Nutritional Properties of Starch in Buckwheat Products: Studies in Vitro and in Vivo

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The nutritional characteristics of buckwheat starch were studied to identify the possibility for reduced postmeal metabolic responses to various buckwheat products. The in vitro rate of starch hydrolysis and resistant starch (RS) formation in boiled buckwheat groats and in a series of breads, baked with 30–70% of buckwheat flour (BWF) or groats (BWG), respectively, were evaluated in vitro. In parallel, postprandial glucose and insulin responses and also the satiety score to BWG and wheat bread with 50% BWG as compared with the reference white wheat bread (WWB) were studied in healthy humans. The highest concentration of RS was found in boiled BWG (6% total starch basis). The RS level in bread products based on different proportions of BWF or BWG (30–70%) varied from 0.9 to 4.4%. The rate of in vitro amylolysis was significantly lower ($P < 0.05$) in all buckwheat products in comparison with the reference WWB. The calculated hydrolysis indices (HI) were lowest in boiled BWG (HI = 50) and in bread with 70% BWG (HI = 54). Consumption of boiled BWG or bread based on wheat flour and 50% BWG induced significantly lower postprandial blood glucose and insulin responses compared with the WWB. The calculated glycemic and insulinemic indices (GI and II) for boiled BWG were 61 and 53 and for the buckwheat bread, 66 and 74, respectively. The highest satiety score was found with boiled BWG. It is concluded that buckwheat has potential use in the design of foods with lower GI properties.

Keywords: *Buckwheat; starch hydrolysis; glycemic index; insulinemic index; satiety*

INTRODUCTION

Over the past two decades there has been a considerable interest in the possibility of improving diabetic control by altering the glycemic impact of the carbohydrates ingested. A tool for ranking foods with respect to their blood glucose raising potential, that is, the glycemic index (GI) concept (*1*), is now widely accepted. Metabolic advantages of a low-GI diet in a long-term perspective are supported by several studies, particularly in individuals with diabetes (*2–4*) or hyperlipidemia (*5*). Moreover, it has been reported that a low-GI meal improves glucose tolerance at the next meal ingested 4 h later (*6, 7*). So-called "second-meal" effects could thus be seen even during a single day.

Moreover, slow digestion and absorption of food carbohydrates have been associated with prolonged endurance time at strenuous exercise (*8*) and also with prolonged satiety meal (*9*). Recent data also suggest a preventive potential against development of maturity-onset diabetes (*10, 11*) and cardiovascular disease (*12, 13*).

A nutritional variable frequently linked to low GI properties is resistant starch (RS). The types of RS identified in foods are physically entrapped starch within whole or partly milled grains or seeds (RS$_1$), native, ungelatinized granules of B-type starches (RS$_2$), and retrograded starch (RS$_3$) (*14*). There are several

indications that the metabolites, formed during fermentation of RS and other indigestible carbohydrates in the large intestine, contribute to the maintenance of colon health and also have beneficial effects on glucose metabolism (*15–18*). Thus, for most healthy adults, foods with higher amounts of RS could be considered to be advantageous.

Among foods screened for their metabolic responses and the content of RS, not much attention has been on buckwheat (*Fagopyrum esculentum* Moench). For some rural populations in countries such as Nepal, Bhutan, and China, buckwheat represents the major staple food. However, in Europe buckwheat is mainly grown and consumed as an alternative crop. The whole seeds, obtained after dehusking either in raw condition or after hydrothermal pretreatment (so-called buckwheat groats), can be used similarly to rice. Also, buckwheat flour can be incorporated into bread dough or pasta products.

Although buckwheat could not be classified as a true cereal, the seeds contain a cereal-like starchy endosperm. Some investigations on the physicochemical properties of buckwheat starch have been carried out (*19–24*). However, only a few studies are available regarding the nutritional features of starch in buckwheat products (*25, 26*), and GI data of buckwheat products are scarce (*1, 27*). The present study was designed to investigate the nutritional properties of starch in buckwheat products. The in vitro rate of starch hydrolysis and the RS formation, respectively, were evaluated in boiled buckwheat groats and in a series of breads baked with increasing proportions (30–70%) of buckwheat flour or groats, respectively. Boiled buck-

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Table 1. Ingredients of the Buckwheat Breads (Grams, Wet Weight)

product	white wheat flour	BWF	BWG	water	yeast	salt	sugar	oil
flour-based breads								
30% BWF	315	135		300	4	4	4	13
40% BWF	270	180		300	3	4	4	13
50% BWF	225	225		300	3	4	4	13
60% BWF	180	270		300	4	4	4	13
70% BWF	135	315		350	4	4	4	13
groat-based breads								
30% BWG	315		135	275	3	4	4	13
40% BWG	270		180	275	3	4	4	13
50% BWG	225		225	275	3	4	4	13
60% BWG	180		270	225	2.5	4	4	13
70% BWG	135		315	225	2.5	4	4	13

wheat groats and bread based on 50% buckwheat groats were further selected to study the glucose and insulin responses in healthy subjects. In parallel, the satiating effect following the buckwheat meals was also recorded.

MATERIALS AND METHODS

Materials. Whole dehusked buckwheat (*F. esculentum* Moench; BW) grains and buckwheat flour were purchased as commercial samples in Slovenia (Goricka ves, Salovci, Prekmurje). Yields from 1997 and 1996 were used for buckwheat flour (BWF) and buckwheat groats (BWG), respectively. According to the traditional process BW grains were dehusked after hydrothermal pretreatment and dried to a 13.2% moisture level. In native groat starch 24.6% of apparent and 28.3% of true amylose were determined previously (*25*). White wheat flour was purchased at a local Swedish market (Kungsörnen, Järna, Sweden).

Boiled BWG. BWG (81.7 g corresponding to the test meal, used in the human study) was placed in cold tap water and left to boil (12 min). A water/BWG ratio of 3:1 (w/w) was chosen to eliminate free water.

Buckwheat Breads. Before breads were baked for analyses, preliminary baking tests were performed to determine the proper water and yeast amounts that would give the most acceptable final product. The breads were made in a baking machine (El-Gennel HB-021E). The formulations of the bread products are given in Table 1. For analyses five flour-based breads were made by mixing BWF (30−70%, w/w) and white wheat flour. In addition, breads with the same proportions of BWG and wheat flour, respectively, were also baked. The cooled breads were sliced, the crusts removed, and the slices frozen. Before analysis, or when being served as a test meal, the slices were thawed at room temperature.

Among the BW breads, a bread with 50% BWG was selected for determination of GI and insulin index (II) in healthy subjects.

White Wheat Reference Bread (WWB). Bread from white wheat flour was made as previously described (*28*). The slices were prepared and treated in the same way as for the BW breads. WWB was used as a reference product in both the in vitro and in vivo studies.

Chemical Analysis of the Test Products. Prior to analysis portions of each bread and boiled BWG were air-dried and milled in a Cyclotec mill (Tecator) to a particle size <0.8 mm. Total starch in the raw materials and in the breads was determined enzymatically following solubilization in alkali as described by Tovar et al. (*29*). However, before the alkali treatment (4 M KOH), the samples were soaked in a phosphate buffer (0.1 M; pH 6.0). By omission of the alkali treatment (*30*), starch corrected for retrograded amylose [used for studies of hydrolysis index (HI) and GI] in the milled material was also determined.

Protein analysis was performed using the Kjeldahl method (Kjeltec Auto 1030 analyzer). The enzymatic−gravimetric method for the determination of total, soluble, and insoluble

dietary fiber (DF) (*31*) was used. Fats were analyzed according to the Schmid−Bondzynsky−Ratzlaff (SBR) method described by Croon and Fuchs (*32*).

Parallel Determination of Potentially Available Starch and RS. To mimic the physiological conditions, the in vitro analysis of potentially available starch and RS was performed on bread samples and boiled BWG without prior mechanical disintegration, that is, in the form "as eaten". A detailed description of the method was recently published by Åkerberg et al. (*33*). In summary, the samples (corresponding to 1 g of total starch) were chewed by six subjects 15 times within a period of ∼15 s. The chewed content was then diluted with distilled water, and the pH was adjusted with 1 M HCl to 1.5 prior to incubation with pepsin ([pepsin] = 50 mg/mL, EC 3.4.23.1, 2000 FIP-U/g; Merck) at 37 °C for 30 min. Thereafter, the pH was adjusted to 5.0 with 1 M NaOH. The following reagents were then added: $MgCl_2/CaCl_2$ solution ([$MgCl_2$] = 0.06 M; [$CaCl_2$] = 0.3 M), pancreatin ([pancreatin] = 40 mg/mL, 8 × USP, Sigma), amyloglucosidase ([amyloglucosidase] = 140 units/mL, EC 3.2.1.3; Boehringer Mannheim), and 2-propanol. The content in the beakers was diluted with distilled water to a final volume of 50 mL. The samples were incubated with constant stirring for 16 h at 37 °C. After completed incubation, RS and nonstarch polysaccharides were precipitated with 95% ethanol (v/v) and filtrated through P2 crucibles. In the filtrates, the glucose was measured at 450 nm using glucose oxidase−peroxidase reagent and expressed as potentially available starch. The RS, comprising RS_1 plus RS_2 plus RS_3, was determined as total starch in dried (105 °C overnight) and milled residues.

In Vitro Rate of Starch Hydrolysis and HI. The rate of starch hydrolysis in the bread samples and in boiled BWG was followed by a dialysis procedure (*34*). Six subjects chewed the bread samples and BWG [corresponding to 1 g of starch, determined according to method of Holm et al. (*30*)] 15 times for 15 s. The sodium/potassium phosphate buffer (KH_2PO_4 + Na_2HPO_4 × $2H_2O$; pH 6.9) was then used to dilute the samples. Thereafter, pepsin ([pepsin] = 50 mg/mL buffer, EC 3.4.23.1, 2000 FIP-U/g; Merck) was added to the samples. The pH was adjusted to 1.5 with 2 M HCl, followed by incubation at 37 °C for 30 min. Before addition of porcine pancreatic α-amylase ([α-amylase] = 110 units/mL buffer, EC 3.2.1.1, 790 units/mg of protein; Sigma), the pH was readjusted to 6.9 with 1 M NaOH. The sample was brought to 30 mL with sodium/potassium phosphate buffer and transferred into dialysis tubings (Spectra Por No. 2, width = 45 mm, MWCO 12000−14000). Each bag was placed into a beaker containing 800 mL of sodium/potassium phosphate buffer and stirred during the incubation (3 h, 37 °C). Every 30 min, aliquots of 1 mL were withdrawn in duplicates for analysis of reducing sugar content with the 3,5-dinitrosalicylic acid (DNS). A standard curve was prepared using maltose. The HI was calculated as follows: for each product, the area under the hydrolysis curve (0−180 min) was expressed as a percentage of the corresponding area obtained after hydrolysis of the reference WWB chewed by the same person.

Blood Glucose and Insulin Responses in Healthy Subjects. Ten healthy subjects (nine women and one man) of mean age ± SEM, 33.3 ± 3.2 years (range = 23−53 years), with normal body mass indices (21.3 ± 0.5 kg/m²) and without any drug therapy, participated in the study.

The buckwheat products (boiled buckwheat groats and bread baked with 50% BWG) and the WWB reference meal corresponded to 50 g of available carbohydrate. Variable amounts of butter and cheese were used to balance the fat (12 g per portion) and protein (15 g per portion) contents of the test meals. The energy content per portion was 1578 kJ. To each meal were added 250 mL of water and 150 mL of coffee/tea. The meals were given as a breakfast in random order (three separate occasions) after an overnight fast. All meals were consumed steadily over 13 min.

Finger-prick capillary blood samples (50 μL) were collected prior to the meal (0) and at 15, 30, 45, 70, 95, 120, and 180 min after the meal for determination of glucose concentration. Sampling (500 μL) at 0, 15, 30, 45, 95, and 120 min was

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Table 2. Total Starch, Potentially Available Starch, and RS Contents in BW Products (Percent, dmb)

product	total starch[a]	potentially available starch[b] ± SEM	RS[b] ± SEM
WWB	81.2	78.4 ± 0.5[h]	0.8 ± 0.0[a]
boiled BWG	72.8	67.9 ± 0.4[abc]	4.4 ± 0.2[f]
flour-based breads			
30% BWF	74.8	71.4 ± 0.2[f]	1.6 ± 0.0[b]
40% BWF	74.9	70.9 ± 0.35[ef]	1.4 ± 0.1[b]
50% BWF	73.7	69.0 ± 0.3[bcd]	0.9 ± 0.15[a]
60% BWF	75.4	73.7 ± 0.7[g]	1.0 ± 0.2[a]
70% BWF	74.5	71.3 ± 0.6[f]	0.7 ± 0.1[a]
groat-based breads			
30% BWG	76.3	70.4 ± 0. 3[def]	2.3 ± 0.2[c]
40% BWG	75.8	69.4 ± 0.4[cde]	2.9 ± 0.1[de]
50% BWG	75.9	68.9 ± 0.4[abcd]	2.9 ± 0.1[de]
60% BWG	74.3	67.5 ± 0.4[ab]	3.1 ± 0.3[e]
70% BWG	73.6	67.3 ± 0.4[a]	3.2 ± 0.2[e]

[a] Values are means of two parallel determinations. [b] Values are means ± SEM; $n = 6$. Means not sharing the same letters in the columns are significantly different ($P < 0.05$).

performed for analysis of insulin. Blood glucose concentration was determined with a glucose-oxidase peroxidase reagent and plasma insulin level with an enzyme immunoassay kit (Insulin Enzymun-Test; Boehringer Mannhein, catalog no. 1289 101).

The GI and II were calculated individually from the 0−95 and 0−120 incremental postprandial blood glucose and plasma insulin areas using WWB as a reference (GI = 100; II = 100) (*1*).

The protocol was approved by the Ethics Committee at the University of Lund, Sweden.

Assessment of Satiety. After the tested isoenergetic meals with a constant carbohydrate/fat/protein ratio had been served, the extent and duration of satiety were evaluated. Subsequently, after every time point of blood sampling, the subjects were requested to numerically assess the feeling of hunger/satiety. A scoring system (*35*) graded from −10 (representing extreme hunger) to +10 (representing extreme satiety) was used. The score at time 0 (before consumption of the meal) was used for setting the baseline. To express the satiety area (SA), the area under the satiety curve (0−120 min) for each test product was calculated and divided by the corresponding area obtained with the reference WWB (SA = 100).

Statistical Analysis. The results are expressed as means ± SEM. The potentially available starch, RS, and the in vitro rate of starch hydrolysis were statistically evaluated by one-way ANOVA using the SPSS/PC+ program (SPSS Inc., Chicago, IL). Comparisons of the means were performed by Duncan's test. A value of $P < 0.05$ was considered to be significant.

The results for GI, II, and SA were assessed by Student's *t* test for paired samples. A value of $P < 0.05$ was taken to indicate significant differences between tested meals.

RESULTS

Total Starch, RS, and Potentially Available Starch. In Table 2, the total starch, potentially available starch, and RS contents in different BW products are listed. The in vitro digestibility of starch in all BW products was >90%, total starch basis. The highest proportion of RS ($P < 0.05$) was found in boiled BWG (4.4%, dmb, i.e., 6.0% total starch basis), followed by the BWG-based bread products. In the breads based on BWF, the RS content (dmb) ranged from 0.7 to 1.6% (corresponding to 0.9−2.1%, total starch basis). Less RS was formed in breads with higher proportions of BWF, whereas in breads with the increased BWG proportion the RS content was higher. In the BWG-based breads 2.3−3.2% of starch was resistant (dmb) (i.e., 3.0−4.3%, total starch basis, respectively).

With the sum of potentially available starch and RS, a mean (± SEM) of 97.2% ± 0.7 was recovered of the total starch analyzed with the one-step analysis according to Tovar et al. (*29*).

In Vitro Rate of Starch Hydrolysis. The percentage of starch hydrolyzed at various time points is shown in Table 3. The lowest rate of starch hydrolysis was found in boiled BWG. In all BW-based bread products the rate of starch hydrolysis at every time point was significantly ($P < 0.05$) reduced compared with the WWB. The lowest rate in the series of breads was shown with the bread baked with 70% BWG.

When the HI was calculated, all of the BW products had a significantly ($P < 0.05$) lower HI (50.4−81.1) than the WWB (Table 3). On the basis of the HI of tested samples, boiled BWG and 70% BWG bread were estimated as most interesting for in vivo testing in healthy subjects. However, the 70% BWG bread was a rather unrealistic product with regard to its sensory attributes. Besides the reduced loaf volume and dryness of the bread, the extremely hard buckwheat grains made this bread rather inedible. Also, grains were not able to hold the bread slice together. Instead, the 50% BWG bread was chosen for the in vivo study.

Postprandial Glucose and Insulin Responses. The mean incremental blood glucose response curves after ingestion of different test meals are shown in Figure 1. Generally, the boiled BWG and the bread product (50% BWG) elicited lower responses than the reference WWB product. The blood glucose level following the boiled BWG meal significantly ($P < 0.05$) differed from the WWB meal at 15, 30, 70, and 95 min. The glucose responses after 50% BWG bread versus WWB could be distinguished ($P < 0.05$) at 30 and 45 min. No statistical differences in glucose levels were observed when the BW products were compared with each other. Moreover, for these products the peak values at 30 min reached the same level. Accordingly, the calculated GIs for boiled BWG ($GI_{95} = 61$) and bread 50% BWG ($GI_{95} = 66$) did not differ significantly. However, in contrast, the GIs were significantly reduced compared with the WWB (Table 5). Mean curves for serum insulin concentration after ingestion of the test meals and WWB meal were more distinguishable (Figure 2). The calculated II for boiled BWG ($II_{95} = 53$) significantly differed from the II of the reference WWB product (Table 5). During the first 45 min the insulin level obtained with 50% BWG bread did not deviate from that with WWB. However, II for the BW bread ($II_{95} = 74$) was significantly ($P < 0.05$) lower as compared to the WWB. No differences were observed between boiled BWG and 50% BWG bread.

Satiety Area. In Figure 3, numerically assessed satiety after ingestion of the test meals and the reference meal is shown. Breakfast with boiled BWG was given higher ($P < 0.05$) satiety scores than the WWB reference at 70, 95, and 120 min. Accordingly, when the satiety area under the curves (0−120 min) was calculated, a significantly higher SA ($P < 0.05$) was established with boiled BWG (SA = 114) than with WWB (SA = 100), but not with 50% BWG bread (SA = 100) (Table 5). The average scores between both buckwheat products were distinguishable only at 95 min.

DISCUSSION

The general conclusion from the present study is that with a series of BW products, a reduced starch hydroly-

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Table 3. Percentage of Starch Hydrolysis in BW Products at Various Time Points and Calculated HI Values[a]

| product | % hydrolyzed starch | | | | | | HI |
	30 min	60 min	90 min	120 min	150 min	180 min	180 min
WWB	12.8 ± 0.4^e	27.3 ± 0.6^d	38.3 ± 0.6^d	47.5 ± 0.6^c	54.3 ± 0.5^c	58.1 ± 0.5^c	100^c
boiled BWG	4.6 ± 0.5^a	11.3 ± 1.2^a	18.0 ± 1.8^a	24.2 ± 2.3^a	30.1 ± 2.6^a	34.9 ± 2.8^a	50.4 ± 4.8^a
flour-based breads							
30% BWF	10.2 ± 0.9^d	20.5 ± 1.6^c	30.7 ± 2.3^c	37.9 ± 2.7^b	44.0 ± 2.8^b	49.6 ± 2.7^b	81.1 ± 4.9^b
70% BWF	9.6 ± 0.7^{cd}	20.2 ± 1.4^c	28.8 ± 1.8^c	36.2 ± 2.1^b	41.8 ± 2.3^b	46.4 ± 2.4^b	76.0 ± 4.1^b
groat-based breads							
30% BWG	9.1 ± 0.4^{cd}	20.1 ± 0.9^c	29.2 ± 1.2^c	37.0 ± 1.4^b	42.9 ± 1.5^b	48.1 ± 1.4^b	77.6 ± 2.8^b
50% BWG	8.0 ± 0.9^{bc}	18.0 ± 1.8^{bc}	26.5 ± 2.5^{bc}	34.1 ± 2.9^b	39.8 ± 3.0^b	45.2 ± 3.1^b	71.4 ± 6.2^b
70% BWG	6.0 ± 0.4^a	13.5 ± 0.9^a	19.9 ± 1.3^a	25.4 ± 1.5^a	30.2 ± 1.6^a	34.0 ± 1.5^a	53.8 ± 3.6^a

[a] Values are means $\pm$ SEM; $n = 6$. Means not sharing the same letters in the columns are significantly different ($P < 0.05$).
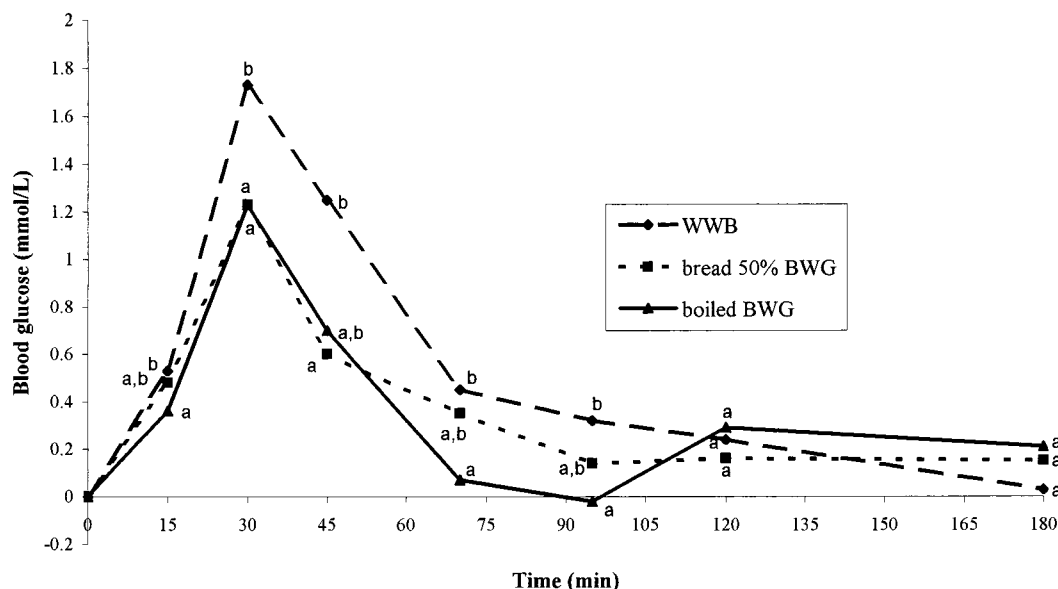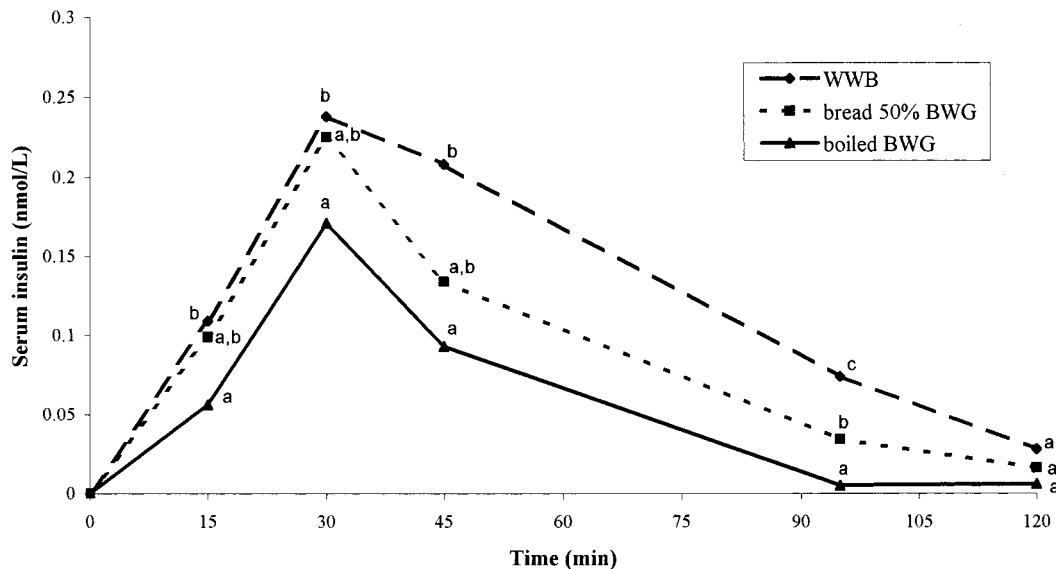

Figure 1. Postprandial blood glucose responses in healthy subjects following ingestion of breakfast meals with buckwheat products and a WWB reference product, respectively. Values are means, $n = 10$.

Table 4. Composition of Products Used in the in Vivo Study (Percent, dmb)[a]

product	starch[b]	fat	protein	DF total	soluble	insoluble
WWB	80.1	2.6	12.7	3.8	1.0	2.8
boiled BWG	70.6	4.0	14.5	7.5	2.4	5.1
50% BWG	73.0	5.2	13.2	6.7	2.1	4.6

[a] Values are means of two parallel determinations. [b] Starch, corrected for retrograded amylose.

sis rate could be achieved, especially when the botanical integrity of whole dehusked BWG was maintained in products.

Native BW starch has a characteristic A-type crystallinity (*24*), otherwise typical for cereal starches. Thus, the nutritional features of BW starch were expected to be comparable with those of true cereal based products. However, some specific characteristics of BW starch were observed.

The highest amount of RS, formed in boiled BWG, was 6.0% (total starch basis). This is in agreement with a previous in vivo study using antibiotic treated rats (*26*). It was reported that 4.9−6.4% of starch in hydrothermally treated and milled BWG passed undigested to the rat hind-gut.

With the increasing proportion of BWG in bread products, the RS levels rose to 4.3% (total starch basis) RS. The BW seeds themselves represent a physical barrier to the amylolytic enzymes (i.e., RS type 1). Some

of the starch in breads with high amounts of dehusked BW kernels may remain intact during baking (i.e., RS type 2), due to insufficient amounts of water for complete gelatinization of the starch granules. Additionally, it is also important that during the baking of BW breads, the groats were exposed to a second cycle of thermal treatment (the first cycle is part of the dehusking procedure). As shown previously (*25*) in BWG, subsequent heating and cooling cycles resulted in significantly higher amounts of RS_3. Thus, in BWG bread products, all three types of RS are likely to be present, RS_1, RS_2, and RS_3, whereas mainly RS_3 (retrograded starch) is expected in BWF breads.

In the literature, no RS data are available for breads with a constituent, which would correspond to our hydrothermally pretreated dehusked BWG.

The explanation for the decreasing RS content with increasing BWF proportion in the dough might be that the size of BW starch granules is smaller ($\bar{x} = 5.8$ μm) than the wheat starch granules ($\bar{x} = 13.8$ μm) (*36, 23*). Accordingly, the surface area and thus the water-binding capacity of BW starch are higher than that of wheat and increase in conformity with the BWF proportion. During baking, these particular features allow the BW starch to be easily and thoroughly gelatinized, and such starch could be more susceptible to the amylolytic enzymes.

As is evident from our study, the replacement of 30% of the wheat flour with BWF surprisingly reduced the HI by as much as 19 units. Starch in BW products may

Table 5. Calculated GI, II, and the Related SA of Test Meals[a]

	GI		II		SA[b]
product	95 min	120 min	95 min	120 min	120 min
WWB	100[b]	100[b]	100[b]	100[b]	100[a]
boiled BWG	61.2 ± 10.2[a]	64.3 ± 10.2[a]	52.7 ± 10.4[a]	51.6 ± 10.8[a]	113.9 ± 4.0[b]
50% BWG	66.2 ± 8.8[a]	66.7 ± 9.5[a]	74.1 ± 10.5[a]	71.5 ± 10.2[a]	100.0 ± 10.7[ab]

[a] Values are means ± SEM; $n = 10$. Means not sharing the same letters in the columns are significantly different ($P < 0.05$). [b] $n = 8$.

Figure 2. Postprandial insulin responses in healthy subjects following ingestion of breakfast meals with buckwheat products and a WWB reference product, respectively. Values are means, $n = 10$.
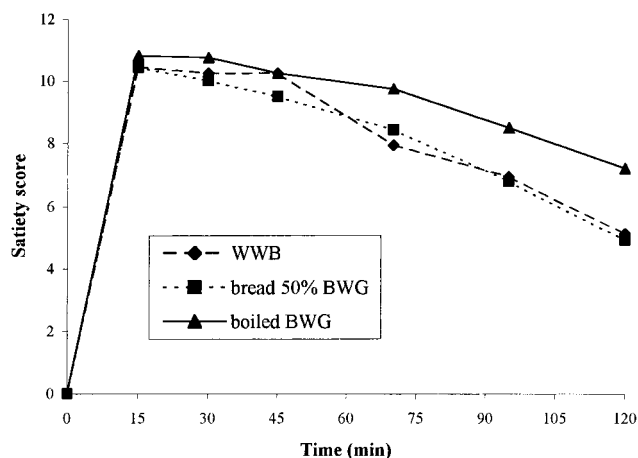

Figure 3. Mean satiety scores following ingestion of breakfast meals with buckwheat products and a WWB reference product, respectively.

behave differently from starch in other flour-based cereal products. It might be speculated that BW itself contains one or more components that could inhibit the amylolytic degradation of BW starch. Ikeda et al. (*37*) investigated the inhibitory activity of BWF extract on amylases from different sources. Both enzymes, included also in our analytical procedure (α-amylases from human saliva and porcine pancreas), were shown to be inhibited by BWF extract. However, the authors hypothesized that the inhibitory substance might be of protein origin. Thus, it is expected that during baking of the BW breads this inhibitory potential might be reduced. Therefore, in our case more stable inhibitory substances, such as tannins (*38*) and phytic acid (*39*) might inhibit starch degradation. BW, in particular, is

an abundant source of tannins [2.5% (*40, 41*] and phytic acid (0.2−0.7%, dmb; unpublished results), which may potentially contribute to the reduced in vitro rate of starch hydrolysis.

In the present study a positive characteristic of starch in boiled BWG in the sense of flattening the metabolic responses was confirmed in vivo. However, the GI of boiled BWG (GI = 61) was lower than reported earlier. According to Jenkins et al. (*1*) and Wolever et al. (*27*) the GI for BW, determined in healthy subjects, was 73, whereas in NIDDM and IDDM subjects the corresponding values were 70 and 90, respectively. The cited GI data seem to be related to boiled groats, although the type and processing condition of product were not defined. An important reason for differences between the cited GI value and that from the present study might be differences in the processing conditions applied. In our case, it is likely that the exposure of BWG to hydrothermal treatment before dehusking remarkably contributed to the reduced accessibility of starch in boiled BWG. Such pretreatment could obstruct the water binding capacity and the swelling ability of starch granules during the second thermal treatment (i.e., boiling) and, thus, consequently result in lower postprandial glycemic response. A similar phenomenon was previously described with parboiled rice (*42*) and bulgur (i.e., parboiled cracked wheat) (*43*).

Bread products with the admixture of 30−50% BWF are a traditional food, known mainly in Slovenia, whereas the BWG-based breads could be considered to be model products. Thus, no comparable data for the GI of BW bread could be found in the literature. However, the improved glycemia in healthy subjects, following the ingestion of a bread based on 50% BWG (GI = 66), is in accordance with the reduced metabolic

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responses reported for bread with the same proportion (50%) of barley kernel (GI = 62), crushed barley kernel (GI = 69), or crushed wheat grain (GI = 61) (*44*), respectively. With regard to the insulin responses after ingestion of BW products, boiled BWG (II = 53) seemed to hold a better potential in the dietary management of diabetes than 50% BWG bread (II = 74). However, the II values of these two products were not statistically different.

Not only the equal caloric value but also the constant ratio of macronutrients are important when the satiating power of particular meal is evaluated. For this purpose, a term of satiety area (SA) was introduced, which should be distinguished from the satiety index (SI), based on 1000 kJ servings (*9*). It was shown that individuals assessed boiled BWG as a meal with the highest satiating capacity (SA = 114). However, the bread based on 50% BWG bread had the same satiating capacity as the WWB. Thus, the GI features seem to be just one of the factors that contribute to the appetite sensations. Psychological effects should not be neglected, especially as the assessors participating in the study were not trained. Also, some of them were served BW for the first time and were not familiar with its taste.

CONCLUSIONS

The present study shows that BW has potential use in the design of foods with a modified course of starch digestion. Boiled BWG or consciously chosen bread may reduce glycemia and insulin demand and hence influence the metabolism beneficially. Boiled BWG and bread based on 50% BWG also contain appreciable amounts of dietary fiber and RS, and boiled BWG also displays a high postprandial satiety.

ABBREVIATIONS USED

BW, buckwheat; BWF, buckwheat flour; BWG, buckwheat groats; DF, dietary fiber; dmb, dry matter basis; DNS, 3,5-dinitrosalicylic acid; GI, glycemic index; HI, hydrolysis index; II, insulinemic index; RS, resistant starch; SA, satiety area; SEM, standard error of mean; WWB, white wheat bread.

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