Upcycled Barley: Unlocking the Nutrition Potential of an Ancient Grain

barley
compendium
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A 21st Century Look at an Ancient Grain

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Upcycled Barley:

Unlocking the Nutrition Potential of an Ancient Grain

Barley has ancient roots as a life-giving food. Its versatility and ability to grow in a broad range of challenging climates has enabled populations across the planet to benefit from this whole grain's unique nutrition bundle for more than 10,000 years.[1,2]

It is also the source of one of the world's most popular beverages—beer. Whether it is ale, stout, lager, pilsner, porter, IPA, sour (and others)—beer is embedded in our global cultural fabric. What's exciting is that, today, the nutrient-rich byproduct of the malting and brewing process—brewers' spent grain (BSG) can be used to enhance the diets of people and the health of our planet.

Historically, BSG has been discarded to landfill or used for animal feed rather than for human consumption.[3] This previously untapped resource can be upcycled into nutrient-rich, climate-conscious ingredients that contain high levels of protein, fiber, and phytonutrients that can be incorporated into a range of beverage and food products.

Instead of expending valuable resources on growing crops to produce new proteins or other nutrient sources, utilizing BSG allows producers to save the protein- and nutrient-rich barley we have.

The process of malting barley and then brewing it for beer, so long part of the world's cultural story, gives us a global, plentiful supply of BSG to work with while limiting the environmental impact.

A 21ST CENTURY LOOK AT AN ANCIENT GRAIN

In short, barley continues to reveal itself as a nutrient-dense ancient grain that offers an impressive second life, to meet growing market demand for food that is better for people and for the planet. Upcycling BSG harnesses the power of untapped nutrition that unlocks its potential as a new kind of functional food—and the future of truly sustainable protein, fiber and quality nutrition source.

Though still widely cultivated today, barley's role as a food source had, for a time, downshifted in the modern era. But the tides are turning again. Barley is a healthful and sustainable ancient grain and has stood the test of time as a key source of nutrition. Now, it is taking the spotlight in an entirely novel way to meet the needs of 21st century consumers by offering solutions to the problems of feeding an ever-growing population, food waste, and climate change.

Barley's health-halo and status as a nutritionally important food are not new. Agricultural experts with an eye on history have described barley as a "sustaining food source in the evolution of humans" and "one of the most important food grains in the ancient world."[3] Even while grains such as wheat, rye, and oats became easier and cheaper to produce, barley has continued to play a vital role in our food system, particularly in the form of animal feed and in the production of alcohol beverages such as beer.

Barley Compendium Highlights

Barley is a nutrient-rich ancient grain that has been an integral part of our food supply dating back 10,000 years. It is the world's fourth largest crop in terms of acreage and production, and one of the most sustainable crops, using very little water while adding nutrients to the soil.

Unlocking its full potential, upcycling the barley in BSG—the product that is left after brewing—promises nutrient dense, functional, climate-resilient, plant-based sources of nutrition for the world's population. And barley's impressive sustainability story makes it primed to play an important role in plant-based nutrition.

Most commonly used by the beer industry, barley has gained a new life through the increased interest in upcycling.

There are decades of quality research published on the nutrition and health of whole grains and barley. And the recent interest and exploration into the nutrition and potential of upcycled barley is newly underway and promising. Particular areas of exploration include cardiovascular health; metabolic health; gut and digestive health; satiety and weight management; immune support (including anticarcinogenic potential) and inflammation; and muscle physiology, recovery, and performance (sports).

With consumers increasingly wanting multiple nutritional attributes from their foods, barley, BSG, and its upcycled forms present a potential convergence of those demands: nutrition and health benefits, taste, versatility in their food choices, and meeting the eco-consciousness of eaters today. The existing and potential applications in the marketplace demonstrate the opportunity for upcycled ingredients from barley to be an important and viable part of the solution to nourish our global population.

It All Starts with the

Grain.

Barley, in Latin *hordeum vulgare*, is a cereal plant and edible grain belonging to the Poaceae grass family.[4] Archaeological evidence suggests that wild forms of barley were consumed near the Sea of Galilee as early as 23,000 BC.[5] It became domesticated by 8,000 BC in and around the Fertile Crescent, cementing its place as a founding crop in Old World agriculture.[6]

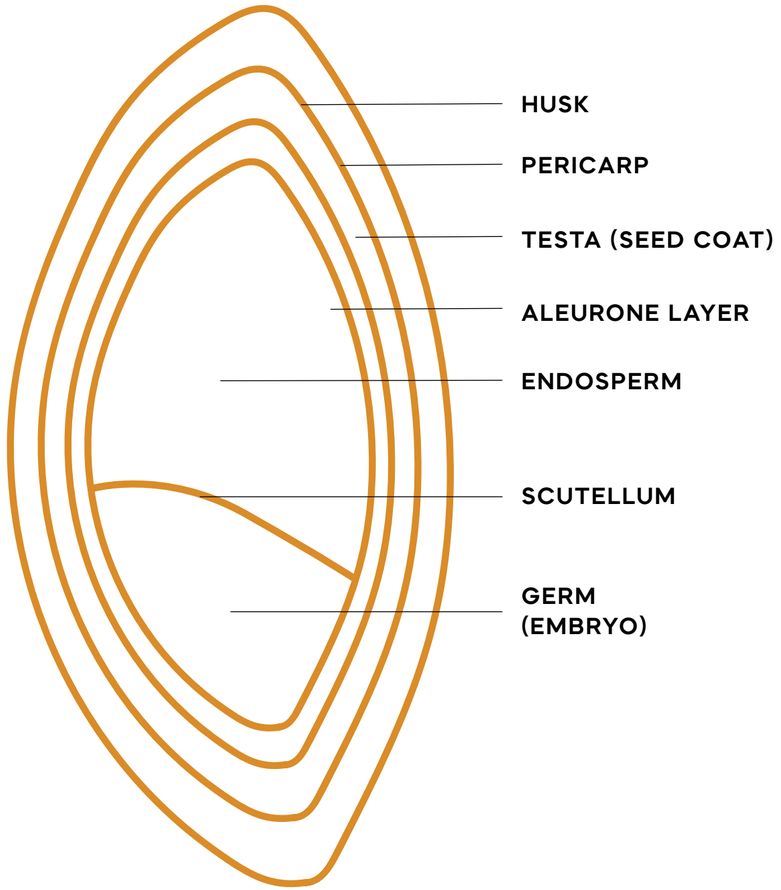
Early on, our ancestors simply ate barley kernels raw. Over the millennia, techniques for soaking, cooking, and grinding barley were developed, setting the stage for the production of porridges, flours, and alcoholic beverages. Barley served for multiple reasons: ale-based poultices were applied medicinally as early as 2,700 BC in lower Mesopotamia, while in Egypt, barley even played a role in religious rites, serving as an important offering to the gods. A focus on nutrition was seen by the Roman gladiators who ate barley breads for stamina and strength.[7] As the grain spread to northern Europe, barley was used to make hearty, long-keeping flatbreads that formed the backbone of diets for poorer peasants.[3]

Barley doesn't, however, support human nutrition in the far-reaching way that it once did. In the US, a mere 1.5% of barley goes directly towards human food use. Another 65% is diverted to animal feed. The other 30% goes towards the production of alcoholic beverages. It's this 30% that becomes the brewers' spent grain (BSG) that would otherwise go discarded, lest it be upcycled into a new form of functional nutrition.[3]

Figure 1

Schematic view of a Barley Grain structure with corresponding nutrients as retrieved

Adapted from Lynch et al. (2016)[10]



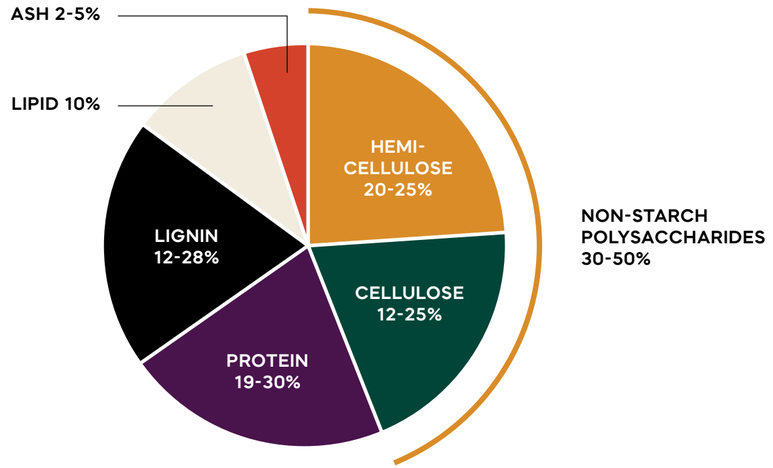
Whole Barley

Barley has an outer layer called the husk that covers the complete grain and consists mostly of cellulose, hemi-cellulose, and lignin. Beneath and attached to the husk is the pericarp, followed by the aleurone. It is the aleurone layer where beta-glucan and arabinoxylan fibers are found.[8] In the center of the grain is the endosperm, consisting mostly of starch, protein, and beta-glucan.[9]

Figure 2

Barley BSG composition

Adapted from Lynch et al. (2016)[10]

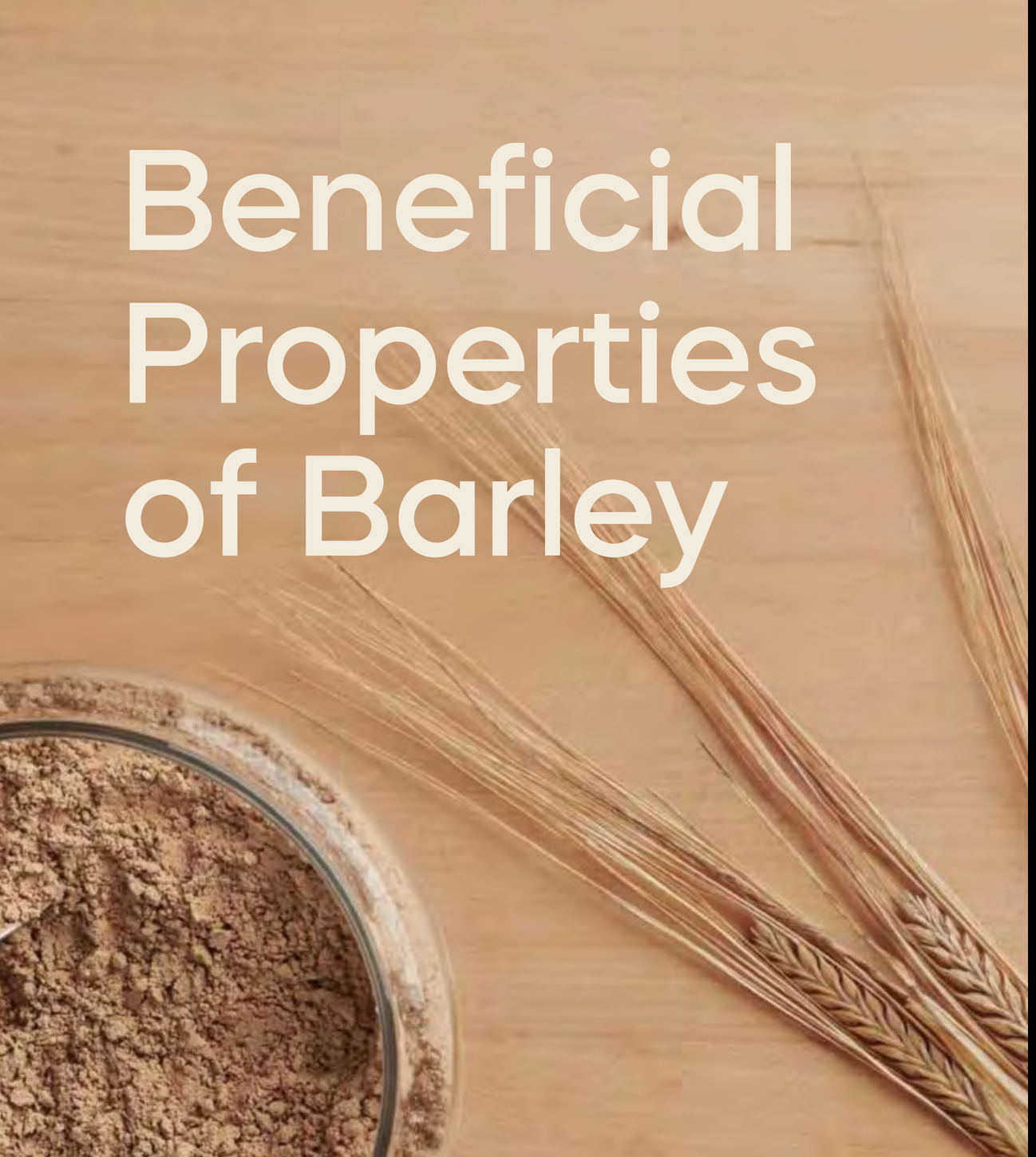


The Value of Barley:

A Nutrient-Dense Whole Grain

Barley is a whole grain (Figure 1), a family of nutrient-dense foods almost universally recognized for their important contribution to public health and wellbeing. Whole grains are recognized as “one of the three food groups that are fundamental constituents of a healthy dietary pattern,” according to the 2020-2025 Dietary Guidelines for Americans (DGAs).[11] To this end, the DGAs recommend consumption of at least three “ounce equivalents” of whole grain daily or six “ounce equivalents” of foods made with an equal mix of whole and refined grains, and that at least half of all grains consumed be whole grain.[11] This equates to approximately 48 grams of whole grain daily, or 96 grams of foods made with an equal mix of whole and refined grains. Of course, it’s well-known that Americans are not getting enough whole grains. Nationally representative data shows that the average U.S. adult consumes less than one ounce of whole grains per day—that is far below (less than 20%) the recommendation of the modest advice to make “half your grains whole grains.”[12]

Whole grain consumption is associated with a lower risk for heart disease, diabetes, certain types of cancers, and other chronic health problems.[13] Whole grains also support feelings of fullness and satiety, which may make it easier to maintain a healthy weight.[14,15] While refined grains have been stripped of much of their nutritional value in favor of functionality, whole grains such as barley retain this key currency—the husk and aleurone layers contain most of the fiber and phytonutrients.[8] Whole grain barley is naturally rich in fiber, vitamins, minerals, and phytochemical compounds, each known to play an integral role in promoting health and vitality.[16]



Beneficial Properties of Barley

- Rich in fiber, particularly the beneficial soluble fibers beta-glucans
- Contains B vitamins, potassium, iron, magnesium, and selenium
- Bioactive compounds including phenolics, tocopherols, and phytosterols
- Protein including essential amino acids
- Low in fat
- Intrinsically cholesterol-free

Upcycled Barley: BSG

Barley is arguably best known because of the global brewing industry. BSG is a byproduct of the brewing process that historically has been used for animal feed or ended up as food waste, negatively impacting the environment. Yet BSG is rich in key nutrients the human body needs. With more attention to how food waste impacts climate change and advances in technology, upcycling ingredients from BSG into foods and beverages has started to become an important and effective way to add more nutrients into the human diet while simultaneously lowering the environmental impact on our planet. Barley's role in the beer-brewing process starts with pre-fermentation and the malting of barley. Next is the brewing of the malted barley, which leads to the solubilization and extraction of the carbohydrates along with some proteins through an endogenous enzymatic process. Once barley is malted and made into wort (the liquid extract from the carbohydrate-rich portion of the grains that eventually turns into beer), the insoluble part of the grain is separated through lautering or filtration steps, and ultimately becomes what is known as brewers' spent grain (BSG). On average, approximately 20 kilograms of BSG is produced per every 100 liters (26.4 gallons) brewed beer. [17,18]

In fact, BSG could be considered just as valuable as the parent grain itself. Nutrients in BSG include fiber, highly bioavailable proteins, B vitamins, minerals, and a multitude of powerful phytochemical compounds.[17,19–21] And each year, a staggering 39 million tons of BSG are generated worldwide.[22] Ultimately, BSG harnesses significant nutrition for public health, and this resource has long gone untapped—until now.

Giving upcycled barley a more prominent role in our food system is an opportunity to enhance the nutrition of our food products in a way that is both sustainable and environmentally responsible.

What Barley Offers: The Nutrition Story

Barley, as a member of the whole grain family, is among the health-promoting plant foods that experts say deserve more space on our collective plates. However, barley offers unique nutritional properties that, in many ways, set it apart from its cereal cousins. Several of those properties are conferred onto brewers' spent grain (BSG), and in fact, the transformations that occur during the barley upcycling process result in nutrients and other compounds with the potential to support health and wellbeing.

What Barley Offers: The Nutrition Story

1. Fiber in Barley & BSG

In addition to being rich sources of a host of other nutrients, barley, BSG, and ultimately its potential as an upcycled ingredient deliver noteworthy fibers, and of particular importance to health—beta-glucan and arabinoxylan. These fibers are not present in every plant food, and they have been implicated for their significant health potential.

One of the most well-known soluble fibers, present in high concentrations in barley, is beta-glucan, a non-starch polysaccharide found primarily in the cell walls of the endosperm and the aleurone layer of the grain (Figure 1).[8] By dry weight, barley's beta-glucan content is usually in a range of 3% to 11% dry weight, and reach as much as 20%—which far exceeds other cereal grains including oats.[10,23,24]

Beta-glucan offers notable and documented health benefits. As a type of soluble fiber, it increases gastrointestinal viscosity, creating a gel-like network, which serves to help impede the uptake of dietary cholesterol and reduce the reabsorption of bile acids.[23,25] These actions are thought to have a net cholesterol-lowering effect, which can contribute to a lower risk for cardiovascular disease and stroke.[26] Research has shown that the heart health benefits can be achieved by consuming at least 3 grams of barley beta-glucan per day.[27,28] Beta-glucan also functions as a prebiotic fiber, supporting the balance of beneficial bacteria that contribute to the overall health and function of the microbiome.[28–30]

Another important fiber in barley and BSG is arabinoxylan, that in its soluble form, is associated with beneficial health effects ranging from impacting cardiovascular disease risk factors, to blood glucose response, and to gut health and its impact on the microbiota.[31] Finally, two insoluble fibers—cellulose and hemicellulose—in barley have noted health effects. Due to their association with reduced insulin secretion and impact on lowering glycemic index, insoluble cereal fibers have shown the potential to help reduce appetite, ad libitum food consumption, increased feelings of fullness, as well as reduce or slow the glycemic response to a meal.[32,33]

Filling the Whole Grain Gap Through Fiber

Whole cereal grains such as barley are rich sources of dietary fiber. Higher intakes of dietary fiber are known to reduce the risk of heart disease, type 2 diabetes, obesity, and some cancers, meaning that adequate consumption of this nutrient can serve as a potent protector in decreasing chronic disease risk.[34–38]

Meanwhile, an astounding 95% of Americans fall significantly short of consuming the recommended 25 grams to 38 grams of fiber daily, with a mean dietary fiber intake of just 17 grams.[38] Many U.S. consumers are aware of this so-called fiber gap, and in fact, a full 50% say that consuming more fiber is a high health priority.[39] In Europe, depending on the country, an intake between 25 grams and 35 grams of fiber is recommended, while the average daily intake ranges between 14 to 25 grams.[40] With their high fiber content—17.3 grams fiber per 100 grams dry weight 41 for barley and on average 60 grams fiber per 100 grams of brewers' spent grain[10] (Figure 3)—barley and upcycled foods made with BSG are uniquely poised to help fill this gap.

What Barley Offers: The Nutrition Story

2. Quality Plant Protein

Barley's protein content—13 grams per 100 grams dry weight—is deserving of consideration.[41] The major protein groups found in barley are the hordeins and glutelins in the endosperm, and albumins and globulins in the germ and bran.[42***] While whole grains are not traditionally seen as notable protein sources, in fact, barley offers eight of the nine essential amino acids (AA) such as tryptophan, threonine, isoleucine, leucine, methionine, phenylalanine, valine, and histidine (its limiting essential AA, as is the case in other grains, is lysine, which is present in barley but in lower amounts). These amino acids are necessary for human health as they play a critical role in most cellular functions.[43] While the full protein potential of barley may be little known, the grain has significant standing to contribute to overall protein intake. This is particularly true for those following a vegetarian or vegan diet, who rely heavily on a variety of plant-based foods including whole grains and beans to obtain a complete amino acid profile. The protein quality of barley is determined with the PDCAAS method and established to be[0.59,44] and is easily combined with complementary plant proteins like pulses to produce complete protein.[45]

The mention of complete proteins deserves a closer look as well. BSG, and upcycled barley as a result, in particular contain a high percentage of bioavailable proteins particularly rich in the same eight of the nine essential amino acids as the barley grain. In addition, it has high compatibility with other proteins such as whey, pea, and soy that results in nutritional complementarity and protein completeness.[46]

One concern for certain populations is the fact that barley, like wheat and rye, is a gluten-containing grain. A seed-storage protein, a member of the hordeins and containing the amino acids proline and glutamine[44,47], researchers are in general agreement that gluten poses no harm to the general population.[48–51] Of course, gluten-containing grains and other products containing gluten must be avoided by those with celiac disease.[52] And for the same reason, those with non-celiac gluten sensitivity or wheat allergy may need to avoid consumption of barley as well. Allergy to barley itself, however, is rare, though there have been a few isolated case reports of allergic reaction due to exposure to barley in children.[53–55]

On the Topic of Gluten

Greater awareness of celiac disease (as well as food intolerances and food allergies in general) has put gluten in the spotlight in recent years, leading to concerns surrounding the consumption of gluten-containing grains such as wheat, rye, barley, and triticale, and claims of supposed health benefits derived from eating a gluten-free diet. But are these claims warranted?

In most cases, the answer is no. Of course, strict avoidance of gluten is necessary for the 1% of people worldwide who have celiac disease. A further 0.6% to 6% with non-celiac gluten sensitivity (NCGS) may also benefit from eating a gluten-free diet.[56] But for the vast majority of the population, avoiding gluten is unnecessary—and could in fact result in nutrient deficiencies and health risks to those who are not diagnosed with celiac or NCGS.

Of course, there is no debating the advantage—and indeed, the imperative—to avoid gluten in cases where medically necessary. However, there is no high-quality evidence supporting gluten avoidance for those without celiac disease or NCGS. In fact, people who unnecessarily avoid gluten may find it challenging to meet daily requirements for fiber and micronutrients abundant in gluten-containing whole grains such as B vitamins, iron, zinc, magnesium, and potassium, and have also been shown to have lower vitamin D and calcium levels.[51,57,58] Limiting or avoiding gluten-containing whole grains can also raise overall dietary fat content and increase the potential risk of and consequences from obesity, hyperlipidemia, hyperglycemia, and heart disease. Additionally, gluten-free diets impose a significant cost burden and have the potential for social impairments or restrictions.[49,59]

Picking More Plant Proteins

While half of U.S. consumers are trying to eat more fiber, nearly two-thirds say that they are looking to increase protein intake in their diets.[39] Higher-protein diets are considered to be a generally safe and effective tool for weight reduction that can help prevent obesity and obesity-related diseases. This is largely due to the ability of dietary protein to help bring satiety and hunger hormones into balance[60,61], and increase diet-induced thermogenesis and hepatic gluconeogenesis.[62,63] Considering that more than 70% of U.S. adults ages 20 and older are overweight or obese[64], these properties offer significant potential to support health and wellbeing. Proteins, of course, also provide the building blocks for human tissue in the body, in particular muscle tissue. And many studies have shown that both muscle strength and overall mass can be increased through the combination of protein consumption in tandem with resistance exercise.[65,66] Additionally, amino acids and other components in protein have shown to play a role in exercise recovery, including delayed onset muscle soreness, as we will explore further ahead.[44,67–70]

Proteins from different origins can differ in quality, structure, and rate of digestion. Though animal-based proteins are known for their “complete” amino acid (AA) profile and thus considered of high quality—many at significant environmental cost—plant-based proteins stand to offer their own unique benefits and can easily be combined with others to achieve the same level of completeness in AA profile.[71] This dovetails with the increasing consumer desire to eat more protein from plant-based sources. In fact, nearly 1/4 of consumers say that they are choosing more plant proteins now compared to a year ago.[39]

This shift can in part be attributed to growing consumer awareness surrounding the health benefits of a more plant-forward diet. Simply replacing 3% of daily energy from animal protein with plant protein is associated with lower all-cause mortality.[47,72]

Nutritious + Functional + Complementary

Upcycled barley is considered a functional ingredient and is compatible with others like whey, pea, and soy, providing nutritional complementarity—a complete protein. This potential for barley protein lends itself to versatility in the ways it can be used. With plant proteins in high demand, the naturally-occurring sweetness of barley along with the smooth mouthfeel and palatability makes it a food ingredient that hits on multiple priorities: nutrition plus function plus taste plus sustainability.

Figure 3

How barley compares to other commercially available raw material protein sources

BARLEY
hulled

WHEAT
flour, whole wheat, unenriched

BSG

BROWN RICE
medium grain, raw

PEA
green, raw

SOY
flour full-fat

	BARLEY	WHEAT	BSG	BROWN RICE	PEA	SOY
PROTEIN (G)	12.5	13.2	26.5	7.5	5.42	37.8
CARBOHYDRATES (G)	73.5	72	59.3	76.2	14.4	31.9
FIBER AS PART OF CARBOHYDRATES (G)	17.3	10.7	56.4	3.4	5.7	9.6
FAT (G)	2.3	2.5	10.6	2.7	0.4	20.6
WATER (G)	9.44	10.7	3.6	12.4	78.9	5.16
VITAMIN B2 (MG)	0.29	0.17	1.0	0.04	0.13	1.16
VITAMIN E (MG)	0.57	0.71	0.5	0	0.13	1.95
MAGNESIUM (MG)	133	137	191	143	33	429
ZINC (MG)	2.77	2.6	7.6	2.02	1.24	3.92
IRON (MG)	3.6	3.6	12	1.8	1.47	6.37

Source (for all except BSG): FoodData Central, USDA. fdc.nal.usda.gov

3. Micronutrients, Phytochemicals & Other Compounds in Barley & BSG

The unrefined nature of whole barley translates to a grain that is rich in minerals and vitamins. Barley contains roughly 10 times more magnesium than most corn, wheat, and oat products, while also delivering high concentrations of calcium, potassium, phosphorus, sodium, and sulfur, and smaller amounts of iron, zinc, copper, and manganese.[73] Many of these minerals work in tandem with barley's high B vitamin content—specifically folate, niacin, thiamin, and vitamin B6. These are vitamins which have been shown to support healthy cholesterol levels and help protect cardiovascular function.[74–77]

No discussion of barley nutrition is complete without mentioning the grain's phytonutrient profile. Barley has been shown to have higher phenolic activity compared to many other whole grains[78], and boasts a particularly broad spectrum of phytochemicals including:

- Flavonoids such as flavonols, anthocyanidins, proanthocyanidins, catechins[79], and quercetin. These compounds have shown in vitro to exert antioxidant and antimutagenic functions and have been associated with reduced risk of cardiovascular disease.[80]

- Tocols and tocopherols such as vitamin E. Barley is a source of this nutrient and research has shown it to be both bioavailable and convey antioxidant functions.[81] Tocols found in cereals like barley have been associated with reduced risk of cardiovascular disease and certain types of cancer.[82]

- Plant sterols such as sitosterol, stigmasterol, campesterol, brassicasterol. These cholesterol-like structures may block the body's absorption of cholesterol and contribute to lower cardiovascular disease risk.[73]

- Phenolics such as ferulic acid and gallic acid, which boast high antioxidant activity, hence reducing oxidative stress. These phenolic compounds have been associated with risk reduction for diabetes, certain types of cancer, and neurological disease.[83]

There has been some concern, due in part to some recent attention in the popular media, about antinutritional factors including lectins, tannins, and phytic acids found in cereal grains and other foods.[84] Some of these compounds are inherent within the grains themselves, evolving as a natural defense mechanism. As a category, these factors may sometimes induce undesirable responses in humans, such as increased levels of inflammation and potentially inhibiting partial absorption of certain micronutrients.[85] However, phytochemicals and polyphenols that are inherently found in grains are thought to offset inflammation triggered by lectins.[86] This is especially likely in the case of barley, whose lectin content is demonstrably lower than many other grains.[87,88]

Table 1

Hulled Barley Nutrition at a Glance[41*]

PROTEIN	13 G
CARBOHYDRATES	74 G
FIBER	17 G
FAT	2.3 G
VITAMIN B2	0.3 MG
VITAMIN E (MG):	0.6 MG
MAGNESIUM	133 MG
ZINC	2.8
IRON	3.6

(*PER 100 G UNCOOKED)

Upcycled Barley: Nutritional Properties

The malting, milling and mashing processes in the first few steps of brewing beer help to liberate previously locked-in nutrients not accessible via whole barley in its unaltered form. BSG consists of husk layers once covering the original barley grain, including the pericarp and seed coat, along with other insoluble parts of the barley grain (Figure 1). These layers are rich sources of valuable proteins[89], fibers, and phytochemicals[8]. Through the process of upcycling, BSG can be transformed into a functional food ingredient offering many of barley's benefits while also making available nutrients and compounds that may otherwise remain largely untapped.

Among these nutrients—one of significant importance both to our population and the food industry alike in bringing quality foods to consumers—is protein. On average, BSG consists of 20% dry matter protein[44], which has a demonstrated potential to enhance nutrient and mineral bioavailability and solubility.[90] The solubilization of the barley endosperm during the brewing process also generates bioavailable peptides and amino acids, that largely go into the beer during brewing.[44] In vitro, protein peptides derived from BSG have shown to exhibit immunomodulatory functions through cytokine suppression.[91] The protein compounds derived from BSG have also been shown to exhibit antioxidant, anti-inflammatory, and ACE-inhibiting activity, suggesting a potential to support human health by helping reduce chronic disease risk.[92]

BSG also contains valine, isoleucine, and leucine which are called branched-chain amino acids. The high proportion of these performance-forward branched-chain amino acids has shown promise in supporting athletic performance, particularly for athletes following a plant-based diet, and in aiding muscle recovery and helping decrease delayed onset muscle soreness.[67,69,93]

Derived from the barley husk, BSG is rich in dietary fibers including cellulose, lignin, hemicelluloses, and arabinoxylans (AX).[18,94] AX is present at up to 40% on a dry weight basis.[10] This high presence of AX is another characteristic that differentiates BSG from whole barley, whose fiber properties are most noted and researched around its beta-glucan content. Barley's beta-glucan is greatly diminished in the beer-brewing process, resulting in a very low final content of beta-glucan in BSG.[95] However, what the grain loses in beta-glucan benefits, it gains in what recent research has shown to be promising functions and benefits of the other soluble fiber, arabinoxylan, that remains in upcycled ingredients from BSG.[95,96] Research shows that soluble AX, and its shorter-chained version AXOS, have the potential to act as a prebiotic fiber and may increase populations of beneficial gut microbiota.[96,97] Prebiotic fibers such as soluble AX have shown to play an integral role in the production of short-chain fatty acids (SCFAs), which findings suggest may be involved in reducing cholesterol synthesis, inducing immune response, modulating the postprandial glycemic response, increasing absorption of certain minerals, and even offering potential protection against colon cancer.[10,98] Moreover, soluble AX may provide a solution toward closing the fiber gap in which <5% of Americans are meeting the recommended intake of fiber.[94]

BSG retains many of the bioactive components found in whole barley. One important polyphenol, ferulic acid, is often bound to AX and present in BSG.[99,100] Ferulic acid has been linked to a number of potential health benefits from antioxidant functions, to anti-inflammatory effects, and to gut and immune health.[101] Additionally, BSG has demonstrated high levels of other phenolic compounds including p-coumaric, sinapic, and caffeic acids.[17,20,21] Secondary metabolites are also exhibited including alkaloids, plant growth factors, food-grade pigments, and phenolic acids.[102] Many of these compounds, including phenolic acids in particular, are thought to offer antioxidant potential that may induce anti-carcinogenic and immunomodulatory effects.[10,91]

Finally, as with its whole grain source described previously, the antinutritional factor lectin in barley is much lower than other grains to begin with, leaving BSG similarly low and potentially lower.[87,88] Though further research is needed to validate these findings, antinutritional factors like lectins, as well as tannins and phytic acid, that are found in some grains and plant-foods, have shown to be present in BSG at lower levels.[103] Together, the overall nutrient profile—in terms of high-quality protein, dietary fibers, and phytochemicals; and low potential nutritional liabilities—of BSG lends further clout to the nutrition story and opportunity for upcycled barley BSG, one where the nutrition quality and potential for benefiting human health are increasingly clear.

FODMAPs in Barley & BSG

A Special Contribution from Elke Arendt, MSc., PhD, DSc, professor in the School of Food and Nutritional Sciences, University College Cork (Ireland)

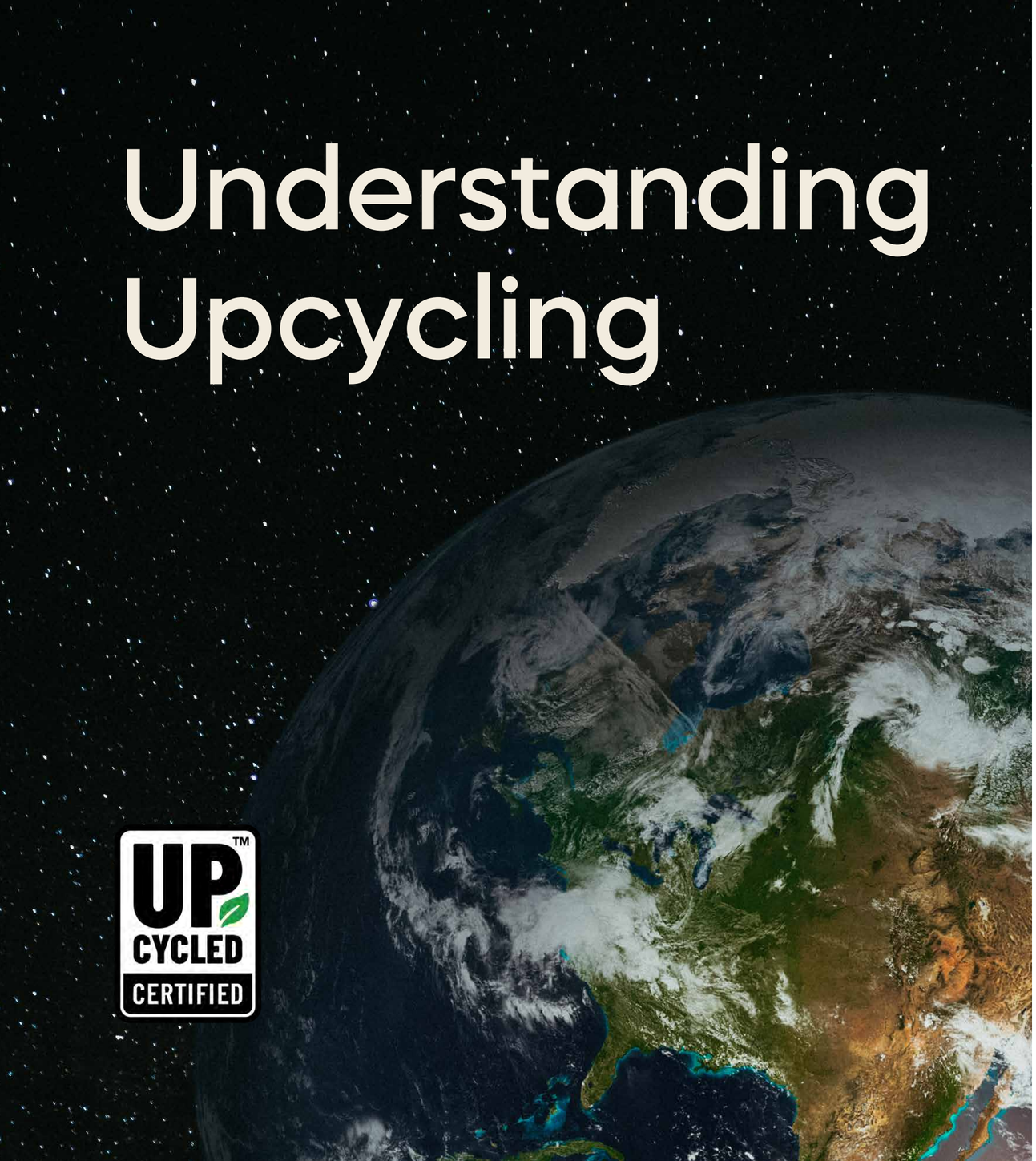
Prof Arendt is a global expert and preeminent scholar in the area of cereals, malting and brewing science, with special focus on plant proteins, valorization of side streams, functional beverages, and food structure. Professor Arendt's research program at UCC has produced over 400 peer-reviewed research papers, 3 books, 35 book chapters, 7 patents and approximately 600 additional published articles and abstracts.

The acronym FODMAPs (fermentable oligosaccharides, disaccharides, monosaccharides, and polyols) is an umbrella term comprising the commonly cited list of foods high in these FODMAP compounds: Fructose present in a food in higher levels than lactose; polyols (also referred to as sugar alcohols), and; the oligosaccharides fructans and α-galactooligosaccharides. These are all forms of dietary carbohydrates that are not absorbed well in the body or in some cases, not absorbed at all. Due to the lack of digestive enzymes or mucosal transporters, FODMAPs are delivered to the large intestine having not been processed or absorbed in the small intestine, and then are rapidly fermented by bacteria in the colon.

While these physiological mechanisms and occurrences are physiologically normal in human digestion in general, in sensitive individuals, they can trigger a number of unpleasant gastrointestinal symptoms, such as altered bowel functions, abdominal pain, and excess gas. These are symptoms associated with irritable bowel syndrome (IBS), a condition defined as functional gastrointestinal disorder (FGID). A recent re-evaluation of the global prevalence of FGIDs showed that 40.3% suffer from different subtypes of gastrointestinal disorders, and ~4% were identified as IBS. The study, based on surveys in 33 countries, also demonstrated that IBS is a worldwide disorder.[104] Research has shown that a dietary therapy with a reduced intake of FODMAPs—commonly referred to as a Low-FODMAP diet—can alleviate symptoms in more than 70% of patients diagnosed with IBS.[105–107]

While FODMAPs are ubiquitous across various food categories, in cereals, the predominant FODMAP compounds are called fructans. Other FODMAP compounds are not naturally present in cereals or found only in very low levels.[108] There are different types of fructans (e.g. inulin, levan, graminan, neo-inulin or neo-levan) distinguished by their linkage type between glucose and fructose and their positional factors.[109–111] Barley grains are low in these compounds overall, typically containing between 1% and 4% fructans, depending on breeding and cultivar.[108,112] During the malting process of barley, fructan content actually increases somewhat, by up to 30%[113–115], however the BSG portion ultimately contains no or very low levels of fructans. Ultimately, what occurs is that these fructan oligosaccharides are highly soluble in warm water[108,116], and as a result, they are extracted from the grains during the brewing process, leaving the BSG exhausted from fructans. As a consequence, BSG is a nutrient-rich ingredient that is also suitable for low FODMAP applications in developing functional products and food innovations for individuals requiring or looking to follow this dietary approach.

Understanding Upcycling



Upcycling, or the creative repurposing of surplus food, keeps waste out of our landfills. Upcycling is also on the verge of striking it big. While it was dubbed the “coolest trend you’ve probably never heard of” by Forbes in 2021[117], research shows that many younger consumers are already familiar with the concept of upcycled food, and a majority see it as good for the environment and worthy of purchasing.[118]

The reasons why are simple. Upcycling is the simple act of extracting more from the resources we already have. It transforms the byproducts of the food manufacturing process into entirely new, high-quality products for humans. This can help feed a growing global population without putting an added burden on the planet: Because these byproducts would not have otherwise gone to human consumption and instead to animal feed, incinerators, or the landfill, the upcycling process ultimately reduces the overall use of natural resources and has a substantial positive impact on the environment.

Upcycled foods are produced using verifiable supply chains to ensure that waste is truly being reduced. Ingredients like upcycled barley are certified by the Upcycled Food Association (UFA), the world’s first third-party certifier to set robust standards for upcycled ingredients and help consumers easily identify upcycled products. In fact, the more than 200 products and ingredients (as of August 2022) that have already received Upcycled Certified status are projected to divert more than 703 million pounds of food waste each year.[119]

Figure 4

The major nutrients found in upcycled barley

FIBER

QUALITY PROTEIN & AMINO ACIDS

MINERALS
including calcium, magnesium, phosphorus, silicon, vitamin E, iron

PHYTOCHEMICALS
with anti-inflammatory, antioxidant, and antibacterial properties

Upcycled barley retains significant nutrients, including

- Fiber, arabinoxylan (AX) in particular
- Bioavailable proteins rich in eight of the nine essential amino acids including tryptophan, threonine, isoleucine, leucine, methionine, phenylalanine, valine, and histidine (lysine is the limiting AA, still present but at lower levels)
- Minerals including calcium, magnesium, phosphorus, silicon, vitamin E, zinc, some B vitamins, and iron
- Flavonoids, tocopherols, phenolic acids, and other phytochemical compounds containing anti-inflammatory, antioxidant, and antibacterial properties

Barley's Health Impact

The nutritional profiles of barley and BSG have been established as noteworthy and unique. Existing research points to positive effects and health benefits in a number of areas, particularly for whole grain barley, which has been the subject of scientific investigation for several decades. And newer and emerging research has been done on BSG and which shows promise.

Barley and BSG come intrinsically packaged with high concentrations of beneficial fibers, protein, phytochemicals, vitamins, and minerals that have been shown to have specific, standalone promise for our individual and collective wellbeing, including an ability to reduce the risks of many of the most significant health challenges faced today. Naturally, further exploration is needed to understand how these nutrients and properties have the potential to support—and indeed, improve—human health.

1. Cardiovascular Health

Regular whole grain consumption is strongly associated with a reduced risk for cardiovascular disease.[13] Barley in particular, possesses unique nutritional qualities that deliver significant heart health benefits. The cardiovascular health effects of barley and BSG principally come from beta-glucan, arabinoxylan, and phenolic compounds. Beta-glucan fibers have been shown to lower levels of blood lipids including total and LDL cholesterol by inhibiting cholesterol and/or fatty acid synthesis, as well as absorption.[120] Meta-analyses, in fact, have concluded that a daily consumption of 6.5 to 7 grams barley beta-glucan may be enough to significantly reduce LDL and non-HDL cholesterol levels by around 7% in adults who are healthy as well in those who have high cholesterol.[121] Another meta-analysis of 126 studies similarly showed the total and LDL cholesterol-lowering effects of barley beta-glucans, as well.[27] While there is not as much research yet on BSG itself, an earlier study with 79 hypercholesterolemic subjects found that supplementing 30 grams per day of barley bran flower made from BSG led to a significant decrease in LDL cholesterol after 30 days.[122]

Impressively and importantly, research has shown consumption of just 3 grams of soluble beta-glucan from whole grain barley or certain dry milled barley products can result in cholesterol-lowering effects on par with what is achieved with oat products, which are widely-known to have a beneficial impact on cholesterol.[123] This evidence helped pave the way for the FDA's 2008 approval of the health claim for whole grain barley as a cholesterol-lowering food.[124] A few years later, the European Food Safety Authority (EFSA) similarly approved the use of a health claim for products with a minimum of 3 grams barley beta-glucan, confirming the relationship between barley beta-glucans and lowered blood cholesterol, which is associated with a lower risk of coronary heart disease.[125]

Arabinoxylan, the fiber most abundant in upcycled barley, may have heart health and cholesterol-lowering potential as well. There is a growing and sizeable number of studies on the functions and health effects of arabinoxylan.[31,126,127] In a randomized crossover trial in subjects with metabolic syndrome, researchers found that after 4-weeks supplementing the diet with a combination of arabinoxylan and resistant starch provided alongside standard treatment with statins led to significant improvements in fasting LDL and total cholesterol compared to subjects not taking statins.[128] The researchers speculated that this may have to do with the fibers competing in the liver for the enzyme that plays a role in cholesterol production and metabolism, adding that the combination of AX and resistant starch might be an effective adjunct approach to managing cholesterol alongside cholesterol-lowering drugs. In 2018, the European Union approved the claim that "arabinoxylans added to foods have particular utility for people with disturbed metabolic responses or type 2 diabetes to support improved cardiovascular health."[129] Arabinoxylan may also positively impact heart health via anti-inflammatory pathways. The fibers have demonstrated the ability to modulate blood sugar[130] and postprandial triglycerides[131], which may serve to support lower inflammation levels and in turn, support cardiovascular health. Though much of the research has looked at arabinoxylans found coming from whole grain wheat, BSG is also rich in this important fiber.

Barley's heart-health benefits don't come from fiber alone though. Phenolic compounds such as phytosterols are abundant in barley, particularly sitosterol, stigmasterol, campesterol, brassicasterol, Δ5-avenasterol, and Δ7-avenasterol. BSG is a rich source of phenolic compounds and certain phytosterols as well.[102] These cholesterol-like substances may exert antioxidant and cholesterol-inhibiting effects that work to reduce blood cholesterol levels and, in turn, help lower heart disease risk.[73] In addition, ferulic acid, as one of the most abundant phenolic compounds in BSG, has been used in clinical applications with cardiovascular diseases such as coronary heart disease, stroke, chronic heart failure, and related conditions.[132] Further, ferulic acid has been associated with lowering blood lipids including total and LDL cholesterol, triglycerides and increasing HDL cholesterol, as well as improving markers of oxidative stress in the aorta and liver, and other markers of inflammation in the body.[120] Some research has also shown ferulic acid plays a role in the regulation of blood pressure, a risk factor for heart disease.[120]

Also worth noting is the high magnesium content found in both barley and BSG, as adequate intake of bioavailable magnesium is associated with lower heart disease risk.[73] While the mineral alone plays an important role in heart health, it may also be that the magnesium in barley works in tandem with the grain's fiber and phenolic compounds to exert a synergistic effect on supporting and protecting the cardiovascular system.[133]

2. Gut Health & Digestion

Increasingly, the health of the gut and microbiome is thought to be linked to the health of the body as a whole. Mounting evidence shows us that this vast community of microbiota can affect everything from blood sugar to cholesterol, to inflammation, and to mood, and in turn, potentially influence one's risk for developing chronic health problems ranging from heart disease[144], to diabetes[145], to Alzheimer's disease[146], and to depression.[147]

What's more, the state of the microbiome is largely dependent on both short- and long-term dietary habits including the types of foods eaten (or excluded), and other factors like infant feeding patterns, antibiotic usage, and genetics.[148] Barley's unique fiber profile, in particular beta-glucan and soluble arabinoxylan, support the growth of short chain fatty acids (SCFAs) via microbial fermentation, which help facilitate the development of beneficial bacteria strains including *Lactobacillus* and *Bifidobacteria*, as well as improve gut motility, and strengthen the gut barrier function and metabolic function.[73,149] In a randomized, controlled crossover trial in adults with mildly elevated cholesterol, favorable shifts in the gut microbiome were observed after supplementing different forms of beta-glucan, specifically resulting in changes in gut bacteria associated with reduced cardiovascular risk factors.[150]

In addition to beta-glucan, arabinoxylans—present in barley and in higher quantities in BSG—once they are extracted and solubilized have been shown to have gut health effects. Studies conducted primarily on wheat show that arabinoxylans also encourage the growth of beneficial gut microbes including *Bifidobacteria* and *Lactobacillus*.[97] A randomized clinical trial in 47 overweight subjects revealed that after 6 weeks of supplementing with arabinoxylan versus placebo, those who were supplemented resulted in significant beneficial shifts to the gut environment, favoring both the growth of beneficial bacteria and reduction of harmful bacteria, in addition to an improved fermentation profile and concentration of SCFAs.[151]

Researchers note that the arabinoxylan fibers present in BSG substantiate the potential of upcycled barley in serving a role as a prebiotic and in supporting a healthy gut environment.[102] Of particular interest, arabinoxylan oligosaccharides (AXOS)—the compounds resulting from the hydrolysis of arabinoxylan—in previous research have exhibited prebiotic activity in the gut, and shown potential in helping regulate the bacterial metabolism and distribution in the colon.[152–154] Further research is needed to explore the multiple factors in barley and BSG that may play a role in promoting and protecting gut health, a topic of considerable interest within the scientific community and also to consumers.

3. Satiety & Weight Management

Increasing dietary intake of whole grains has long been a recommended strategy for supporting healthy weight and reducing the risk of obesity.[155] The fiber, in whole grains as well as their derivatives such as upcycled barley BSG, is thought to promote satiety and slow digestion, while working in concert with phenolic compounds and phytosterols that may have a beneficial impact on metabolism, body weight, and adiposity.[155] In a prospective cohort study with nearly 90 thousand healthy adults followed for an average of 6.5 years, researchers found a beneficial association between consumption of dietary fiber—especially cereal fiber—and future weight and waist circumference gain.[156]

Barley's beta-glucans and arabinoxylans again, seem to confer a notable advantage in weight control. Soluble beta-glucan fibers have been shown to elevate the viscosity of digested matter in the gut, slowing the rate at which food moves through the gastrointestinal tract and exerting an appetite-suppressing effect.[157] The fibers found in barley (beta-glucan and arabinoxylan) and BSG (arabinoxylan) have also been positively correlated to alter microbiota composition in the gut, which may also work to help reduce obesity risk.[73,97] What's more, these benefits may translate to real-world weight changes: When obese Japanese subjects consumed 4.4 grams of beta-glucan-rich barley daily for 12 weeks, they experienced a significant reduction in visceral fat, body mass index (BMI), and waist circumference.[158]

Satiety is not achieved by fiber alone though. BSG's high-quality protein, containing all 9 essential amino acids (though lysine is found in more limited amounts as with other whole grains), is likely to play a contributing role. While research specifically investigating the satiety-inducing effects of upcycled barley is still needed, it is known that protein consumption in general plays an important role in maintaining feelings of fullness via the release of satiety hormones, supporting healthy weight management and fat loss[159], and managing the release of blood glucose.[160]

4. Inflammation & Immune Support (including Anti-carcinogenic Potential)

Epidemiological studies have demonstrated a consistent link between whole grain consumption and reduced risk of certain types of cancer.[161] This relationship holds true for barley and is thought to be due to the grain's unique profile of anti-inflammatory and immunomodulatory properties. Bioactive compounds such as phenolic extracts and tocotrienols may exert anticarcinogenic effects that may help thwart the ability of cancer cells to form or proliferate.[73] These compounds occur in both whole grain barley as in BSG and include ferulic acid, p-coumaric, sinapic, and caffeic acids.[10,102] At least one bioactive compound found in barley, protocatechualdehyde, has been shown to demonstrate anti-cancer activity by the down regulation of certain proteins in cancer cells.[162]

Whole grain barley's beta-glucan has demonstrated potential to inhibit the growth of cancer cells, including melanoma, breast, and lung cancer cells.[163] Additionally, BSG's derived protein hydrolysates have also demonstrated antioxidant and anti-inflammatory activity thought to potentially play a role in reducing chronic disease risk.[164] Overall, while more research is needed to further understand barley and BSG's anti-inflammatory, immune system-related, and anti-carcinogenic properties and their mechanisms, there are promising implications in what is known so far.

5. Muscle Recovery & Sports

Barley has been relied upon as a strength- and stamina-supporting staple food since the time of the Roman gladiators.[7] As a whole grain, barley is a rich source of complex carbohydrates that provides the high-quality fuel needed for endurance performance. But the malting and brewing processes shift barley's nutritional profile. After shedding its starchy properties in the beer-brewing process, what remains in BSG is high-quality protein—at least 20% by weight.[44]

Upcycling BSG into a second source of nutrition involves obtaining highly soluble protein compounds from the spent grain. These protein components contain performance-forward branched chain amino acids (BCAAs), including leucine, isoleucine, and valine.[44] Using the knowledge of the role of BCAAs in muscle recovery, it is of interest to explore BSG's potential in supporting athletic performance via aiding muscle function[67], whether and to what extent the BCAAs in barley may benefit recovery[68], and how it may impact or help reduce delayed-onset muscle soreness[69].

Another amino acid of interest, glutamine, which is present in barley protein in high concentrations, is a conditional essential amino acid which plays a key role in a number of cellular processes. One primary function is in the recovery of muscle cells, which may help attenuate the inflammation and injury resulting from intense aerobic and exhaustive exercise.[70] Glutamine is abundant in the blood and muscles, but is conditionally essential as a result of high-intensity training; intramuscular glutamine levels can decrease sharply during training and require time and recovery strategies through diet to accelerate muscular repletion and replenish body sources.[70,165]

In a study in well-trained half-marathon athletes testing the effects of wheat gluten hydrolysate (WGH), a plant protein hydrolysate with a similar amino acid composition as barley protein, researchers found that the expected post-race increases of creatine kinase—a marker for muscle injury—was suppressed in a dose-dependent fashion as a result of consuming post-race WGH.[166] Attenuating muscle injury, soreness, and inflammation caused by exercise, and accelerating the recovery period post-training and between exercise bouts, are of high priority both to athletes and researchers in sports performance and nutrition. These potential effects from protein type, quality, and specific amino acids/combinations—ones that barley and BSG provide—may be particularly relevant for athletes following a primarily plant-based diet, as well as the competitive or recreational athlete looking to optimize their performance and recovery. Focused research in this area is warranted.

Table 2

Amino Acid Score of BSG protein isolate, Whey Protein Isolate, Pea Protein Isolate and Soy Protein Isolate (per 100g)

Amino Acid	BSG protein isolate*	Whey Protein**	Pea Protein**	Soy Protein**
Aspartic acid	8.6	10.8	11.5	11.6
Threonine	3.5	6.8	3.7	3.9
Serine	4.1	5.4	4.8	5.3
Glutamin/glutamic acid	22.5	17.3	16.6	19.1
Glycine	4.1	1.8	4.0	4.3
Alanine	4.6	4.9	4.3	4.3
Valine	5.5	5.5	5.1	5.0
Methionine	2.1	1.8	1.0	1.3
Isoleucine	4.0	5.8	4.8	4.8
Leucine	7.1	10.4	8.4	8.0
Tyrosine	3.9	2.4	4.0	3.8
Phenylalanine	5.5	3.1	5.1	5.2
Lysine	3.6	9.5	7.4	6.3
Histidine	2.1	2.0	2.5	2.6
Arginine	4.9	2.4	8.4	7.5
Proline	10.0	6.9	4.4	5.2
Cysteine	1.4	1.9	1.0	1.4
Tryptophan	1.4	1.7	0.9	1.3

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BSG's Effects on Health:

What We Know, What's to Come

As populations face an ever-growing risk for chronic conditions ranging from heart disease and diabetes to obesity and cancer—seeking strategies to both reduce disease risk and also optimize health by improving physical performance and recovery—it may at times seem unlikely that modest, even simple, lifestyle measures have the power to make a difference. But research consistently shows that they do, and among these, none may be more powerful than eating a more plant-based diet.[168] Within this dietary framework, whole grains typically form the sustaining, inexpensive, and delicious base. Their upcycled derivatives, including upcycled barley BSG, position these already-wholesome grains as foods with added value in this arena and provide also within the ever-growing trend and demand for functional foods—foods with inherent nutrition and added value, too.

Barley, of course, is just one of many whole grains that can be incorporated into these health-forward eating patterns. Barley, and we now know also BSG, come packaged with high concentrations of beneficial fibers, protein, vitamins, minerals, and phytochemicals that have been shown to have specific, individual functions to help the body to function optimally, as well as the potential to help promote health and reduce the risks of many of the most important health challenges we face today.

While studies on the direct health effects of BSG are limited, whole grain barley has been extensively studied for its impact on human health and ability to contribute to reduced chronic disease risk. We know that BSG is rich in many of the same nutrients and compounds as its whole grain counterpart (Figure 3). At the same time, it also contains high quality nutritional compounds such as arabinoxylan and a high proportion of high-quality proteins rich in branched-chain amino acids. These qualities, alongside the supporting evidence about the role of specific nutrients to health promotion and chronic disease risk, speak to BSG's potential as a potent and effective functional food ingredient.

Future research is needed to show whether and to what extent upcycled barley may:

- Support cardiovascular health via reducing inflammation, supporting glycemic control, and encouraging healthy cholesterol levels
- Promote a healthy glycemic response and/or glucose metabolism via prebiotic fibers
- Encourage satiety and weight management through fiber and high-quality protein
- Support immune health and reduce inflammation through phytochemicals like phenolic compounds, which may also exert an anticarcinogenic effect through a variety of mechanisms
- Positively influence athletic performance and muscle recovery with high-quality proteins rich in branched-chain amino acids, glutamine and other compounds
- Serve as a unique functional food ingredient that can help fill America's whole grain and fiber gap
- Serve as a sustainable, plant-based protein option that supports the environment

Opportunities for Future Exploration

BSG, for its upcycling potential, stands at the forefront of the challenge of using nutrition to address human health concerns while honoring the need for more sustainable food practices. It boasts significant potential as a functional food ingredient that requires minimal production resources and keeps waste out of our food supply.

Researchers and industry partners have the opportunity to work together to learn more about the pathways by which upcycled barley can best support human health and nutritional needs while uncovering the novel avenues and applications most appealing to consumers. In the meantime, emerging clinical trials on BSG may soon provide added insight into key areas including:

- **Bioavailability of minerals in humans**
- **Mechanism studies on phytochemicals**
- **Evaluation of functional and physiological effects of single nutrients and combined nutrients on human health**
- **Effects of upcycled BSG ingredients in the field of sports nutrition, performance, and recovery**

Applications for Upcycled Barley

Today & Tomorrow

Incorporating upcycled barley BSG into functional packaged food products isn't a dream for another day. Leaders in the industry are already producing products with a clean, neutral taste and smooth, highly soluble consistency that fit seamlessly into a wide range of functional packaged foods. Upcycled barley BSG proteins can also easily be combined with other plant-based proteins, such as pea protein, to create protein blends that are nutritionally complete. These features make UFA-certified upcycled barley BSG protein an advantageous way to enhance the protein and overall nutrition content of the meals, snacks, and beverages that consumers enjoy every day.

Brands such as Rise and Regrained (Upcycled Foods Inc.) are already showcasing this versatile ingredient, in products ranging from baking mixes and pastas to snack puffs and bars. Others, such as EverGrain, are actively developing sustainable ingredient solutions and resources for customers and product developers. These resources will address key application areas for the upcycled barley BSG industry such as ready-to-drink and ready-to-mix beverages, plant-based milks, snacks, bars, pasta, breads, pita chips and crackers, waffles, tortillas, cookies and brownies, and meat-alternative product categories.[10]

Indeed, the opportunities are many in an effort to optimize the nutrition in a wide range of food products, and are limited seemingly only by the imagination of food industry leaders and manufacturers. Picture higher protein plant milks; soy-free plant-based protein bars that still deliver a range of essential amino acids; and breads, crackers, and other baked goods that bring a source of high quality, nutrient-dense proteins and fibers from upcycled ingredients. Researchers report that an inclusion between 10-40% on a dry weight basis has been used, and yields a product with increased fiber, protein, or both and decreased starch overall in the end product.[10] The inclusion of BSG at various levels is being evaluated by scientists and the food industry for its impact on sensorial and functional aspects to optimize its inclusion for texture, volume, color, and nutrition, keeping in mind a threshold where it would begin to decrease in any of these areas.

Upcycled barley BSG serves as an opportunity for individuals to experience a traditional grain like barley in an entirely new form: Shoppers who regularly sample the latest plant-based milks or protein bars, and who are seeking new and also planet-friendly foods, will likely be intrigued by novel whole grain-derived options. And those who are prone to seeing plant proteins as something foreign may be drawn to products made with a food that feels familiar and is trusted. It's the same barley many have known and loved, made modern with 21st-century health and environmental needs in mind.

In Summary

The Bottom Line on Upcycled Barley

This report has offered an opportunity to see barley in an entirely novel light. But this, of course, is just the beginning of a new chapter for this ancient grain—through its upcycled potential as BSG.

We are starting to understand how upcycled food systems can play an integral role in meeting the nutrition needs of a growing population while reducing our expenditure of valuable resources, and minimizing waste. With its ability to be re-optimized into entirely new, clean-label food products, upcycled brewers' spent grain (BSG)—effectively saved barley—seems uniquely positioned to become a leader in this space due to its availability, scalability, and potential for human nutrition. The pioneers in the upcycled barley BSG space, too, are continuing to uncover barley's nutritional potential and have been successful in creating food ingredients that deliver on nutrition, sustainability, palatability, and ease of use.

The potential is there. Ample connections can be drawn between the nutritional strengths of barley and BSG and their ability to address some of the most pressing concerns consumers face today: Addressing chronic disease risk through nutrition and while simultaneously contributing toward minimizing the effects of greenhouse gas emissions and climate change. And effectively being one of the many ways forward toward nourishing people and planet toward better health. What is known about barley and health is substantial, and the nutrients in upcycled barley BSG ingredients have been identified, and scientists are starting to make connections on the potential health benefits, while also identifying the important research that needs to be done in the time to come. Meanwhile, we already know that upcycled barley BSG gives the world the opportunity to experience the barley we have long known through a new lens. And perhaps more importantly, that it offers a large-scale and exciting way to think about what it means to eat well and sustainably while supporting optimal health, nutrition, and wellbeing for our population.

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AUTHOR DISCLOSURE

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