Malting Canadian Barley: Chemistry

IN THIS CHAPTER, SOME OF THE IMPORTANT BIOCHEMICAL CHANGES THAT take place during the malting process will be outlined. The major aim of malting is to convert barley into a product (malt) that has appropriate colour, aroma and physical characteristics and that will yield a high level of extractable, fermentable material during brewing with minimal processing problems. Transforming barley into malt is a complex process in which the interior of the barley kernel is significantly altered through a series of biochemical reactions. The art of the maltster is to control these reactions so as to produce a malt with desired predetermined characteristics. Before these biochemical reactions are discussed, however, it is important to look at some of the components and tissues of the barley kernel that play important roles during malting and brewing.

Barley Kernel Structure

A diagram of a barley kernel is shown in Figure 1. The embryo, at the base of the kernel, is one of two living tissues in the kernel. The other living tissue, the aleurone layer, will be discussed later. During germination, the embryo produces roots and the acrospire which, if allowed to grow, will develop into a new plant. During initial stages of steeping, water enters the grain through the base of the embryo.

The endosperm, which may be thought of as the energy store of the kernel, is the largest tissue in the kernel. It consists of a continuous, highly organized network of cells with walls that contain the highly viscous polysaccharide β-Glucan. Threads of β-Glucan, therefore, are present throughout the endosperm. The cells are filled with starch in the form of discrete bodies, or granules, and represent about 60% of the kernel’s weight. The granules are embedded in a matrix of protein with fairly high levels around the endosperm periphery and relatively low levels in central regions of the endosperm (see Figure 2).

Encircling the endosperm, except where it meets the embryo, is the aleurone layer, which is rich in protein and lipids. This layer is three cells thick in barley, but only one cell thick in other cereal grains. These living cells, which synthesize a range of hydrolytic enzymes during germination, play an important role in malting.

Outside the aleurone layer and completely surrounding the kernel are a number of other tissues such as the testa, pericarp and hull. These all play a role in the malting process such as mediating the rate of water uptake during steeping, protecting the embryo during malting and forming the filter bed to clarify malt extracts during brewing. Of particular importance for malting and brewing, however, are the biochemical changes that take place in the embryo, endosperm and aleurone tissues.
Successful malting requires complete destruction of the endosperm cell walls, controlled breakdown of the endosperm protein matrix, increased solubility of barley proteins and the formation of an array of hydrolytic enzymes to carry out these changes and to generate malt that has a high fermentable extract during mashing. To accomplish these changes, the malting process takes place in three stages: steeping, germination and kilning. Many of the biochemical reactions important to the malting process start during steeping, continue through germination and are only arrested at the late stages of kilning. Many of these reactions are reactivated during mashing.

Canadian cultivars of malting barley exhibit little or no dormancy. They require only a limited maturation period before achieving full germination energy and can be safely malted a few weeks after harvesting.

**Steeping**

Steeping is the process of soaking the barley in water. The moisture content of barley is raised to levels of 40 to 46% to ensure adequate hydration of the endosperm, thus enabling hydrolytic enzymes to move throughout the endosperm in a uniform manner and carry out the desired biochemical reactions. It is essential that all regions of the endosperm are hydrated because dry spots will remain unchanged (unmodified) during malting and cause problems during brewing. Relatively low temperatures are used for steeping (15°C to 18°C) to encourage uniform water uptake.

Initially, water is taken up through the embryo. This tissue is hydrated rapidly and begins to respire within a few hours after the start of steeping. Oxygen is required for respiration, and so the kernels rapidly remove oxygen from the steep water. The oxygen must be replaced with bubbling air. This is done by removing the water during the air rest, which allows the kernels direct access to air. It is important that kernels are supplied with adequate levels of oxygen during steeping to maintain embryo metabolism, which promotes vigorous and uniform germination. At the end of steeping, kernels should be uniformly hydrated, have a moisture content of 40 to 46%, and show evidence of chitting (visible white tips of developing rootlets protruding from the base of the kernel).

As Canadian barley starts to germinate very rapidly after the initiation of steeping, the grain must have access to adequate levels of oxygen so that germination is not impaired. Care must be taken not to oversleep the grain or excess proteolysis may occur with a corresponding loss of malt quality. On the other hand, low out-of-steep moistures (40 to 42%) may reduce the effectiveness of β-Glucanases and lead to the production of malt having higher than desirable levels of β-Glucan.

Factors that determine the rate of water uptake include:

1. Barley cultivar
2. Kernel size
   - Small seeds hydrate more rapidly than large seeds.
3. Water temperature
   - Water uptake increases with temperature.
4. Growing environment
   - This affects endosperm structure. Starchy or floury kernels pick up water more rapidly than vitreous or steely kernels. Uniform water uptake by all kernels is essential for successful malting.
Germination

The hydrated barley kernels are maintained in a moist state and copious amounts of air are passed through the grain bed. A good flow of air (oxygen) is necessary to promote vigorous and uniform germination and to maintain the temperature of the germinating grain at appropriate levels (15° to 20°C). Further growth of the roots and development of the acrospire under the hull are physical signs of germination. Unseen, however, important changes are taking place inside the kernels.

Hormones, such as gibberellic acid, which are synthesized in the embryo, move out to the aleurone layer and trigger the synthesis of a wide range of catalytic enzymes in the aleurone cells. Many of these enzymes then move into the endosperm to break down endosperm components such as cell walls, protein and starch. Beta-Glucan degrading enzymes (β-Glucanases) are synthesized rapidly in aleurone and embryo tissues, and move through the endosperm breaking down β-Glucan. This destroys the endosperm cell walls. Cell walls in the distal tip region of the endosperm are the last to be attacked by the β-Glucanases. Figure 3 shows barley endosperm before and after germination, illustrating the complete breakdown of endosperm cell walls.

Some protein-degrading enzymes (proteases) are present in mature kernels; however, the levels increase significantly (mainly in the aleurone layer) during germination because of synthesis. A smaller increase comes from the embryo. These enzymes must move through the endosperm, solubilizing the protein and breaking up the protein matrix to release the starch granules. Distal tip proteins are the last to be modified in this way. Only 20 to 25% of barley proteins are soluble in water. This level must be raised to 40 to 42% during malting. Raising the level ensures adequate destruction of the protein matrix, reduces the potential for protein-induced hazes in beer, provides peptides and amino acids for appropriate colour formation in wort, and provides amino acids for yeast nutrition during brewing. Excessive protein degradation leads to undesirably high wort colour and poor foam stability in beer. Therefore, protein degradation, or modification, must be carefully controlled during malting. This is why the proportion of malt protein that is soluble in water is an important malt quality factor.

The combined effect of β-Glucanases and proteases is destruction or modification of the endosperm structure. Various tests are carried out on malt to measure this parameter. These tests include: hot water extract, fine and coarse extract difference, friability and Kolbach Index.

As the germinating barley kernel requires energy to maintain growth, it must utilize its energy reserves—the insoluble starch granules. Aleurone cells and, to a lesser extent, the embryo, synthesize α-Amylase, a major starch-degrading enzyme. This enzyme is primarily responsible for the degradation and solubilization of starch granules during malting and for the rapid degradation of solubilized starch to starch dextrins during the brewing process.

Figure 3. TOP: Barley endosperm showing β-Glucan deposits in the cell walls. BOTTOM: Malt endosperm showing disappearance of β-Glucan in the cell walls.
Alpha-Amylase alone cannot reduce all the starch products to the small sugars, glucose and maltose that are required by the embryo during malting and the brewers’ yeast during brewing. Other enzymes are required for this, the most important being β-Amylase. This enzyme exists in the endosperm of mature barley in two forms – the free (or soluble) β-Amylase, and the bound (or insoluble) β-Amylase. During germination, the bound form is converted to free β-Amylase. After three days of germination, all the β-Amylase is in the free form. Beta-Amylase does not attack whole intact starch granules, rather, it rapidly hydrolyzes a high proportion of solubilized starch and starch dextrins to maltose.

As starch is the major component of malt extract, its utilization during malting must be minimized. Therefore, although high levels of α-Amylase are required in malt so that starch degradation during the brewing process is rapid, the action of this enzyme during malting should be limited. The art of the maltster is to encourage rapid synthesis of the enzyme during malting but limit its action on the starch granules. High quality malt will contain large amounts of both amylases. Malt diastatic power (DP) is a measure of β-Amylase. A more specific method is often used to measure α-Amylase.

Canadian barley germinates rapidly and produces high levels of enzymes. Germination temperatures must be controlled and kept relatively low to prevent excessive protein breakdown. Typically, germination temperatures will start at about 18°C to promote rapid enzyme development and endosperm modification. Temperatures are then lowered to about 14°C to control protein breakdown without restricting hydrolysis of β-Glucan. Controlling the extent of protein breakdown reduces the formation of soluble proteins and reduces the risk of excessive colour formation in the resulting malt.

When the maltster determines that endosperm modification has been completed and that adequate levels of α-Amylase have been formed, germination must be terminated before starch is degraded and malting losses become unacceptably high. This is accomplished through kilning.

**Kilning**

Dry air of increasing temperature is passed through the green malt to reduce its moisture content. The enzymes that have been developed so carefully during germination are sensitive to high temperatures when the malt’s moisture content is high. Therefore, the moisture content of the green malt should be lowered with warm rather than hot air during the initial stages of kilning. Developing an appropriate kilning regime is complex and the regime chosen depends on the type of malt required. Usually, the air temperature is raised from about 30°C initially to a final temperature of about 80°C over a period of 24 to 30 hours. Malt enzymes are more stable at high temperatures when the moisture content of the malt is low. Under low moisture and high temperature (70°C to 80°C) conditions, complex chemical reactions take place between products of starch degradation (sugars and dextrins) and protein degradation (peptides and amino acids), forming compounds that provide colour and aroma to the malt.

Kilning ultimately stops biological activity in the malt. As the moisture content of the malt decreases, enzymic activity slows down and eventually stops. Finished malt at a moisture content of 4 to 5% is a stable product and not subject to bacterial or fungal spoilage. It is crisp, slightly sweet, has a pleasant flavour and aroma, is darker in colour than the initial barley and readily cracks open with light milling.

Canadian barley has the potential to germinate and modify rapidly and produce high levels of hydrolytic enzymes. Even though some enzyme activity is inadvertently lost during kilning, the final malt still contains more than adequate enzyme levels. These high enzyme levels coupled with good soluble protein levels make Canadian malt ideal for brewing with starch adjuncts. Canadian malt can also be used successfully in all-malt brews or when syrups are used as adjuncts.