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Topics in Brewing: Malting Barley

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ABSTRACT

Based on metric tons (t) of production, barley is the 11th ranking world crop and is 4th among the cereal grains, after corn, rice and wheat. Brewers focus on the importance of barley to fermented malt beverages, but the major global use of barley is as livestock feed in areas where corn is less available. Barley also contributes to the human food supply in the Middle East and North Africa. The story of barley represents a considerable accomplishment for a simple grain, evolved from a grass tens of thousands of years ago, to becoming one of the first cultivated cereals in the world, to being the basis of barter and exchange at the dawn of civilization, to being carried to the ends of the earth by explorers and settlers, to being the most ecologically diverse grain grown on the planet, and to becoming the most important ingredient in beer. This article reviews some of the history of barley, its role in grain production, and a review of the evolution of the attributes of various malting barley varieties. The brewing impacts of various varieties and a look ahead at projected future issues are discussed.

Keywords: feed barley, modification, six-row barley, S/T ratio, two-row barley, winter barley

SÍNTESIS

La cebada es el cultivo número 11 en el mundo en cuanto a toneladas producidas, y cuarto entre los granos de cereal, después de maíz, arroz, y trigo. Si bien los cerveceros lo ven como una materia prima a sus bebidas fermentadas, su mayor uso global es como alimento de animales en áreas donde el maíz es menos disponible. La cebada también contribuye a la alimentación humana en el medio oriente y el norte de África. La historia de la cebada representa un logro para un sencillo grano que evolucionó de grama hace decenas de miles de años para llegar a ser uno de los primeros cereales cultivados en el mundo; a ser la base de trueque y cambio en el amanecer de la civilización; a ser llevado a los fines del mundo por exploradores y colonos; a ser el grano de mayor diversidad ecológicamente cultivado en el planeta y a ser el más importante ingrediente en la elaboración de la cerveza. Este artículo repasa algo de la historia de la cebada, su rol en la producción de granos y un resumen de la evolución de los atributos de diferentes variedades de cebada cervecero. También se discute el impacto de diferentes variedades y se discute asuntos futuros de posible interés.

Palabras claves: cebada de alimento animal, cebada de dos hileras, cebada de seis hileras, cebada de invierno, modificación, tasa sol./total

A Brief History of Barley

Origins and Taxonomy

Barley (genus *Hordeum*) is in the same grass plant family Gramineae as wheat (genus *Triticum*) and rye (genus *Secale*). Barley is an annual, and is naturally self-pollinating. Barley is very diverse and likely developed from three gene centers: the Far East (Tibet and China), the Middle East (Syria and Israel), and East Africa. The Middle East is generally recognized as the source of barley as we know it because of its association with the earliest two-row barley types, with barley cultivation, and with the earliest recording of brewing. Pre-cultivation evidence of wild barley (*Hordeum spontaneum*) has been dated at 17,000 BC at a site on the south shore of the Sea of Galilee. Collection of wild barley, inferred archeologically by early reaping sickles, has been found in the area that is now Israel in the period 10,000–8,000 BC. Evidence of barley cultivation, inferred by the presence of both planting and harvesting tools, is dated at the period of sedentism (an archeological term referring to civilizations moving from a nomadic life to gathering into settlements and villages, accompanied by the domestication of animals and the cultivation of crops). This evidence includes barley along with the early wheat types, emmer and einkorn. Archeological evidence indicates the cultivation of two-row types by about 8,000 BC (*Hordeum distichum*) and the cultivation of six-row types by 6,000 BC (*Hordeum hexastichum*). This evidence of cultivation was found in the Middle East, in present day Lebanon, Iran, Iraq, and Turkey. Archeological evidence does not reveal whether two-row types preceded six-row types or six-row types preceded two-row types, and theories exist for both cases. The six-row first theory is supported by plant theory that a six-row barley plant had to exist with six fertile florets before four became sterile and evolved to only two healthy florets. The two-row first theory is supported by archeology; six-row types appeared later than two-row types, but we must note that six-row types were very common and widely grown by 6,000 BC. In reality, we just do not know where or when the early hybridization between row types occurred. Understand that all discussed above is clearly the area of "what we *think* we know"! It is archeologically inferred, not documented by written history. All of it occurred prior to any written languages, which were not developed until the 3,500–3,000 BC period.

Prehistory is clear enough. Both row types existed, and it should be considered a myth that six-row is a relatively mod-

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ern creation to support adjunct brewing. Today there are approximately 4,300 identified barley cultivars. From this collection, currently 1,780 two-row types and 1,670 six-row types have been documented.

Barley Adaptation

Barley is the most widely adapted cereal in the world, grown closer to the poles and at higher elevations than any other cereal. Barley is a cool climate crop cultivated in the spring and summer in the temperate latitudes, and with cultivation moved to higher elevations in the more tropical latitudes. The production range for barley includes a subarctic growing region that extends as far as 70° north latitude, and a subtropical zone of cultivation that extends into North Africa. Barley is cultivated at elevations as high as 4,000 m (13,120 ft) in the Andes and as high as 4,700 m (over 15,415 ft) in the highlands of Tibet.

Barley grows best on well-drained soil, in relatively cool conditions, especially cool nights, and with 500–1,000 mm (20–40 inches) of annual rainfall. Barley is considered the most drought and salinity tolerant of the small grains. Although barley is widely adapted, yields vary widely based on climate and soils. The best non-irrigated growing conditions in the world are in northern and central Europe, typically a cooler climate region with adequate natural rainfall. Compared with this high productivity barley area, the North American prairies are a little too hot with not quite enough natural rainfall for barley. In the United States, significant yield advantage is gained by growing barley under irrigation in the higher elevations of the Intermountain West. The range of world productivity can be illustrated by comparing the most productive region, Colorado's San Luis Valley (irrigated) with yields as high as 7.16 t/ha (133 bu/ac) to the least productive region, Iraq at .83 t/ha (15.4 bu/ac)!

Yields at a single location are very similar among row types and varieties (Table 1). It is soil and climate that drive the performance differences. Additionally, irrigation and elevation drive the yield differences between the North American states and provinces. Colorado barley production represents the highest yield in North America, as high as 7.16 t/ha (133 bu/ac). This region represents a cool climate at an elevation of 2,285 m (7,500 ft) and irrigation is used to supplement natural rainfall. By contrast, the dry land barley production in the Red River Valley is at an elevation of 275 m (900 ft) with a typical yield of 3.24 t/ha (60.2 bu/ac).

A key adaptation attribute is the shorter growing season for barley. It has the earliest maturity of the cereal grains, typically just an 80–85 day crop. The shorter season means barley can be grown in a more northern climate that is less suitable for corn or soybeans. In North America, this allows a vast growing area for barley on the northern U.S. and Canadian prairies, above and generally separated from the corn and soybean belt of the U.S. Although seed hybridization and genetic modification of competing crops is shortening their growing seasons and allowing them to push further north, barley maintains an advantage. Wheat is similar to barley at an 83 to 93 day growing season and competes most closely with barley for the same growing areas. Typically corn and soybeans have up to a 100 to 110 day growing season.

Table 1. Average barley yields[a]

	Yield average (t/ha)	Yield average (bu/ac)
French spring	5.94	110.5
German spring	4.71	87.5
U.K. spring	5.38	100.0
U.S. spring dry land	3.24	60.2
U.S. spring irrigated	3.83	71.3
Canadian spring	2.91	54.1
Ethiopia	1.55	28.8
Iraq	0.83	15.4

[a] Source: USDA/FAS (Jan 2013)/Malteurs de France (2012).

Why is Malted Barley Used for Brewing?

The question of why barley is the preferred grain for brewing can be answered in a single sentence: because barley has a retained husk, a relatively low husk to endosperm ratio, easily digestible starch, moderate protein, and moderate lipids. Any grain can be malted; all grains possess the capacity to germinate from a quiescent seed into a seedling plant. However, their germination outcomes vary greatly and some of the characteristics of the grain itself (high husk content or high lipids content), or of the germination process (high kernel consumption with high malting losses) will make a lesser malt. Barley is unique among the cereals because it retains its husk through harvesting, malting, and grain handling. Wheat, rye, and triticale do not have a retained husk. We know that the husk fraction after milling at the brewery is critical in brewing for lautering, but the grain retained husk is also critical in malting to regulate water uptake, to protect acrospires, and to maintain kernel shape. Without a husk, the grain kernel will deform and pack too tightly during malting. The husk also provides a casing that prevents the starch endosperm from becoming sticky and hard to handle. We need only to look at the difficulties of wheat malting to provide an example of malting a grain without husk. Wheat takes up water very quickly in a short steep and germinates aggressively. If left too long in germination, it becomes gummy and difficult to handle. The acrospires grow in every direction instead of being protected under the husk.

The barley starch gelatinization temperature range, 58–65°C (136–149°F), coincides with the most active barley malt saccharification enzyme activity range of 63–69°C (145–156°F). Wheat and rye starch gelatinization is similar to barley, but corn, rice, and sorghum have problematic gelatinization temperatures at the upper limits of barley malt enzyme activity. To overcome this gelatinization temperature issue, grains with gel points above malt enzymes are either cooked in a cereal mashing process or they are flaked, torrified, or micronized ahead of delivery to the brewery to damage the starch prior to direct addition to the malt mash.

The Role of Barley in Global Grain Production

When considering grains and oilseeds, the basic human diet generally consists of a major carbohydrate source and a major fat source. For carbohydrates, the global agricultural community considers only rice and wheat as food grain. All other grains, notably corn, barley, sorghum, oats, rye, triticale, and millet are considered to be "coarse grains." These coarse grains are largely assigned to animal feeding. Approximately half of the world population consumes rice as their primary carbohydrate source, and the other half consumes wheat. The classification is not absolute. For example, there are considerable corn carbohydrates in the North and South American diets. And across large areas of Africa, sorghum is the primary carbohydrate source in the human diet. For fat, soybeans dominate with 58% of all sources, but canola (rapeseed), cottonseed, peanuts, and sunflowers are significant oil sources across the globe. Although it is widely adapted and grown in more than 100 countries, barley is not a major global crop. As shown in Table 2, barley represents less than 5% of global grain and oilseed production.

It is currently estimated that 22% of the world barley crop is used for malting, with the rest going to animal feed and only a minimal use as food. It remains a very important animal feed in regions not suited to corn. Most barley-producing countries are self-sufficient, or have import/export only with their immediate neighbors.

Current World Barley Production Distribution

Production in the major barley producing countries is shown in Table 3. The sheer size of the "All Others" category (more than nine times U.S. production) indicates just how widely barley is grown.

Globally, there has been a long term decline in barley production, a pattern not unlike the decline we have seen in North America. In 1980, 161 million t of world barley was produced, with just 10% of the crop needed for brewing, and barley represented 10% of world cereal and oilseed production. In 2012, 130 million t of barley was produced, with 22% of the crop needed for brewing, and barley represented less than 5% of world cereal and oilseed production. During this period of a 19% decrease in world barley production, world beer production increased from 798,500,000 barrels in 1980 to an estimated world beer production of 1,687,500,000 barrels in 2012, a 111% increase.

Table 2. 2012 world grain and oilseed production[a]

	Metric tons (thousands)	% of total
Corn	852,300	29.1%
Rice (rough form)	684,632	23.4%
Wheat	654,310	22.4%
Oilseeds	465,810	15.9%
Barley	129,810	4.5%
Sorghum	59,060	2.0%
Other (Oats, rye, millet)	80,060	2.7%

[a] Source: WASDE/FAS (Jan. 2013).

Table 3. 2012 world barley production[a]

	Metric tons (thousands)
Russia	13,900
France	11,300
Germany	10,420
Canada	8,010
Australia	7,000
Ukraine	6,700
Spain	5,800
Turkey	5,500
United Kingdom	5,500
Argentina	5,500
United States	4,800
All others	45,380
Total world	129,810

[a] Source: USDA/FAS (Jan. 2013).

Over this 32 year snapshot, barley production declined in absolute terms, barley declined as a percentage of world cereal and oilseed production, and world beer production more than doubled.

Current estimated brewer malt usage averages:

- Global malt usage, all brewers: 0.89 bu/bbl (30.3 lb/bbl) (11.65 kg/hL)
- U.S. large adjunct brewer malt usage: 0.67 bu/bbl (22.8 lb/bbl) (8.85 kg/hL)
- U.S. large all-malt brewer malt usage: 1.60 bu/bbl (54.4 lb/bbl) (20.94 kg/hL)

World Barley Trade

The major grain-producing countries are also the primary barley exporters. Argentina, Australia, the E.U. (primarily France and Germany), Ukraine, Russia, and Canada are leading barley exporters. France, Germany, Canada, and Australia export both barley and malt; others generally export barley only, and Ukraine and Russia export feed barley only (Table 4). Note that the U.S. is not a significant barley exporter; in fact, it is a net importer of barley as brewers and maltsters increase their sourcing of Canadian barley. Just 4% of U.S. barley production is exported, while the U.S. exports from 40–55% of all of its wheat, rice, sorghum, and soybean production. Interestingly, more than 50% of all of the world barley trade goes to the Middle East for feed, 40% of it to Saudi Arabia alone. Camels, sheep, and goats in Saudi Arabia annually consume more than twice the barley volume that is required for all North American brewing!

Winter Barley

Winter barleys are varieties that possess the trait of winterhardiness, and are grown with an overwinter agricultural cycle. Winterhardiness is a complex genetic trait in a plant that involves the ability to escape and withstand the stresses of winter, specifically the direct effects of freezing. The trait is not unique to barley; several cereals have varieties that possess it. Significant production of winter wheat is grown around the world and there are winter varieties of oats and triticale. Most notable in the winterhardiness trait among the winter cereals is winter rye, which is reported to be able to germinate at temperatures as low as 1°C (34°F), and once established, to be able to survive winter temperatures as low as –34°C (–30°F). Overall as a cereal, barley is less winter tolerant than wheat or rye.

Table 4. 2012 major barley exporters and importers[a]

Country	Exports (1,000 t)	Country	Imports (1,000 t)
Argentina	4,000	Saudi Arabia	7,000
Australia	3,800	China	2,400
EU (France, Germany, U.K., Spain)	3,500	Middle East (Israel, Jordan, Kuwait, U.A.E.)	1,900
Ukraine	2,500	Iran	1,000
Russia	2,200	North Africa (Libya, Morocco)	900
Canada	1,300	U.S.	450
U.S.	200		

[a] Source: USDA/FAS (Jan. 2013).

The winter agricultural cycle consists of a fall planting, fall germination into a seedling above the soil surface, and then overwintering as a seedling plant (barley is a grass family plant, think of your lawn). The plant then resumes growth in the spring and reaches grain maturity approximately 3–4 weeks earlier than spring sown barley.

Winter cereals are grown for their significant yield advantage over spring-sown cereals. This advantage ranges from 10 to 35% in various growing environments. Winter crops provide cover to protect winter soil and avoid the year to year variability of spring field work. They utilize soil elements more effectively over the longer season and their earlier harvest generally avoids the hottest and driest period of the summer. This is critical in irrigated production areas because it can eliminate a final water application. In dry land production areas it reduces the risk of high protein and thin barley in the final stages of the crop. Winter cereals are favored by producers in their overall farm plan because equipment and personnel work load distribution is greatly improved with a combination of winter and spring crops. Winter wheat in the U.S. is well advanced with a large area of production south of the corn and soybean belt across the southern Great Plains states of Nebraska, Kansas, and Oklahoma. 75% of all wheat produced in the U.S. is winter wheat and it enjoys an 18% yield advantage over spring wheat and durum.

After breeding and selection that establishes a variety has adequate winterhardiness, there are still regional limits by climate. Where climate allows, winter barley is a large player in world barley production, with its primary use as feed (Table 5).

A few final comments on winter barley: Even in a region with a history of success with winter barley, a single winter season can be a problem. Across Europe, the 2011–12 winter crops experienced an extremely cold period with variable snow cover for three weeks in February 2012, resulting in significant winter kill. When these conditions occur, spring barley is over seeded into the winter barley field.

European brewers tend to use some winter barley for malting, but do not talk about it, with the exception of U.K. ale brewers. Usage is cost based and does not typically exceed inclusion in the malt blends above 15%. With its high yield, winter malting barley is less expensive to grow and the advantage is passed on as lower malt cost. Although French and German winter barley malts are used, the conventional wisdom persists that winter malts are "lesser" malts than spring barley malts.

The story of Maris Otter emphasizes the importance of agronomic success as a necessary element to keep a barley variety in production. Maris Otter has been described by U.K. maltsters as "bolder" and more robust, with better husk adhesion. Real ale brewers state that Maris Otter has a "preferred flavor." After release in the 1960s, it was recognized and embraced in the U.K. as having very good malting and brewing characteristics, although with a lower extract. However, when evaluated on the continent, it did not have adequate winterhardiness for that climate. It also had poorer yield and was less plump than the competing winter two-rows. Maris Otter was never embraced for full scale production; it is no longer on the U.K. recommended varieties list. However, it maintains a revered place as the winter two-row standard among brewers. Small volumes (6% of U.K. winter barley) continue to be grown in the U.K., but only upon request and for a premium.

In the U.S., winter barley breeding efforts have accelerated in recent years and winter two-rows have been released. Charles was the first successful introduction, released by USDA ARS Aberdeen in 2005 and placed on the AMBA approved list in 2009. Charles is typically grown under irrigation and has a 20% yield advantage over irrigated Metcalfe. Charles has good malting quality but exhibits limited winterhardiness. Endeavor was also released by USDA ARS Aberdeen and is currently in plant scale trials. Endeavor has a significant yield advantage over Charles, but the winterhardiness adaptation, and the malting and brewing quality are yet to be proven. For 2013, AMBA has added the German winter malting barley variety Wintmalt to its recommended varieties list. Table 6 shows AMBA recommended winter varieties.

Table 5. Winter barley production, % of total barley production[a]

	Winter barley % of total (multi-year average)
Germany	79%
France	72%
United Kingdom	48%
Czech Republic	28%
Denmark	25%
E.U. average	47%
Canada	0%
United States	<1%

[a] Source: Malteurs de France/USDA.

Feed Barley

Barley is one of the three major feed grains in the world, along with corn and oats, and is a versatile and widely used livestock feed. Digestible energy is the most important attribute that must be considered for the feed grains that supplement forage and there is no question that corn has the highest digestible energy of all feed grains. However, corn contains less protein than barley and corn protein is not very digestible by ruminants. Corn feeding usually requires supplemental protein. Barley contains approximately 90–95% of the digestible energy of corn and is higher in digestible protein. Barley also has higher fiber and higher vitamin and mineral contents such as lysine and phosphorous. In a comprehensive scoring of all feeding attributes, barley and corn will generally be ranked as equivalent. Feed use of barley expands dramatically to the preferred grain to supplement forage in regions and climates not suitable for corn. Climate wise, the most productive barley areas tend to be the least desirable areas for corn.

A precise definition of "feed" barley requires elaboration, because barley becomes feed barley through three pathways.

Malting barley that is grown in excess of malting needs. This was the most common source of feed barley for many years in North America. Barley producers had access to a sound feed market and it was common to simply grow malting types and then direct their crop to the most advantageous market at harvest. Producers could depend on a good financial return on malting types and a fair and adequate return on the

Table 6. 2012 winter malting barley varieties (two-row malting unless noted)[a]

France	Arturio (6R), Esterel (6R), Azurel (6R), Vanessa (2R)
Germany	Wintmalt, Malwinta
United Kingdom	Cassata, Pearl, Flagon, Maris Otter
United States	Charles, Endeavor

[a] Source: AMBA, Malteurs de France, HGCA, Braugerstenjahrbuch.

sale of barley as feed. However, this situation no longer exists. Change has been driven by the glut of ethanol plant feed byproduct DDGS (dried distiller's grain with solubles). DDGS is rich in concentrated corn and residual yeast proteins, fiber, fat, vitamins, and minerals. Since barley was previously used to provide a protein, fiber, and mineral supplement, now the ethanol plant DDGS are readily available and can be inexpensively obtained as a barley replacement. The result is that the market for feed barley as a protein feed component has been totally destroyed and is nonexistent. A barley producer can no longer fall back to a feed market with his excess barley and now will only grow malting barley with a pre-plant contract. The magnitude of this impact cannot be minimized. Producing 13.9 billion gallons of ethanol in U.S. results in a DDGS byproduct stream of 40.5 million t. While most is fed to cattle and dairy for energy, it is estimated that 6 million t of DDGS are fed as protein supplementation. Compare this DDGS availability to the total U.S. barley production of just 4.8 million t!

Barley rejected for malting. This typically happens because of high protein, low plump, or high thin. This pathway still exists, but generally at a loss to the barley producer. A barley producer that has marginal acreage or a history of lack of success with his malting barley making grade simply stops growing malting barley rather than taking this risk. It only takes a few bad experiences with malting barley quality acceptance procedures to lose interest in growing malting barley. But without viable barley feed markets to support and to provide an outlet for excess or rejected malting barley, farmers are increasing reluctant to grow any malting barley without a preplant contract.

Feed barley specifically bred for feed. This is the predominant pathway for feed barley today. Breeding primarily focuses on yield. In the U.S. Intermountain West, feed types currently have a 5% yield advantage over malting types on dry land production, and a 15% yield advantage on irrigated production. Beyond yield, modern feed barley breeding also focuses on higher digestive energy, higher mineral content, overall feed digestibility, and nutrient utilization. Beyond feed barley harvested as grain, barley is also grown for forage and hay. Forage barley is harvested green at the milky dough stage for either direct feeding as hay or silage.

Current common U.S. feed for grain varieties: Haxby, Baronesse, Champion

Current common U.S. forage varieties: Haybet, Hays, Horsford, Stockford, Westford

A final word on feed types vs. malting types. All barley can be malted since we know feed barley does germinate and will grow into barley plants in production agriculture. The issue is that feed types do not produce balanced malt attributes after germination. For example, Steptoe, a predominant six-row feed variety from the late 1970s through the 1990s, produced pilot malting results of 33 S/T ratio and 1,250 ppm beta glucan when tested in a standard pilot malting procedure.

The Role of Barley in U.S. Grain Production

History of Barley Production in the U.S.

The knowledge of how to brew beer has always followed civilization and the need for barley follows beer. Barley is not native to North America and came to the Americas with explorers and settlers. The English brought two-rows and the Dutch brought mainland European six-rows, both to the Eastern colonies. North African six-rows came with the Spanish to Mexico. The North African barleys were better adapted to warmer and more arid regions. These six-rows moved north into California's Central Valley and became known as Coast type barley. In the first settlements along the Atlantic Coast, conditions were not favorable for barley. The colonies were south of the best latitude for barley and they experienced hot, humid summers. Barley did do slightly better in New England than in the Mid Atlantic colonies. Movement of production to western New York improved performance with six-rows being favored over two-rows. New York was the leading U.S. barley production state in 1849. Agricultural journals of the 1850s reported that six-row barley was more common in New York than two-row. During this period, U.S. barley production was not adequate for demand and significant barley came from Canada. A malting industry and flour milling industry developed in Buffalo, NY, on local and imported barley and wheat.

The first major westward trend in barley production followed the east to west population and industry movement. Population and brewing centers in Cincinnati, St. Louis, and Milwaukee needed malt. Only around Milwaukee was barley well adapted, so barley production in the areas to the north and west of Chicago and Milwaukee expanded. The 1849 gold rush took people and an increased need for malt and beer to California. Here the eastern barleys and the barleys from the Spanish mission movement into the Southwest met in California. By 1869, the U.S. barley production centers were western New York, eastern Wisconsin, and central California. Six-rows dominated in the East and Midwest, and they were generally either white aleurone Oderbrucker types or blue aleurone Manchuria types. The Mediterranean six-rows did well in California, but when they were expanded to Oregon and Washington, they did not do as well and the European two-rows that had previously not been well adapted in the Midwest and east finally found a more suitable climate. The McKinley Tariff act of 1890 ($0.30/bu) effectively ended Canadian barley imports to Buffalo, and also effectively ended the malting industry there. By 1899, western New York no longer produced significant volumes of barley. The New York production was made up by expansion to southeastern Minnesota, and into the Red River Valley. The malting industry previously centered in Buffalo moved to Wisconsin. By 1900, barley production remained concentrated in the Midwest, with western production only needed to support western brewing. Only minor amounts of barley made the transit from the west back to the east at that time.

The second major westward trend in barley production occurred after prohibition. Two significant events occurred that moved barley west and north, and set the barley production areas that we recognize today.

The introduction of hybrid corn and the introduction of the new crop soybeans. They were very productive and competitive with barley in Illinois, Iowa, southern Minnesota, and Wisconsin, and drove barley north and west to the Red River Valley. Corn and soybeans also brought a new set of diseases that caused barley yield losses and animal feeding problems. This caused the first U.S. epidemic of fusarium head blight, vomitoxin problems with swine feeding, and beer gushing.

The development of irrigated lands in the Intermountain West. Dry land farming was very difficult for the early settlers in Montana, Wyoming, and Idaho. But government sponsored irrigation projects in the early twentieth century led to exceptionally high grain yields of excellent quality. Concerns by the malting and brewing industries about the loss of barley in the Midwest caused them to contribute support to state and federal agencies to develop malting barley production in the west. This effort resulted in an expansion of irrigated barley acres in the western higher elevations, mostly with the better adapted two-row varieties. The increased use of two-row malting barley in the U.S. outside of the brewing needs on the West Coast was not until the 1950s. There were no "national" brewery networks in the U.S. until 1948, and when they formed, the companies wanted common national malt blends. Eastern only regional breweries remained all six-row except for special products, but the national brewery networks began the use of two-row and six-row blends across the country.

The 1946 Practical Brewer describes malt usage at the time as follows: "the most commonly used malt is made from 6-row Manchurian type barley grown in the North Central States. Lesser used types are made from 6-row Mediterranean type barley and 2-row type barley grown in the Western States."

The 1946 Practical Brewer also comments on the two-row barley types at the time: "Hannchen and Hanna grown in Oregon, California, Montana, and the state of Washington" and "two-rowed varieties grown on limited acreages in the western United States for special markets."

Usage choices at the time were more determined by malt and barley freight costs, not a brewing style choice. Barley history prior to the 1950s does not really discuss the suitability for brewing of row types or varieties. It appears that the focus in this 300 year period in the U.S. from colonization to 1950 was on attaining adequate and quality "barley" generically. Six-row adaptation in U.S. agriculture long preceded U.S. lager brewing and adjunct brewing, and it should be considered a myth that six-row usage in the U.S. was driven by the beginning of adjunct brewing in the 1870s.

Table 7. 2012 U.S. grain and oilseed production[a]

	Metric tons (thousands)	% of total
Corn	273,830	62.5%
Soybeans	82,060	18.7%
Wheat	61,760	14.1%
Rice (rough basis)	9,353	2.1%
Sorghum	6,274	1.4%
Barley	4,790	1.1%

[a] Source: WASDE/FAS (Jan. 2013).

The Current Role of Barley in U.S. Grain Production

Barley is now just 1% of total U.S. grain and oilseed production, and is declining. U.S. agriculture is dominated by corn, followed by wheat and soybeans. As noted in Table 7, rice, sorghum, and barley are minor crops. The U.S. is the largest exporter of wheat and corn in the world, among the top three exporters of soybeans and sorghum, and the fourth largest exporter of rice, but not a significant barley exporter. Barley is just not productive enough for the U.S. to be a world export player.

Current North American Barley Production Distribution

Of the 4,300 documented world barley varieties, approximately 150 are grown in the U.S. Barley is grown in reportable volume in at least 22 states, including places ranging from North Carolina to Maine. During 2012, U.S. barley production distribution by variety was estimated at 36% two-row malting, 32% six-row malting, and 32% feed. The Mid-Atlantic states grow the most barley outside of the malting barley areas for livestock feeding. Only eight states are important in the U.S. for malting barley, with North Dakota, Montana, and Idaho as the production leaders (Table 8).

There are very obvious barley yield differences across the U.S. states and Canadian provinces. As noted in the adaptation section, this is largely attributed to the higher elevations of the Intermountain West and to the states where a higher percentage of the barley is grown under irrigation, i.e., Colorado, Idaho, and Wyoming.

Barley and Malt Profiles

Two-Row and Six-Row Technical Basics

Since six-row barley malt has a long history in North America and has been is a major feature in U.S. brewing, a discussion about barley varieties and their profiles should start with the differences between six-row and two-row types. The focus is on the technical specifics and we do not advocate for any particular malt type or profile. Each individual brewer makes his choices for his purposes and those choices should be respected.

Two-row and six-row types are the same barley plant species, so why are their malts different? We propose that the

Table 8. 2012 North American barley production[a]

	Metric tons (thousands)	Bushels (thousands)	2012 yield (t/ha)	2012 yield (bu/ac)
North Dakota	1,341	61,610	3.28	61.0
Idaho	1,169	53,690	4.89	91.0
Montana	912	41,870	2.85	53.0
Washington	274	12,600	3.87	72.0
Colorado	147	6,765	6.61	123.0
Minnesota	124	5,700	3.07	57.0
Wyoming	116	5,340	4.79	89.0
Oregon	83	3,816	3.87	72.0
Eight states	4,167	191,391	3.84	71.5
All other	629	28,893	2.38	44.3
U.S.	4,796	220,284	3.65	67.9
Alberta	4,463	204,998	3.20	59.5
Saskatchewan	2,351	107,999	2.40	44.6
Manitoba	618	28,398	3.00	55.8
Three provinces	7,433	341,395	2.93	54.5
All other	579	26,607	2.51	46.7
Canada	8,012	368,002	2.90	46.7

[a] Source: WASDE/FAS (Jan. 2013), StatsCan (Dec. 2012).

difference is simply the degree of kernel fill between plump and thin kernels. Consider this in a very simplified way.

A barley kernel consists of a starchy endosperm plus an "everything else" package. The starchy endosperm component contains primarily reserve carbohydrate. The "everything else" package consists of an embryo with a bordering scutellum containing lipids and protein, and progressive endosperm surrounding layers of aleurone, testa, and pericarp, all enclosed in a husk. The aleurone layer is the location of preformed enzymes and the future enzyme potential of the barley during germination.

As the starchy endosperm increases or decreases with kernel size, the relatively fixed "everything else" package moves around as a percentage of the total kernel. Two-row kernels arranged on the rachis share the space with four sterile florets, resulting in more space for larger kernels to develop (Figure 1). Two-row heads will typically have 24–30 kernels. Two-row kernels are plump and symmetrical, with straight creases. Six-row kernels arranged on the rachis are crowded, resulting in the cramped development of smaller kernels. Six-row heads typically have up to 60 kernels, with all the kernels being thinner, longer, and irregularly shaped. One third of them are straight and resemble two-row kernels, and two thirds of them are twisted with flaring creases.

Differences in brewing impact between two and six-row malts are driven by the dilution of the non-endosperm "everything else" elements by varying amounts of starchy endosperm. Two-row have a higher dilution of "everything else" by the larger kernels vs. less dilution of "everything else" by the smaller six-row kernels.

This size phenomenon also occurs within type. Plump, low protein six-row grown on irrigated land approaches two-row barley characteristics, just as thin, high protein two-row grown on dry land approaches six-row barley characteristics. Size dilution determines malt extract, two-row being higher with larger kernel size and more endosperm. Size dilution also determines barley protein, with six-row being higher with a smaller kernel size and less endosperm dilution of "everything else." Total protein in barley is driven by the producer's supplemental nitrogen (N_2) application, factored by final kernel fill. N_2 is applied in the spring after a soil test for residual and available N_2 from the previous crop. That amount is fixed before the seasonal rainfall occurs. Kernel fill is then determined by the available moisture through the growing season. High rainfall results in high plump with low protein; low rainfall results in thin barley with high protein. Higher barley protein typically leads to the malting protein artifacts of higher malt soluble protein, free amino nitrogen (FAN), enzymes, color potential, and husk ratio. Often overlooked is the typically higher soluble protein to total protein ratio (S/T or Kolbach index) required to modify and digest the increased protein structure in the endosperm cell walls into a functional malt. Starchy endosperm cell walls contain 5–10% protein as well as beta glucan and arabinoxylan. High functionality malt must have the protein component of the cell wall structures digested to free the starch as free flowing extract. The malt attributes of two-row and six-row are summarized in Table 9.

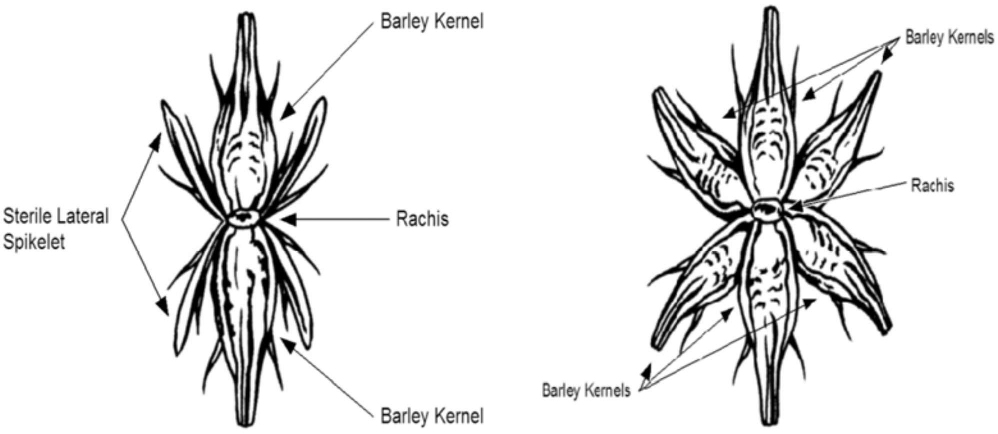
North American Variety History

The Evolution of Two Barley Types to Three Barley Types

The evolution of barley types and varieties in North America is really a discussion about the evolution of modification profile and modification balance. Modification is a catchall term that maltsters use to describe the total transition from barley to malt. Within the catchall description is carbohydrate modification and protein modification. The maltster must achieve both, and malting is not complete until both are at satisfactory levels. Protein modification as measured by S/T ratio must proceed until enzymes are produced, FAN is produced, and the cell wall structure around the endosperm is degraded. Simultaneously, carbohydrate modification as measured by beta glu-

Table 9. Two-row and six-row malt attributes

	Two-row malt	Six-row malt
Husk ratio	Lower	Higher
Total protein	Lower	Higher
Soluble protein	Lower	Higher
FAN	Lower	Higher
Enzymes	Lower	Higher
Color potential	Lower	Higher
Extract	Higher	Lower
S/T ratio	Lower	Higher



Two-row barley head **Six-row barley head**

Figure 1. Two-row and six-row barley heads (source: Busch Agricultural Resources).

can must proceed until the cell wall degradation is confirmed and the extract is free flowing. It is typical for a maltster to push the S/T ratio only until the carbohydrate modification is complete. Modification balance between the protein track and the carbohydrate track is important to recognize. Every variety has its own natural modification profile balance. There is no exact S/T ratio common to every malting variety. At a single number some varieties are overmodified and some are undermodified. For example, a 44% S/T ratio represents overmodification for some two-row varieties (Grace) and undermodification for other two-row varieties (AC Metcalfe). Protein modification leads in the malting process as the enzymes that enable malting are produced and carbohydrate modification lags as the beta glucanase is produced last during malting, followed by very late beta glucan reduction. A simplification of the malting sequence is that protein modification must be allowed to proceed until beta glucan is reduced. This concept of modification profile is an important attribute when tracking variety evolution.

1960s

Fifty years ago, it was clear that there were just two barley types in North America, six-row and traditional two-row. In the U.S., the Midwestern six-row varieties Larker and Dickson were dominant, having followed the earlier varieties Kindred and Traill. Since the 1940s, all of these six-row varieties had been white aleurone. In Canada, the six-row varieties Conquest and Bonanza dominated and were still blue aleurone. The white vs. blue distinction reflects pigmentation in the aleurone layer in blue barleys that make the kernel appear blue when pearled. All six-row malting types of this period were the result of North American breeding efforts.

Additionally there was Coast six-row barley in the western U.S., the varieties Coast, Atlas, and Winter Tennessee (just a name, not a true winter variety). These barleys were descendants of the Mediterranean six-rows brought to Central America and California by Spanish explorers and settlers. Compared to Midwestern six-rows, they were characterized as having larger kernels with a thick husk and moderate protein. But in the malt plant they exhibited slower modification and lower enzyme potential. Use was limited to western brewing and they completely left use by the early 1970s.

Two-row barley at the time should be described as pre-Klages traditional two-row. The varieties Betzes, Piroline (both German origin), Hannchen (Swedish origin), and Hanna (Austrian origin) were varieties that were all brought from Europe and none of the two-row malting types at this time (pre-Klages) were from North American barley breeding efforts. Current all-malt craft brewers likely have not brewed with these varieties. These barleys all required 5 day germination at malting.

1970s–80s

Thirty-five years ago, it was necessary to start talking about three barley types, six-row, the pre-Klages traditional two-row, and the new North American two-row types, Klages and Harrington. In the U.S., Midwestern six-row was evolving to Morex (1978) and Robust (1983), replacing Larker and Dickson. The Coast six-row types were no longer in use in brewing.

Pre-Klages two-row, which we are calling traditional two-row, still existed; the same Betzes, Piroline, Hannchen, and Hanna were still grown in the West and in Canada.

The third barley type, which we will call North American two-row, represented the first two-row malting barleys from North American breeding programs. Klages, released in 1972 from the Agricultural Research Service (ARS) Idaho, and Harrington, released in 1981 from the University of Saskatchewan, were the first of their type. This three barley type premise requires an explanation of just how dramatically Klages and Harrington changed the North American view of two-row barley. The major change was that the S/T ratio level on the new two-row varieties moved from the high 30s of the traditional two-row types to the low to mid 40s. This was very significant because the higher S/T ratio was on North American total protein levels. This resulted in the increase of the malt protein artifacts of malt soluble protein, FAN, enzymes, and color potential, moving them toward the six-row malt numbers. The S/T ratio change was variety driven from its breeding; it was not a malt processing event. The lower S/T ratio on Betzes and Hannchen, and on today's European varieties, means that those varieties can achieve satisfactory carbohydrate modification without going past 40 S/T ratio. Klages and Harrington were the first two-row varieties that could not complete the expected carbohydrate modification until the S/T ratio reached 42–44 S/T. With the S/T ratio increase, there was a corresponding drop in beta glucan and an increase in malt extract release and availability. This caused great consternation among traditionalists, but the higher S/T ratio artifacts of enzymes and FAN were embraced by adjunct brewers. This malt made it easier to brew American light lagers and enabled the "dry" beer revolution in Japan.

After introduction and approval, Harrington quickly replaced Klages on superior grain yield and the ability to hold kernel plumpness on dry land growing conditions. Harrington became the dominant North American two-row malting barley for more than 20 years. A few early all-malt craft brewers know Klages, but most have only seen Harrington as the two-row malt standard before moving on to Metcalfe.

Comparison of the two-row and six-row types is shown in Table 10.

1990s–Current

Today, we talk about current North American two-row and six-row, and only nostalgically about traditional two-row. And we speculate why traditional two-row barley in the European profile is not available in North America. In the U.S., the most common current Midwestern six-row varieties are Tradition (2003) and Lacy (1999). In Canada, the six-row that has remained in production is now all white aleurone six-row that has been previously bred in the U.S. Legacy (2000), Tradition, and Stellar ND (2005) are most common. There is no longer

Table 10. Two-row vs. six-row variety malt profiles[a]

	Traditional two-row (1960s)	North American two-row (1980s)	Six-row (1980s)
Total protein	11.8	12.4	12.8
S/T ratio	38.0	43.3	42.0
Soluble protein	4.5	5.4	5.4
FAN	na[b]	212	204
Diastatic power	95	135	155
Alpha amylase	26	58	48
Beta glucan	na	120	147
Extract	79.0	80.2	78.2
Varieties	Betzes, Hannchen	Klages, Harrington	Morex, Robust

[a] Typical analysis for illustration—total protein and soluble protein will vary with region and crop year.

[b] Values not available.

any significant production of blue aleurone malting barley in North America. Breeding of new six-row varieties has followed the same pathway as two-row breeding; specifically, increasing S/T ratios that have pushed enzymes and FAN higher, and beta glucan reduction that has released higher extract levels. Comparison is shown in Table 11.

Traditional two-row has disappeared from North America. The 2012 crop report from Idaho does show that Piroline was produced in small quantities as a feed barley in southeast Idaho because of its drought tolerance.

North American two-row has continued to evolve. In the U.S., AC Metcalfe (1997), Conrad (1993), Moravian, Hockett (2008), and Merit (1990) are leading varieties. In Canada, AC Metcalfe and CDC Copeland (1999) are dominant. With the exception of Moravian, these varieties represent an extension of Klages and Harrington breeding with additional major changes to S/T ratios, up from the low to mid 40s of Klages and Harrington to the high 40s for the most recent varieties. Another step closer to the numbers of six-row in the "protein artifacts." Since traditional two-row is not currently available in North America, we need to bring European two-row types to the discussion to demonstrate just how different North American two-rows really are. The evolution of North American two-row and a comparison with the current European two-row is shown in Table 12.

Note that the current two-row varieties in Europe do not look very different from the two-row barley introduced into North America many years ago and then abandoned in the 1980s. The difference exists simply because the Europeans have maintained a very consistent and classic view of the description of the highest quality barley for brewing and enforced it with their new variety breeding guidelines. The classic malting barley description long used by European maltsters and brewers has three elements:

(1) Low husk content: 10–11% of kernel weight, certainly not exceeding 11%
(2) Very plump kernels: >90% on 2.5 mm screen (6.3/64th inch)
(3) Moderate protein level: preferred 10–11%, certainly never exceeding 11.5%

This description favors two-row barley over six-row barley, and can only be approached in North America with irrigated two-row barley.

Beyond not following the classic European definition of quality malting barley, important differences between North American barley and European barley were created and maintained with different breeding goals. The breeding goals in the U.S. have been expressed by the preferences of the adjunct brewers. The principal breeding goal difference is that the Europeans will not allow the S/T ratio to expand. This is consistent with the traditional belief that highly modified malt can produce thin beers with poor foam quality. The Weihenstephan guidelines for S/T ratio for German spring two-row remains 39–42%. The HGCA (Home Grown Cereals Authority) in the U.K. has an S/T ratio guideline of 40–43%. These are in contrast to the North American breeders S/T ratio guideline of 42–47%. Beyond this wider S/T ratio range allowed in the North American guidelines for breeders, North American guidelines also have a much higher expectation for FAN and diastatic power, and a much lower expectation for beta glucan. The Weihenstephan guidelines for malt beta glucan are <300 ppm and the U.K. guidelines for lager malt are <250 ppm. We now have North American barleys that reflect these higher modification and lower beta glucan goals. The germplasm of traditional European two-rows has not been prominent in North American breeding since Betzes was a parent of Klages. Table 13 shows the current dominant barley varieties grown in the world.

All-malt brewers in the U.S. that study classic materials or import European malts understand the difference between

Table 11. Evolution of six-row variety malt profiles[a]

	Six-row (1980s)	Six-row (today)
Total protein	12.8	12.8
S/T ratio	42.0	48.0
Soluble protein	5.4	6.1
FAN	204	235
Diastatic power	155	175
Alpha amylase	48	57
Beta glucan	147	100
Extract	78.2	79.1
Varieties	Morex, Robust	Tradition

[a] Typical analysis for illustration—total protein and soluble protein will vary with region and crop year.

Table 13. 2012 world spring malting barley varieties[a]

United States – two-row	AC Metcalfe, Moravian, Conrad, Merit, Hockett
United States – six-row	Tradition, Lacy, Robust
Canada – two-row	AC Metcalfe, CDC Copeland
Canada – six-row	Legacy, Stellar ND, Tradition
France	Sebastian, Tipple, Concerto
Germany	Grace, Quench, Marthe, Propino
United Kingdom	Tipple, Concerto, Quench, Propino
Australia	Baudin, Buloke, Gairdner, Commander

[a] Source: AMBA, CMBTC, Malteurs de France, HGCA, Braugerstenjahrbuch, Barley Australia.

Table 12. Evolution of two-row variety malt profiles[a]

	North American two-row (1960s)	North American two-row (1980s)	North American two-row (today)	European two-row (Current)
Total protein	11.8	12.4	12.0	10.4
S/T ratio	38.0	43.3	47.0	40.0
Soluble protein	4.5	5.4	5.6	4.2
FAN	na[b]	212	230	145
Diastatic power	95	135	152	75
Alpha amylase	26	58	65	42
Beta glucan	na[b]	120	95	175
Extract	79.0	80.2	81.6	81.9
Varieties	Betzes, Hannchen	Klages, Harrington	AC Metcalfe, Conrad	Grace, Quench

[a] Typical analysis for illustration—total protein and soluble protein will vary with region and crop year.
[b] Values not available.

European and North American two-row types and will comment that we have a need for the classic type to be grown in North America. Looking beyond the obstacles to agriculture, we have to ask ourselves, do we really want the classic two-row in North America? We have to consider that the major adjunct brewers currently have the malt that they want, but more importantly, the North American all-malt brewers have been using Harrington and AC Metcalfe types for so long that they have shaped and adapted their processes and products to them. All-malt brewers currently have mashing procedures and attenuation levels based on the higher North American enzymes, and they currently have fermentation control techniques and fermentation profiles based on the higher North American FAN.

Beyond enzymes and FAN, brewers would have to adjust to the European beta glucan profile. To achieve the lower protein artifacts on lower barley protein, the traditional European two-row malts generally have less carbohydrate modification as indicated by higher beta glucan and higher viscosity. It is not abnormal to routinely see 180 beta glucan in malt shipments of the European two-row types. Would U.S. all-malt brewers accept 160–180 ppm beta glucan after working with 110 ppm and less for the last 35 years?

Beyond the adjustments that brewers have to make, we would need to recognize that there are other "interested parties." We would have to deal with both barley total protein levels and the high barley plump levels to obtain a true European type two-row. Production agriculture would need to adjust nitrogen practices to consistently provide barley below 11.5% total protein. This would reduce yields. Protein could be reduced on dry land production, but the plump profile could not be provided without irrigated production, so the European barley in North America would need to be produced only on irrigated land in addition to being grown with less nitrogen. The crop would be produced on an even more narrow geography that would be limited to the U.S. Intermountain West. Not following the irrigated and reduced nitrogen guidelines will not result in success. Scarlett, a popular French variety adapted worldwide from 1999 to 2010, has been grown in the U.S. The barley was grown on dry land without nitrogen control in Montana and the resulting malt looks more North American than European when the higher total protein level is malted. Malting would also be impacted. Most, but not all, European two-rows are still malted with five day germination. Five day germination would be a difficult but not an impossible fit for today's North America malting plants.

Brewing Impacts of Barley Varieties and Types

Each barley type and variety has its own set of characteristics determined by its genetic makeup. Some of the varying characteristics originate from how nitrogen is taken up from the soil and deposited in the grain, different levels of optimized protein and carbohydrate modification, and different levels and distribution of enzymes. These attributes have varying brewing impacts. We will review in general the direction that each attribute will take the brewing process.

Husk ratio and content. Smaller kernel six-row has more husk; therefore, it will enhance brewery lautering and is useful in non-syrup adjunct brewing when the malt is "diluted" by other grains without lautering material. However, husk material can have a negative flavor impact if over extracted at lautering. On balance, once the lautering needs are met, any additional husk is considered a flavor risk. High husk is mandatory for high ratio adjunct brewing, but high husk can be a flavor negative for all-malt brewing. This makes lower husk two-row more desirable for all-malt brewing.

Total protein and protein modification profile. Examining the differences between two examples tells us a lot about brewing impacts. Table 14 compares a classic two-row, European Quench, to a current North American six-row, Tradition.

The Quench has a classic European modification profile, a conservative S/T ratio on a low total protein, resulting in lower soluble protein, lower FAN, lower enzymes, and higher beta glucan. It is typical of the pre-Klages two-rows in North America, Betzes and Hannchen, although my personal experience was that Betzes' diastatic power was closer to 95 units. The Tradition is typical for U.S. six-row today. A higher S/T ratio on a typical North America total protein, resulting in a higher soluble protein, higher FAN, higher enzymes, and a low beta glucan.

Soluble protein (Sol Pro). The non-FAN soluble protein portion is important for foam and mouthfeel. For adjunct brewing, the level must be high enough to survive dilution by the second grain to provide these beer attributes. High levels in all-malt brewing would be advantageous except for two qualifiers: (1) high soluble protein will be accompanied by high FAN and high enzymes, and (2) the high S/T ratio to achieve higher soluble degrades protein sizing and results in less high molecular weight protein (HMW). This can damage foam quality and reduce mouth feel.

Free amino nitrogen (FAN). This is the simple protein nutrient base for yeast at fermentation. Again, a high number in adjunct brewing is required due to adjunct dilution, but in all-malt brewing the high number can over stimulate fermentation.

Diastatic power and alpha amylase (DP/AA). These are the enzymes that are required for starch simplification to digest complex carbohydrate to fermentable sugars. High levels are needed for the adjunct starch, much less is required for malt starch only. AA is important for digesting adjunct starch, but is already in good balance with DP for malt-only brewing. All-malt brewers typically do not even have AA in their specifications. High enzyme levels can create mashing control issues for all-malt brewers accompanied by higher than desired attenuation.

Beta glucan (BG). This will generally be higher in lower S/T ratio malts. Starchy endosperm cell walls are made up of beta glucan, arabinozylan, and protein. A lower S/T ratio level generally represents a reduction in cell wall digestion increasing the beta glucan level and reducing extract levels.

Summing up the expected brewing impacts of these modification attributes, the six-row has soluble protein, FAN, and enzymes that better manage adjunct addition. If these numbers

Table 14. Classic two-row vs. six-row malt profiles[a]

	Classic 2R European (Quench)	Current 6R U.S. (Tradition)
Total protein	10.4	12.8
S/T ratio	40.0	48.0
Soluble protein	4.2	6.1
FAN	145	235
Diastatic power	75	175
Alpha amylase	42	57
Beta glucan	175	100
Extract	81.9	79.1

[a] Typical analysis for illustration—total protein and soluble protein will vary with region and crop year.

are projected to dilution by a 30% adjunct inclusion, the result is 3.95 Sol Pro, 165 FAN, 125 DP, and 40 AA, which are not that much different from the classic two-row used in an all-malt process. This gives us insight into the minimum levels that are actually needed to carry the brewing process.

Beta glucan has been driven to very low levels in North America. The levels found in malt today are well below the number that is recognized to cause processing difficulty. Lauter tub processing difficulty is associated with 200–220 ppm beta glucan, so the current 100 ppm level is not really necessary to ensure ease of process. However, beta glucan can be considered the "glue" the holds extract together and some brewers look at the higher extract value that can be achieved with lower beta glucan, especially below 100. This is a cause for debate, the balance between releasing more extract vs. consuming extract during malting at higher modification levels. Also, maltsters do not like this approach; the more functional malt with higher extract for the brewer comes at the expense of higher malting losses for the malt plant.

The traditional view of brewing impact difference of two-row and six-row are summarized in Table 15.

Adding the current North American two-row AC Metcalfe to the variety profile table emphasizes how the North American two-row types have evolved to meet all the requirements for adjunct brewing and they can now be used interchangeably with six-row. They now possess the attributes of six-row on the brewing impact table. Although the North American two-row shown in Table 16 is at a modest total protein level, the variety modification profile is significantly different and the modification delivers dramatically different soluble protein, FAN, and enzymes. These differences can be a process hindrance to all-malt brewers, indicated by higher and more difficult to control attenuation levels, and higher levels of fermentation stimulation.

The key take away from this discussion is that variety makes a difference. The modification profile determined by variety cannot be fundamentally changed by the maltster. Every discussion about malt should include the variety involved, and every malt specification should start with variety. In most cases, if a brewer does not like the malt profile he or she is receiving, the solution is in changing barley variety, not by pushing other aspects of the malt specification outside of the modification profile for the variety in use.

Table 15. Two-row and six-row malt brewing impacts

	Two-row	Six-row	Attribute impact
Husk ratio	Lower	Higher	lautering efficiency (+), flavor (-)
Total protein	Lower	Higher	
Soluble protein	Lower	Higher	mouth feel (+), foam (+), haze (-)
FAN	Lower	Higher	yeast nutrition (+)
Enzymes	Lower	Higher	conversion and attenuation (+)
Extract	Higher	Lower	endosperm to husk ratio (+)
S/T ratio	Lower	Higher	required for higher protein levels

Challenges to Malting Barley – A Look Ahead

Challenges to Barley Research

Research in all cases, and barley research is no exception, is funded by the interested parties of the product of the research. The product of the research, including new variety development, must have economic value for the outcomes to be funded and to be executed. For agriculture, the economic value is generally driven by the volume of the crop. For malting barley, the issues are simply, "what is the volume of the crop, what is the total economic value of barley, and who are the interested parties willing to fund the research?"

Based on the volume of the U.S. barley crop and its limited role in U.S. agriculture, there is very little private research on barley. Some seed companies that focus on wheat have smaller programs on barley to leverage the similarities between the two grains, but seed companies and other agricultural businesses focus on the improvement of the major crops of corn, soybeans, and wheat. In contrast, several private seed companies across Europe are breeding barley because it has a high economic value in agriculture there, and the private companies can achieve an investment return on research. In Europe, there is significant research competition to introduce new varieties among several seed breeders and change happens quickly on improved yields.

Federal level funding of barley research is limited. Barley is not within the top twenty agriculture value crops in the U.S. After the grains and oilseeds previous noted, barley is also behind livestock, poultry, and many fruits and vegetables in the U.S. in economic value. Beyond brewers, malting barley does not have significant value for anybody else. State level funding of barley research is also under pressure. State-provided funding for university agricultural research is based on the economic importance of the crop in the state. When examining the rank of barley in economic importance in the principal barley producing states, we see that even in those states, it has little significance. The barley significance in major malting barley producing states is detailed in Table 17.

These challenges result in the prediction of several trends for North American barley research that can be summarized as of 2013:

- There will be a continuing loss of current research positions to retirement and to assignment away from barley. Very few new barley research positions are expected to be added in the immediate future.

Table 16. Classic two-row vs. North American malt profiles[a]

	Classic 2R European (Quench)	Current 6R U.S. (Tradition)	North American (Metcalfe)
Total protein	10.4	12.8	12.0
S/T ratio	40.0	48.0	47.0
Soluble protein	4.2	6.1	5.6
FAN	145	235	230
Diastatic power	75	175	152
Alpha amylase	42	57	65
Beta glucan	175	100	95
Extract	81.9	79.1	81.6

[a] Typical analysis for illustration—total protein and soluble protein will vary with region and crop year.

Table 17. Economic value of barley in principal malting barley states[a]

	% of U.S. malting barley	Barley as % of state economic value	Barley ranking in state
North Dakota	41%	1.5%	9th
Idaho	27%	7.7%	4th
Montana	21%	7.0%	3rd

[a] Source: USDA/NASS (May 2012).

- There will be few or no Congressional earmarks for research facilities in the immediate future. This has been the most common funding mechanism for agricultural research facilities.
- Industry advocacy for malting barley and industry funding are very important, but their funding contributions are more for directing and leading the base funding from federal and state sources. The "heavy lifting" in agricultural research funding comes from the political power that results from crop economic value.
- It is likely that the rate of variety introduction will slow from the current rate.
- It is likely that new varieties that are introduced will not be very different from the current varieties. The accumulated success in the existing germplasm will continue to be extended in small incremental changes to existing varieties.

Challenges to Barley Production

Within the constraints of what crops are suitable to climate, planting decisions in agriculture are made based on the net return per acre planted. This net return is calculated as the gross return less the cost of production. Farmers are very skilled at tracking the exact cost of production for each of their potential crops. Their challenge is determining the gross return available per acre, which is the grain yield per acre factored by the price per unit that can be achieved. Farmers can lock in the price per unit for all the major crops with a future contract, an agreement to sell their crop at a contract price at a date after harvest. This contract price factored by the anticipated yield that can be achieved allows the farmer to predict his gross and net return for all the major crops. This mechanism is not available for barley since there is no futures contract market available in North America, so a farmer must take an alternate approach to reach a malting barley planting decision. Barley is simply not productive enough to stand alone in North American agriculture without a contract that establishes its harvest value. It will not be grown without a pre-plant contract to establish its harvest value, and contracts must be priced to overcome the return to the farmer of the competing crops for malting barley to be reliably acquired.

This is not as complicated as it may appear. In most of the primary malting barley growing areas, barley competes with wheat, and barley contracts are tied to the value of wheat. Barley currently has a higher yield than wheat and has lower production costs, so a barley contract can generally be indexed to wheat at 75–85% of the value of the wheat future price. The frustration for barley buyers is that barley contract pricing does not respond to barley inventories or barley supply and demand calculations; it is tied to wheat and follows wheat regardless of where the wheat price goes. Wheat is a major world food grain and its future price is determined by the global food supply and demand situation. The U.S. exports 50% of its wheat crop and is the largest wheat exporter, providing 20% of the wheat in world trade. Canada is also a major wheat trader, exporting 70% of its wheat crop.

Beyond linkage to wheat, barley competes with corn and soybeans in North Dakota. Corn has higher production costs than barley, but very high grain yields that can provide high returns when corn prices are high. Soybeans have lower production costs than barley, and lower yields, but very high prices will deliver a high return. Corn and soybean returns represent a moving target for barley buyers because as well as price volatility; both crops have had consistent yield improvements with genetic modification. At this time, wheat has not been impacted by genetic modification, but it is likely to be impacted within the next 10 years. In this environment, the key focus of a barley buyer is to concentrate on the future contract prices and the current productivity of the competing crops to accurately price competitive barley contracts.

The good news for barley buyers and brewers is that there is a large and more than adequate volume of "barley friendly and suitable" acres in the U.S., and malting barley acres can easily be obtained with competitive contracts to any volume required. Except for North Dakota, it is still relatively easy to make a barley growing contract after a fair evaluation of the farmer's barley vs. wheat return per acre. Some recent results from the 2012 crop include:

2012: U.S. malting barley was grown on approx. 3,244,000 acres
2012: In the U.S. malting barley areas, approx. 587,000 acres were planted with feed barley varieties
2012: In the U.S., approx. 14,500,000 acres were planted with spring wheat and durum

These challenges result in the prediction of several trends for North American barley production that can be summarized as of 2013.

- All malting barley has to be acquired through pre-planting contracts. There will be virtually no malting barley grown without a pre-plant contract. This is not really a prediction, it is current reality. When the 2012 barley production report is dissected, non-malting states removed, feed barley varieties removed, and an acceptance rate is applied to the malting barley, the usable available malting barley was approximately 127 million bushels. U.S. malting plants running at capacity require 125 million bushels and U.S. brewing production requires 109 million bushels. This 2012 level of acreage and production represents a balance with the current industry need and acreage will not likely fluctuate greatly from this level going forward.
- Pricing for barley contracts will be tied to the global food supply through global supply and demand for wheat. For example, after a long period of price stability below $4.00/bu, wheat moved to near $13.00/bu on fears of a global shortage in 2008. It then settled somewhat and recently has ranged from $8.50 to $9.50/bu. During January 2013, reports of adequate global wheat stocks softened wheat future prices.
- In barley areas suitable for corn and soybeans, high return values for those grains based on their supply and demand can trump the wheat relationship and take the barley price higher. Corn prices for the future crop following the drought-shortened 2012 corn crop are currently volatile.
- Western and Canadian two-row will ultimately be the competition for Midwestern six-row barley, not corn and soybeans. At the farm gate, six-row has less intrinsic value than two-row. Irrigated two-row barley has less cleanout, higher barley to malt conversion rates, and higher extract. Today, six-row can command a higher

farm gate contract price because the two-row advantage is canceled by the freight cost to bring the higher value barley east to the malting plants. In the future, if corn or soybeans take the Midwest barley contract premium beyond the freight cost, or if malting capacity continues to shift west, Midwest six-row barley production will end.

- Malting barley production will continue to move west and north to areas that provide the stable relationship with wheat, and to avoid a volatile relationship with corn and soybeans. This will lead to a tighter variety profile being grown on a more narrow acreage. Total system inventories will be slightly longer to provide weather risk and quality risk protection. Brewers should not fear the contracting of all malting barley; it represents stability and the ability of the brewer to better define choice.

Final Thoughts

Barley variety makes a difference. During malting, the varietal differences manifest themselves primarily as a specific balance between protein and carbohydrate modification, resulting in a range of malt outcomes for soluble protein, FAN, enzymes, and beta glucan. Maltsters recognize these differences by malting only pure variety lots. Any blending of varieties takes place after malting and storage, just prior to shipment. The maltster has the responsibility only to malt to the specific modification of each variety. Just as a maltster cannot change barley total protein or kernel sizing, he cannot malt to change one variety profile into another variety profile. Brewers must be careful to make certain that their malt specifications align with the barley varieties that are in his blend. Specification discussions should always include the variety involved, and every malt specification should be based on a variety. Brewers that use blends of several varieties should know the varieties and ratios that make up the blend.

With malting barley now being grown only with a contract prior to planting, brewers with specific needs for variety and protein level must make commitments for their future malt needs to their maltster well in advance. For example, commitment must be made in November 2013 for 2014 barley production that will be delivered as malt in 2015. Later commitment, after all the barley is planted, reserves malt plant capacity but likely the brewer will be purchasing more generic "Brewer's Pale Malt" and receiving the maltster's available pool blend of variety, protein level, and general specifications.

This material is intended to provide a pragmatic assessment of the current landscape. The comments on the comparison of North American two-row and classic European two-row are intended to be a matter-of-fact assessment of the history and current situation for educational purposes. They are not intended to render a judgment on the evolution history, or to advocate for any barley type or variety.

Malting and brewing success is in the eye of the beholder. There are as many opinions about barley variety and malt outcomes as there are brewers. All brewers make barley variety and malt choices for their interests and those choices should be respected.

SUGGESTED READING

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