Developing Barley-Fortified Wheat Based Foods

Gary G. Hou and Veronica Jimenez
Wheat Marketing Center, Portland, Oregon

1. Introduction

Americans are increasingly at risk of premature death from both cardiovascular disease and diabetes due to overweight, elevated cholesterol, high blood pressure, and abnormal blood sugars. These risk factors are partially contributed by a diet low in fiber and high in refined grains, sugars, and saturated fats.

A great interest has recently risen in the development of "functional" foods, products that may provide a health benefit beyond the traditional nutrients. Foods rich in antioxidants and a low glycemic index (GI) can reduce the risk of increased postprandial oxidative stress, which is one of the constituents of the onset of several chronic diseases.

Barley is a rich source of soluble and insoluble fiber. β-glucan, a fraction of the soluble dietary fiber, is the primary component in barley that is responsible for lowering serum cholesterol and blood glucose. The Food and Drug Administration (FDA) finalized a rule in 2006 allowing barley foods to carry a health claim specific to soluble fiber and coronary heart disease. Barley can be part of the solution to the development of healthy foods in American diet.

2. Barley production

Barley is a cereal grain that belongs to the Poacea family, the Triticeae tribe and the Hordeum genus. All cultivated barley belongs to the Hordeum vulgare. According to the National Barley Growers Association, barley is grown in 27 states across the United States. Major producing states, in descending order of production, include North Dakota, Idaho, Montana, Washington, Colorado, Wyoming, Virginia, Minnesota, Maryland, South Dakota, Oregon and Utah. It is also grown in many different countries throughout the world. Other major producers include Australia, Canada, Germany, Russia and Ukraine.

Barley is commercially used for animal feed (51%), malt (44%), seed (3%), and human food applications (2%) in the U.S. In addition to domestic use of barley, exports of the grain averaged about $155 million for barley and its milled products, $44 million for malt and malt extracts and $269 million for beer between 1991 and 2000 (Source: National Barley Growers Association).

3. Barley types

Cultivated barley can have either 2-row or 6-row head type on which either covered or hulless (naked) seed develop. Commercial barley is known for the following types:

1) Covered barley: Barley kernels with the tough inedible outer hull still attached. This hull must be removed before barley can be used for human consumption.
2) Hulled barley: Covered barley that has been minimally processed to remove only the tough inedible outer hull. Because hulled barley has been minimally processed, most of the bran and endosperm is left intact and the germ is present,

making hulled barley whole grain. Hulled barley is available in different forms: kernels, flakes, grits and flour.

3) Hulless barley: The tough inedible outer hull is loosely adhered to the kernel. The outer hull is so loose that when the barley is harvested in the field, the outer hull often falls off. This type of barley requires minimal cleaning after it is harvested, so most of the bran and endosperm is left intact and the germ is present. This barley is considered whole grain.
   Hulless barley has two types: normal and waxy. The normal type has the traditional ratio of amylose to amylopectin starch fractions as found in regular barley. The waxy type has a very high percentage of amylopectin starch. Hulless barley is available in different forms: kernels, flakes, grits and flour.
4) Pearled Barley: Covered barley that has been processed to remove the hull and then pearled or polished further by an abrasive scouring process. Pearled barley may also be called blocked, pot or scotch barley. The pearling process may remove some of the bran, germ or outer endosperm, so some soluble insoluble fiber, trace minerals and micronutrients may be lost. Pearled barley is not considered whole grain.

Hulless barley is commonly used for human food. Even though the current usage of hulless barley in human diets and animal feeds is quite small, it has vast potential uses. Lack of acceptance by the food and feed industries and lack of consumer awareness are due partly to the lack of a sufficient volume of hulless barley production and partly to food recognition of its food and feed value.

4. **Research objectives**

The objectives of this research were: 1) to improve the nutritional and health benefits of wheat-food based products by adding barley flour, which has a high content of β-Glucan (soluble fiber); and 2) to reformulate products and optimize the addition levels of each barley flour in different wheat products.

5. **Experimental approach**

1) Raw materials
   a) Barley flour

      Three types of barley flour were used in this study and they were Salute, Radiant, and Sustagrain. Both Salute and Radiant were received as grains, so they required cleaning, pearling, and milling processes. Based on the experiment, both grains were pearled by 25% and the de-hulled grains were milled into flour using a Falling Number grinder. Sustagrain was received as a whole grain flour. The flour analysis results of these three barley flours are shown in Table 1. The β-glucan contents of these barley grains were reported as 6.0% (12% mb) for Salute, 5.5% (12% mb) for Radiant, and 11% (as-is moisture) for Sustagrain.

Table 1. Barley flour analysis results

Barley type	Moisture (%)	Ash (%, 14% mb)	Protein (%, 14% mb)
Salute	8.81	1.050	9.06
Radiant	10.57	1.052	9.16
Sustagrain	5.66	2.232	12.46

b) Wheat flour

U.S. hard red spring wheat (HRS), hard red winter wheat (HRW), and soft white wheat (SW) flour were used in the study. Each type of wheat flour was selected for specific product based on product requirements. HRS flour was used for bagels; HRW was used for instant ramen noodles, pan bread, and flour tortillas; and SW was used for sugar-snap cookies. Table 2 lists the basic flour analysis data.

Table 2 Wheat flour analysis results

Flour type	Moisture (%)	Ash (%, 14% mb)	Protein (%, 14% mb)
Hard red winter	13.18	0.493	12.79
Hard red spring	13.11	0.590	14.39
Soft white	11.55	0.542	10.37

c) Wheat flour and barley flour blends

In each formula, 10%, 20%, and 30% of wheat flour was replaced by each of the three barley flour. A control sample that did not contain barley flour was included as reference for the comparison of product quality.

2) Product types

In this study, five wheat-based products were tested and they were instant ramen noodles, bagels, flour tortillas, pan breads, and cookies. These products are very popular in the U.S. and elsewhere. Improving the health benefits of these commonly consumed foods would have a great benefit to consumers and increase the overall consumption of wheat flour.

3) Formulation modification

Substitute of wheat flour with barley flour requires some formulation changes. Here are some of the changes made in each product formulation during the experiment:

a) Instant fried ramen noodles: 1% extra water was needed in the formula as every 10% of wheat flour was replaced by barley flour.
b) Bagels: 3-4% extra water was needed in the formula as every 10% of wheat flour was replaced by barley flour. In addition, 0.02-0.05% extra instant yeast was added when wheat flour was replaced by barley flour.
c) Flour tortillas: 1-2% extra water was needed in the formula as every 10% of wheat flour was substituted by barley flour. Tortilla dough also required longer resting time to improve product diameter.

d) Pan breads: variable amount of extra water was needed in the formula as wheat flour was substituted by barley flour.
e) Sugar-snap cookies: water amount was adjusted based on the moisture content of the flour blend.

6. **Results**

1) Instant ramen noodles

Figure 1 Instant fried ramen noodles with added barley flour

There is a visible difference of color in the finished product. Noodles made with added Salute barley flour were pale, while the ones added with Radiant were more similar to the control showing a yellowish color. Radiant barley is proanthocyanidin free, and does not affect the color of the product.

Noodles added with Sustagrain flour were the darkest in color and the maximum substitution level was 20%, because the color of noodles with 30% Sustagrain barley flour was brown. This could be potentially unattractive to consumers.

Figure 2 Non-friend instant ramen noodles added with barley flour

For the non-fried (air-dried) instant noodles the color differences were even greater. The most similar noodles to the control were the ones added with Radiant barley flour, which contributed to its yellowish color. Sustagrain noodles were dark and unattractive, but 10% could be acceptable level.

Sensory evaluation by panelists suggested that up to 20% of wheat flour in the instant ramen noodle formula could be substituted by either Salute or Radiant barley flour and the noodle products had acceptable processing characteristics and functional quality (flavor and texture with some differences, yet still acceptable). The blend of wheat flour and Radiant barley flour (80/20) produced the most acceptable instant-noodle processing characteristics and product quality. For Sustagrain flour, the most acceptable level was 10% when color, flavor and eating quality were considered.

2) Bagels

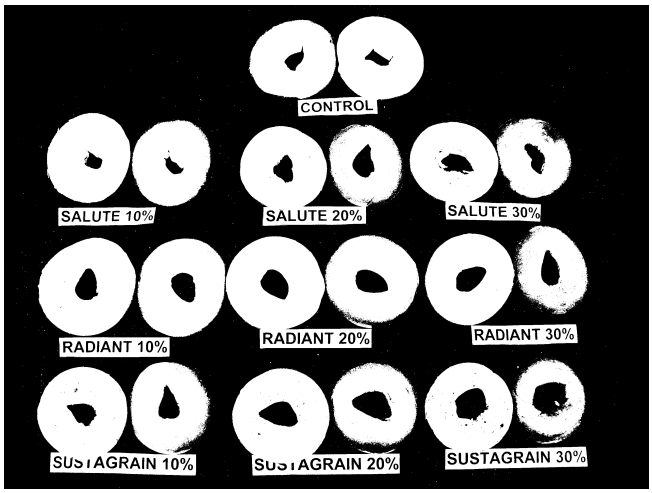

Figure 3 Bagels with barley flour

Bagels added with Salute barley flour were darker, the volume was smaller, and had a residual mouth feel flavor that was not present in the control bagels. Bagels added with Radiant barley flour showed similar color to the control due to the fact that this type of barley is proanthocyanidins free. The flavor was very similar to the control too, and the most acceptable level of Radiant barley flour to replace wheat flour was 20%. Radiant was the best option for bagel products. Sustagrain barley flour gave the bagels a dark color and tough texture. In this experiment, bagels added with 10% Sustagrain flour were acceptable.

In general the sensory panel accepted all bagels with up to 20% added barley flour. The texture was good and the color was darker, but still acceptable. After three days of storage, Salute did not significantly affect the bagel hardness, while Radiant and Sustagrain significantly increased bagel hardness, especially at 30% substitution level.

3) Flour tortillas

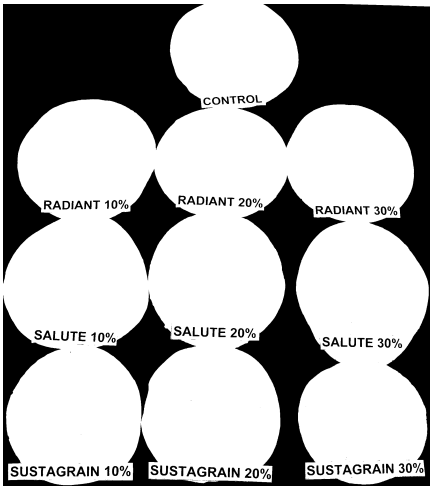

Figure 4 Flour tortillas with barley flour

Flour tortillas added with Radiant barley flour showed the most similar color to the control, while both Salute and Sustagrain made the tortillas darker as the substitution level increased.

As expected, barley flour reduced both the strength and extensibility of tortillas as the substitution level increased. This is due to the lack of gluten to make them stronger. The difference in structure was seen when tortillas were baked, because they had small holes on the surface. The holes made the structure weak and they lacked elasticity like regular flour tortillas. After 4 days of storage, however, the flour tortillas strength continued to weaken but the extensibility increased; the extensibility of tortillas added with barley flour became longer than the control sample.

Barley flour also reduced the tortilla rollability over storage time of 12 days tested. On the 4^{th} day of storage, tortillas added with barley flour started to show cracking while being rolled. On the 12^{th} day, tortillas added with barley flour could hardly be rolled, especially for the ones with Sustagrain flour.

Barley flour did not significantly affect the weight and diameter of flour tortillas. However, in order to produce consistent diameter of tortillas added with barley flour, it was necessary to rest the dough long enough (at room temperature), so the barley dough got softer and easier to extend upon hot pressing. In the case of tortillas with 30% of Sustagrain flour, they were much smaller than the rest of tortillas in this experiment, even if the dough was rested longer. In this case, it would be necessary to supplement with some gluten to support the protein structure to produce bigger diameter tortillas.

Sensory evaluation perceived some differences of taste in tortillas with barley flour; nevertheless the tortillas texture was acceptable. The color difference was also noticeable, but the panel did not mind it even with tortillas that were brown and much darker than the control. This is one of the products that consumers are willing to accept for more healthy benefits.

In overall, Radiant barley flour produced the most similar quality characteristics to the control product. Substitution of wheat flour with barley flour made tortillas darker in color and more brittle. But the consumers still accepted these products for health benefits.

4) Pan bread

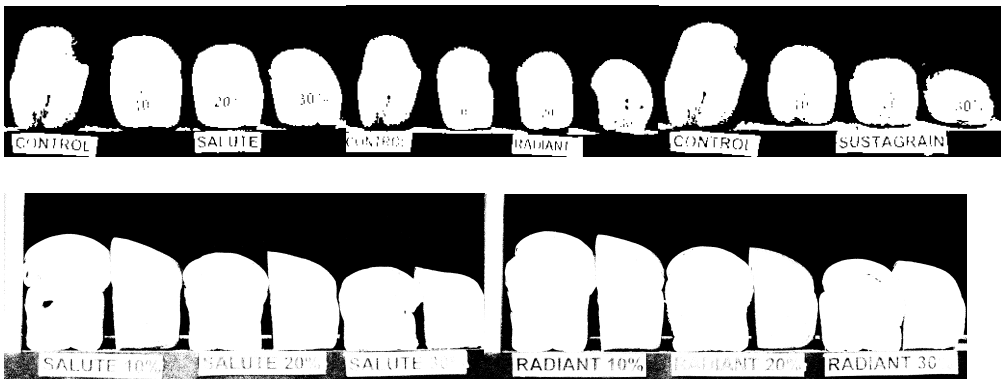

Figure 5 Pan breads with barley flour

Except for the Radiant barely flour which did not affect the pan bread crumb color, Salute and Sustagrain both reduced the bread crumb whiteness and increased its yellowness as the addition level increased, yet the color was still acceptable to the consumers.

Barley flour significantly increased the bread hardness at 20% and 30% addition levels. Substitution of wheat flour by 10% barley flour had similar bread hardness to the control product. The most different texture in the bread was with the 30% Sustagrain barley flour. It was not only very hard in texture, but also caused difficulty in slicing the bread. This can present a problem during commercial formulation production.

The bread dough with Salute and Radiant barley flour in the process lacked elasticity. In the case of adding Sustagrain flour, the dough was tough, even if the water amount was increased. The difference in dough structure affects the behavior of bread during the baking process. The bread core did not expand, so the breads produced with

barley flour had lower specific volume, and the core structure was uneven, presenting big holes in some areas and no holes in other areas.

External scores of bread added with barley were scored lower, due mainly to the smaller volume compared to the control bread. All breads with barley flour gave darker color compared to the control bread, which may not be attractive to consumers. Internal characteristics of bread with 10% of Salute barley flour or 10% of Radiant barley flour were similar to the control bread. Other breads presented very different characteristics in structure, such as big holes combined with small pores, and tough cores, which are not attractive.

A panel of regular consumers of bread tasted the different bread samples. The test was based on the acceptability of the product; it was not a preference test. People were asked to taste the texture and flavor, taking into consideration that samples given were products with additional health benefits. Bread acceptability was very high compared to the analysis results described previously on the texture and volume. The least accepted samples were the ones with 30% of any type of barley flour, but the panelists were willing to accept them given the health benefits of these products.

A follow-up experiment was conducted to see if the bread volume and texture could be improved by adding vital gluten. The amounts of gluten added, were determined based on the content of protein in each type of barley. The results were almost the same. There was not a significant improvement either in bread texture or in volume. Pan bread didn't expand much more than that it did in the first experiment. The effectiveness of other additives must be experimented with.

In summary, pan breads produced with the blend of hard red winter flour and barley flour did not develop an adequate volume and the structure was different from the regular bread. Adding additional vital gluten to the formula was not enough to improve bread volume and texture; it may be necessary to experiment with other additives. However, adding barley flour to the traditional pan bread formula was still a valid option based on the sensory panel evaluation. Consumers were willing to accept products with health benefits, even with some differences in texture, color, and flavor in the products.

5) Sugar-snap cookies

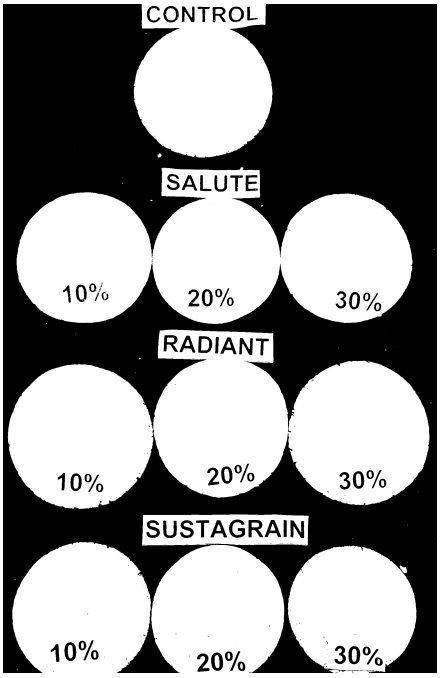

Figure 6 Sugar-snap cookies with barley flour

As the barley flour addition level increased, both cookie diameter and height were increased; however, the cookie spread ratio (diameter/height) remained the same. Cookies with Sustagrain barley flour gave much smaller diameter and height than the control cookies although the spread ratio did not change. During the process, the dough with barley flour was sticky and difficult to handle, but the quality of the final product was very acceptable.

Sensory panelists did not detect barley flavor in the cookies because of high sugar and fat content in the cookie formula. They perceived a difference in color but were unable to taste the difference during sensory evaluation. The color of cookies added with Salute or Radiant barley flour was similar to the control cookies. Cookies added with Sustagrain barley flour were darker, yet acceptable to the panel. Cookie texture was also acceptable to the panel.

7. Summary

Because barley adapts well to different types of environments, both irrigated and dry land, it is grown in 27 states across the country. Barley has beneficial components for health issues. It is a great source of β-Glucan (soluble dietary fiber), and its starch composition is suitable to produce low glucose index (GI) products. As a result, the US Food and Drug Administration (FDA) authorized the use of a health claim for the role of β-glucan soluble fiber from barley in reducing the risk of coronary heart disease.

The main objective of this study was to develop wheat-based products with additional nutritional and health benefits fortified with high β-glucan barley flour. Each of HRS, HRW and SW classes was blended with 10%, 20% and 30% of three types of barley flour including waxy, hulless and hulled types. The varieties tested were Radiant, Salute and Sustagrain. The results of the study are summarized as follows:

- *Instant ramen noodles* containing up to 20% barley flour were acceptable in processing characteristics and functional quality. The best blend was 80% HRW flour and 20% Radiant barley flour (80/20), which gave the most similar product to the control. Extra water was needed in the formula to optimize the noodle process. For Sustagrain barley flour, the most acceptable level was 10% when color, flavor and eating quality were considered.
- *Bagels* containing up to 20% barley flour were acceptable in texture and color to consumers. Extra water and yeast were needed in the formulas to achieve optimum results.
- *Flour tortillas* added with different percentages of barley flours came out successfully. Sensory evaluation perceived some taste differences in tortillas with barley flour; nevertheless the tortillas texture was acceptable. The color difference was also noticeable, but the panel still accepted it for health benefits even with tortillas that were brown and much darker than the control. Radiant barley flour produced the most similar quality characteristics to the control product. However, it was necessary to make some minor adjustments in the process, such as more water addition and extended resting time, so the diameter of the tortillas remained constant.
- *Pan Bread* added with up to 20% barley flour showed acceptable eating quality to consumers although it did not develop adequate volume and bread texture was much harder than the control. The least accepted samples were the ones with 30% of any type of barley flour, but the panelists were willing to accept them given the health benefits of these products. Addition of extra vital gluten to the formula did not improve bread volume and texture; it may be necessary to experiment with other additives.
- *Cookies* made with the blends of wheat and barley flour tended to have sticky dough; nevertheless they yielded good results and had acceptable color and texture to consumers. Sensory panelists perceived a color difference but were unable to detect taste difference. The color of cookies added with Salute or Radiant barley flour was similar to the control cookies. Cookies added with Sustagrain barley flour were darker, yet acceptable to the sensory panel.

In conclusion, high β-glucan barley flour can be a good option to improve the nutritional and health benefits of wheat-based products. By incorporating barley flour into popularly consumed wheat-based products, it could help consumers improve their

health. As wheat products become healthier, it is expected to see continued and sustainable growth in wheat consumption.

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