40.

7. Ho KM, Choo TM, Martin RA, Rowsell J, Guillemette L. AC Parkhill barley. Can J Plant Sci. 2000;80:339–40.

8. Rossnagel BG, Zatorski T, Arganosa G. Food barley development at the Crop Development Centre, University of Saskatchewan. Proceedings of the 18th North American Barley Researchers Workshop, 4th Canadian Barley Symposium; July 17–20, 2005, Alberta, Canada.

9. Ontario Cereal Crops Committee. Variety trial. 2009. Accessed November 22, 2011. Available from: www.gocereals.ca.

10. Gray D, Abdel-Aal E-M, Seetharaman K, Kakuda Y. Differences in carbohydrate composition and digestion in vitro of selected barley cultivars as influenced by pearling and cooking. Cereal Chem. 2009; 86:669–78.

11. AACC International. Approved methods of the American Association of Cereal Chemists. 10th ed. St. Paul (MN): American Association of Cereal Chemists; 2000.

12. Englyst HN, Kingman SM, Cummings JH. Classification and measurement of nutritionally important starch fractions. Eur J Clin Nutr. 1992; 46 Suppl 2:S33–S50.

13. Wolever TMS, Bolognesi C. Source and amount of carbohydrate affect postprandial glucose and insulin in normal subjects. J Nutr. 1996;126: 2798–806.

14. Brouns F, Bjorck I, Frayn KN, Gibbs AL, Lang V, Slama G, Wolever TMS. Glycaemic index methodology. Nutr Res Rev. 2005;18:145–71.

15. Snedecor GW, Cochran WG. Statistical methods. 6th ed. Ames (IA): Iowa State University Press; 1967.

16. Foster-Powell K, Holt SHA, Brand-Miller JC. International table of glycemic index and glycemic load values: 2002. Am J Clin Nutr. 2002; 76:5–56.

17. Bertoft E, Källman A, Koch K, Andersson R, Åman P. The cluster structure of barley amylopectins of different genetic backgrounds. Int J Biol Macromol. 2011;49:441–53.

18. Burton PM, Monro JA, Alvarez L, Gallagher E. Glycemic impact and health: new horizons in white bread formulations. Crit Rev Food Sci Nutr. 2011;51:965–82.

19. Lan-Pidhainy X, Brummer Y, Tosh SM, Wolever TM, Wood PJ. Reducing beta-glucan solubility in oat bran muffins by freeze-thaw treatment attenuates its hypoglycemic effect. Cereal Chem. 2007; 84:512–7.

20. Tosh SM, Brummer Y, Wolever TMS, Wood PJ. Glycemic response to oat bran muffins treated to vary molecular weight of β-glucan. Cereal Chem. 2008;85:211–7.

21. Chillo S, Ranawana DV, Pratt M, Henry CJK. Glycemic response and glycemic index of semolina spaghetti enriched with barley β-glucan. Nutrition. 2011;27:653–8.

22. Thondre PS, Henry CJK. High-molecular-weight barley β-glucan in chapatis (unleavened Indian flatbread) lowers glycemic index. Nutr Res. 2009;29:480–6.

23. Brand-Miller J, Holt S. Testing the glycaemic index of foods: in vivo, not in vitro. Eur J Clin Nutr. 2004;58:700–1.

24. Nugent AP. Health properties of resistant starch. Nutr Bull. 2005; 30:27–54.

25. Björck I, Liljeberg H, Östman E. Low glycaemic-index foods. Br J Nutr. 2000;83 Suppl 1:S149–55.

26. US Department of Health and Human Services. Dietary guidelines for Americans. Accessed January 23, 2012. Available from: http://www.health.gov/dietaryguidelines/.

27. Granfeldt Y, Liljeberg H, Drews A, Newman R, Björck I. Glucose and insulin responses to barley products: influence of food structure and amylose-amylopectin ratio. Am J Clin Nutr. 1994;59:1075–82.

28. Lan-Pidhainy X, Wolever TM. Are the glycemic and insulinemic index values of carbohydrate foods similar in healthy control, hyperinsulinemic and type 2 diabetic patients. Eur J Clin Nutr. 2011;65:727–34.