1. RAW MATERIALS FOR BEER PRODUCTION

Beer is a weak alcoholic beverage that has been produced for centuries from malted grain, water, and hops with the help of microorganisms – principally brewer's yeast but occasionally other yeast and bacteria. Malt is produced by germinating and drying cereal grains under carefully controlled conditions. In many countries, sugars and adjuncts containing starch are employed as alternatives to malt, particularly during periods of economic hardship, such as in wartime and during the period that follows. Adjuncts continue to be used today because they are less expensive to produce than malt.

1.1 BREWER'S MALT

1.1.1 Historical development

In the past, malt was prepared from a variety of cereals. Aside from water, barley (*Hordeum vulgare* L.) is the primary raw material used in beer production, at least in traditional brewing countries. It is also one of the oldest cultivated crops and is thought to have been utilized for malt preparation for the past several thousand years. The first botanical description of barley *(Hordeum sativum,* Poaceae*)* was made in 1753 by Carl von Linné in his work *Species Plantarum* [Bothmer and Jacobsen 1985]. The botanical classification of barley has not been completely standardized, and according to the *Code of Nomenclature for Cultivated Plants* [Brickell et al., 2009], it is divided into a number of categories, including subspecies (ssp.), convarietas (conv.), varietas (var.) and forma (f.).

In prehistoric times, malt was prepared from both six-rowed and four-rowed barleys (*Hordeum vulgare* L., convar. *vulgare* L., f. *hexastichon* and f. *tetrastichon*). In Europe during the Middle Ages, species of six-rowed and two-rowed (*Hordeum vulgare* L., convar. *distichon* (L.) Alef.) barleys were preferred for malting. Today, two-rowed nodding barley (*Hordeum vulgare* L., convar. *distichon* (L.) Alef., var. *nutans* Alef.) is the most commonly cultivated malting barley across Europe, including in Bohemia, Moravia, and Silesia. It replaced erect-eared barley (*Hordeum vulgare* L., convar. *distichon* (L.) Alef., var. *erectum* (Rode) Alef.) and the less common peacock's barley (*Hordeum vulgare* L., convar. *distichon, var. breve* Alef. *(zeocriton* L.) (Figure 1.1). Malting barley varieties grown in what is now the Czech Republic and in other regions of Europe as well as in some countries overseas, can be traced back to the cultivation of this crop in Haná (Moravia) in the 11th century.

Figure 1.1 Six-rowed and two-rowed barley ears (http://vfu-www.vfu.cz/)

Wheat (*Triticum aestivum* L.) was the primary grain used for malt production in Europe until the end of the 18th century (including in the region of today's Czech Republic). Top-fermented beers (white beers) were prepared from wheat malts. Beer produced using barley malt was less common, though a few quality beers were brewed with it at that time. They were known as Märzen (March) beers because they were only brewed during the winter months. Even oats (*Avena sativa*, L.) were utilized in the production of specialty beers, but this practice disappeared from our area during the 17th century. Thanks to the Czech brewing revolutionary, František Ondřej Poupě (1753-1805), who coined the phrase "wheat for cakes, oats for horses, barley for beer", malt has been produced in Bohemia almost exclusively from barley since the 18th century, though it can be made using other cereals. The production of wheat malt, and likewise top-fermented beers began to decline, while the production of bottom-fermented beers grew.

Originally, each brewery produced its own malt. Raw barley was the only commodity that was sold and exported. Malt production took a significant step forward in the middle of the 19th century during the Industrial Revolution with the advent of so-called industrial breweries. Separate commercial malthouses were built, and started selling malt to domestic breweries. These malthouses flourished, and not long afterwards, their malt was also exported to breweries around the globe. Malt production thus became a new branch of the brewing industry [Chodounský 1891; Basařová and Hlaváček 1999].

1.1.2 Specific types of malt

Distinctive malt types exhibiting unique characteristics are created by adjusting the processes of steeping and germination during malting. The biosynthesis and activity of malt enzymes is regulated over the course of these processes. Malt enzymes act on specific substances in the kernel and define the degree of degradation of the high molecular weight compounds, as well as the redox potential and acidity of malt. The degree to which the formation of color and aromatic compounds occurs can be regulated by adjusting the malt kilning process. To ensure reproducibility in beer production and the quality of the final product, it is important to use malt lots prepared from only one or at most two genetically similar barley varieties.

Worldwide, pilsner malts and Munich malts are the predominant malt types used for the production of pale and dark beers, respectively. Other types of specialty malt are utilized to highlight certain characteristics of both pale and dark beers and likewise to create a range of distinctive products (Figure 1.2).

Figure 1.2 Kernels of various malts
(Archive of the malthouse Soufflet, a. s., Prostějov, part of The Soufflet Group)

a – Czech pilsner b – pale caramel c – caramel pilsen d – chocolate

Spring barley malts are the most common malts used in beer production. The attributes of specific barley varieties significantly affect the quality of the malt and the beer produced with them, thereby creating some of the unique characteristics of individual brands. A large number of spring and winter malting barley varieties are cultivated around the world. The cultivation of a given variety gradually increases following its registration and approval. Barley varieties lose specific genetic traits (yield, disease resistance, propensity for germination, specific chemical composition, etc.) after a few years of cultivation. As a result, they are sown with less frequency and are ultimately not grown at all. The cultivation of newly developed varieties expands in the meantime, and the cycle repeats itself. An overview of current malting barley varieties is given in Table 1.1.

Table 1.1 Malting varieties of spring barley: those that are recommended, tentatively recommended, and have been recently added in the Czech Republic [Ječmenářská ročenka 2008]

	Variety name	Registration year	Location of keeper (agent)
Recommended varieties	Bojos	2005	CZ
	Bolina	2004	DE (CZ)
	Calgary	2003	CZ
	Diplom	2002	DE (CZ)
	Heris	1998	CZ
	Jersey	2000	NL (CZ)
	Malz	2002	CZ
	Orthega	1999	DE (CZ)
	Prestige	2002	FR (CZ)
	Pribina	2005	SK (CZ)
	Radegast	2005	CZ
	Sebastian	2005	DK (CZ)
	Tolar	1997	CZ
Tentatively recommended varieties	Braemar	2006	GB (CZ)
	Tocada	2006	DE (CZ)
	Xanadu	2006	DE (CZ)
	Class	2005	DE (CZ)
	Faustina	2003	FR (CZ)
	Kompakt	1995	SK (CZ)
	Nitran	2004	SK (CZ)
	Respekt	2003	CZ
	Saloon	2002	GB (CZ)
Recently added varieties	Aksamit	2007	CZ
	Beatrix	2007	DE (CZ)
	Blaník	2007	NL (CZ)
	Poet	2007	DE (CZ)
	Spilka	2007	DE (CZ)
	Westminster	2007	GB (CZ)

Winter barley malt can give rise to technical problems in the brewing process [Shuhberg et al., 1997]. As a result, in Central Europe, winter barley varieties serve only as an alternative malting barley or to compensate for poor harvests of spring barley. However, two-rowed winter varieties are often used by ale brewers in the UK as well as by craft brewers. Even malt consisting of a number of spring barley varieties with different characteristics can cause irregularities in the production process and in the quality of the finished beer. For assessing the purity of a given barley variety or lot of malt, biological and physico-chemical analysis methods are available [Analytica-EBC]. Genetic methods can also be employed [Shuhberg et al., 1997], even modern identification of barley varieties using microsatellite DNA polymorphism [Sakamoto et al., 2001].

In the mid-19th century, K. N. J. Balling (1805-1868) worked as a professor at Prague Polytechnic, established in 1715. This institution is now known as the Czech Technical University in Prague. Brewing has been taught at the University of Chemistry and Technology in Prague since 1952. Professor Balling developed a basis for systematically and objectively evaluating the quality of malt. He proposed a simple mashing test, a procedure that was later expanded. The method was standardized, agreed upon on at an international level, and became known as the conventional or Congress mash method for comparing malt. This laboratory method is based on infusion mashing and provides results that differ from those obtained during industrial scale malt processing, particularly when decoction mashing is employed. Nevertheless, the behavior of malts in industrial operations can be deduced from the results of the Congress mash method [Basařová and Čepička 1985]. Further analysis (mechanical, physical, and chemical) is necessary for comprehensively assessing the quality of a lot of malt. The results must also be verified with experimental industrial-scale trials.

As our understanding improves regarding the extent to which individual extract components affect beer quality and the production process, the number of quantifiable parameters also increases. The specifications needed to achieve certain qualitative properties (including the unique characteristics of individual beer brands) become narrower. Malt is the raw material that contributes the major portion of extractable substances to the beer production process. Together with wort boiling technologies, it defines the redox capacity of beer. Beer redox capacity plays an important positive role in achieving beer sensory stability and desired resistance to non-biological haze formation.

1.1.2.1 Pilsner malt

Pilsner malt is used for the production of pale lagers, small and specialty beers by altering the original gravity of the hopped wort. Among its typical attributes are low values for malt color (3.0 to 4.2 EBC) [Basařová 1992, 1993]. The values for the color of the wort after boiling are also low. A light color is achieved through a suitable degree of proteolytic modification and curing temperatures of 80 to 85 °C. The resulting formation of color and aromatic compounds is optimal for this type of malt. Pilsner malt possesses sufficient amylolytic enzyme activity to ensure complete and rapid saccharification during mashing. The cytolytic activity, which occurs during malting, leads to the continued degradation of viscous non-starch polysaccharides. Ample proteolytic activity optimizes the composition of the nitrogenous compounds found in the malt.

The varietal purity and the attributes of a given lot of barley are two very important predictors of the quality of malt produced in modern large-scale facilities. Suitable values for homogeneity and the degree of modification are likewise essential. Today, a great deal of emphasis is placed on malt quality to ensure optimal process trajectory and that the fundamental analytical and sensory qualities are adequate in the finished beer. Malt quality also plays a role in the natural physico-chemical stability of beer. Natural beer stability is determined by the pH, redox potential and the composition of the nitrogenous compounds, polyphenols, polysaccharides, fatty acids, etc., in the finished beer. These factors should be optimal, because they also play an important role in the successful application and dosing of stabilizers, which are used to achieve colloidal stability (clarity). Once stabilized, beer should possess a shelf life of several months. The concentration of

oxidizable fatty acids in raw materials (barley and malt) increases during storage. This negatively impacts the stability of beer flavor but can be corrected through the action of the yeast. This is another reason to ensure that conditions are favorable for fermentation [Wackerbauer et al., 2003].

The value for the color of Vienna malt is approximately double that of pilsner malt; therefore, its color lies between that of pale and dark malt and has been used to increase the color of pale beer. The current demand for Vienna malt is minimal. Its usage is now most often limited to the production of certain specialty beers.

1.1.2.2 Munich malt

Munich malt is a primary ingredient of many dark beers and is often referred to as 'Bavarian malt'. It typically possesses a high value for color according to the Congress Methods of Analysis (11.0 to 17.3 EBC), a higher protein content, distinct aromas, a lower extractability and lower malt enzyme activity. Most notably, they contain a wider spectrum and higher concentrations of products from the Maillard reactions (particularly heterocyclic compounds). These are produced in vigorous modification during germination and higher thermal stress during kilning with curing temperatures reaching 100 to 105 °C.

1.1.2.3 Wheat malt

Malt made from wheat (*Triticum aestivum*, L.) is employed in the production of wheat beers and a number of other beer styles. Wheat malt comprises 50 to 80% of the grain bill of Southern German-style wheat beers. In Belgium, beers brewed from grain bills containing 60% barley malt and 40% unmalted wheat are common [Heisel 2006]. Wheat malt imparts distinctive flavors to beer and generally increases head retention. Adding a small amount of wheat malt to the grist can be beneficial for beers brewed with barley malt exhibiting poor foam stability.

Wheat malt is produced in a manner similar to barley malt; however, germination is generally shorter in duration, and the kilning temperatures are not as high [Moll 1994; Narziss 1985].

1.1.2.4 Specialty malt

Various types of specialty malt are used in the production of dark beers and various other beer styles, in order to impart distinctive characteristics to the sweet wort created using more conventionally malted grain. Specialty malt is also utilized together with adjuncts and differs from conventional pale and dark malts in their enzymatic activity, redox capacity, acidity, color, etc. They are added to conventional malts to alter beer color, flavor, and foaming and to increase resistance to premature formation of colloidal haze (among other factors).

Specialty malt products include:
- caramel malt
- coloring malt
- smoked malt
- melanoidin malt
- diastatic malt
- proteolytic malt (sour malt)
- malt for increasing the redox capacity of beer

Caramel malt typically possesses relatively large amounts of aromatic and color compounds. This type of malt is produced by roasting well-modified green malt or moist pale malt in special drums at temperatures reaching 120 to 180 °C. The temperature depends upon the type of caramel malt being produced. They have a moisture

content of 5 to 7% and are extremely hygroscopic. Allowing these malts to rest for 2 to 4 weeks will result in the development of a more pleasant aroma in the beers produced with them. This aroma is highly dependent on their amount of nitrogenous heterocyclic compounds in the malt. This can vary even among malts of the same color and imparts a different aroma to the finished beer [Herrent et al., 1997].

After roasting, the grain endosperm is glassy and translucent. The colloidal compounds generated during malting can have a positive influence on head retention. Depending on the intensity of the roasting process, caramel malts exhibit either minimal enzyme activity or none at all. It is for this reason that caramel malts (particularly the darker types) are incapable of inducing saccharification when used exclusively. They are added to the grain bill in quantities of 4 to 8%. For the production of dark beer, they can be added to the mash itself or even further downstream in the brewing process after mashing is complete, prior to pumping the mash into the lauter tun. Caramel malt kernels are less friable compared to normal malt and separate milling is recommended.

Caramel malts are subdivided into several categories according to the intensity of the roasting process. Different criteria are used to categorize them and describe their attributes. For example, the classification of caramel malt according to its color has not been completely consistent among prominent authors:

- light caramel with a color of 4 to 8 EBC and dark caramel with a color of up to 130 EBC [Narziss 1976, 1985]
- very light caramel with a color of 4 to 6 EBC, light caramel (caramel pilsen) with a color of 50 to 70 EBC, and dark caramel with a color of 100 to 120 EBC [Moll 1994]
- caramel pilsner with a color of 4.0 to 7.0 EBC, light caramel with a color of 50 to 70 EBC, and dark caramel with a color of 100 to 130 EBC [Krüger and Anger 1990].

Basařová and Čepička [Basařová and Čepička 1985] divide caramel malts into four groups:

A. Light caramel malt (caramel pilsen) is mildly roasted at a temperature of 120 °C. The husks and endosperm are light in color. The color of the unhopped wort ranges from 3.5 to 6.0 EBC; the flavor is sweet and full-bodied, but the aroma is indistinct. At least 70% of the dry matter consists of extract, and this malt can be utilized to improve the head retention, redox capacity, and flavor of pale beers.

B. Medium caramel malt is roasted at temperatures between 130 and 150 °C and exhibits a color of 20 to 40 EBC. A cross section reveals the endosperm to be vitreous and yellow to brown in color, while the husks are dark. The malt has an aroma of pure caramel and is sweet in flavor.

C. Normal caramel malt is the most common type of caramel malt. It is roasted at temperatures between 150 and 170 °C. The endosperm is vitreous and is yellow to reddish in color. The husks possess a light to dark brownish hue and are darker at the tips. The color of the malt is 50 to 70 EBC. At least 75% of dry matter consists of extract.

D. Caramel porter malt is used in the production of dark beers. It is roasted at a temperature of 180 °C. The endosperm is dark red to black in color and vitreous. Sweet wort has a strong caramel and some what bitter flavor. It is aromatic with a color value of 100 to 120 EBC.

Coloring malts are used in the production of very dark beers, especially when the desired color cannot be achieved with dark Munich malt. Coloring malts are prepared from finished malts, which have afterwards been moistened and roasted at steadily rising temperatures, which can reach 225 °C. This technique guarantees a high level of melanoidin formation and a gradual degradation of the starch. This method is employed to produce dextrin malt, caramel malt, and black patent malt. The malt can be moistened after roasting to reduce the bitterness.

The endosperm of coloring malt has a chocolate-brown hue. Owing to the high roasting temperatures, coloring malts have distinctly different physico-chemical, physiological, and dietetic properties. The malts must be allowed to rest for at least two weeks prior to use, in order to remove some of the harsh, bitter flavor. They are added to the decoction mash in a single decoction mashing process or to the second decoction in a double or triple decoction mashing process.

Chocolate malt is a special member of this group of malt. Typically, it is dark brown in color, and its organoleptic properties are described as dry, astringent, and sour.

Smoked malt is produced for Scotch whiskey production from barley, which is smoked over peat during kilning. Its aroma is characterized by phenolic compounds capable of being liberated through evaporation during boiling.

Melanoidin malt is used in the production of darker beers. Unlike caramel malts, the dark color as well as the characteristic flavor and aroma of this malt are the result of more intense Maillard reactions. The Maillard products in this malt are created without greatly increasing the kilning temperatures. Melanoidin malts possess a pure malty aroma and flavor without the bitter overtones typical of other specialty malt, such as coloring and caramel malts. At least 74% of the dry matter of this malt is extract, and the color is approximately 20 EBC.

Diastatic malt is used in processing malt weak in enzymatic activity. Diastatic malt can also be used to process adjuncts. Barley with a higher nitrogen content is used for the production of this malt. High diastatic power (at least around 300 Windisch-Kolbach units) is maintained by conducting germination at cool temperatures and careful kilning at approximately 50 °C. Diastatic malt is also used in the preparation of malt extract.

Proteolytic (sour) malt serves to adjust (increase) the acidity of the mash. It can be made from green malt by spraying lactic acid bacteria over the malt during the malting process. This creates a lactic acid content of 0.7 to 4% in the finished malt. The bacteria are subsequently destroyed during kilning. Proteolytic malt can also be made from finished malt. It can be added in quantities ranging from 2 to 10% of the grain bill. The acidity aids in improving the brewhouse yield, head retention, and the shelf life of the beer.

The process of producing malt intended to increase the redox capacity of beer is similar to that of melanoidin malt. Highly modified malts are cured at higher temperatures, in order to bring about strong reducing properties by increasing the products of the Maillard reactions and caramelization. They are said to delay the onset of beer staling during storage and improve the biological stability of beer.

In conclusion, there are a number of other specialty malts worthy of mention that can be produced from cereals other than barley (see Chapter 1.2 for additional information).

Chit malt does not affect the color of sweet wort, but it contains a greater number of high molecular weight compounds, which positively influence head retention and add body. Germination is very short, ranging from 48 - 72 h to 96 - 120 h [Narziss 1985]. It is more similar to adjuncts (unmalted cereals) and is therefore added to overmodified malts in quantities of 10 to 20% of the total grain bill. Malt flakes produced by means of similar processes exhibit comparable attributes.

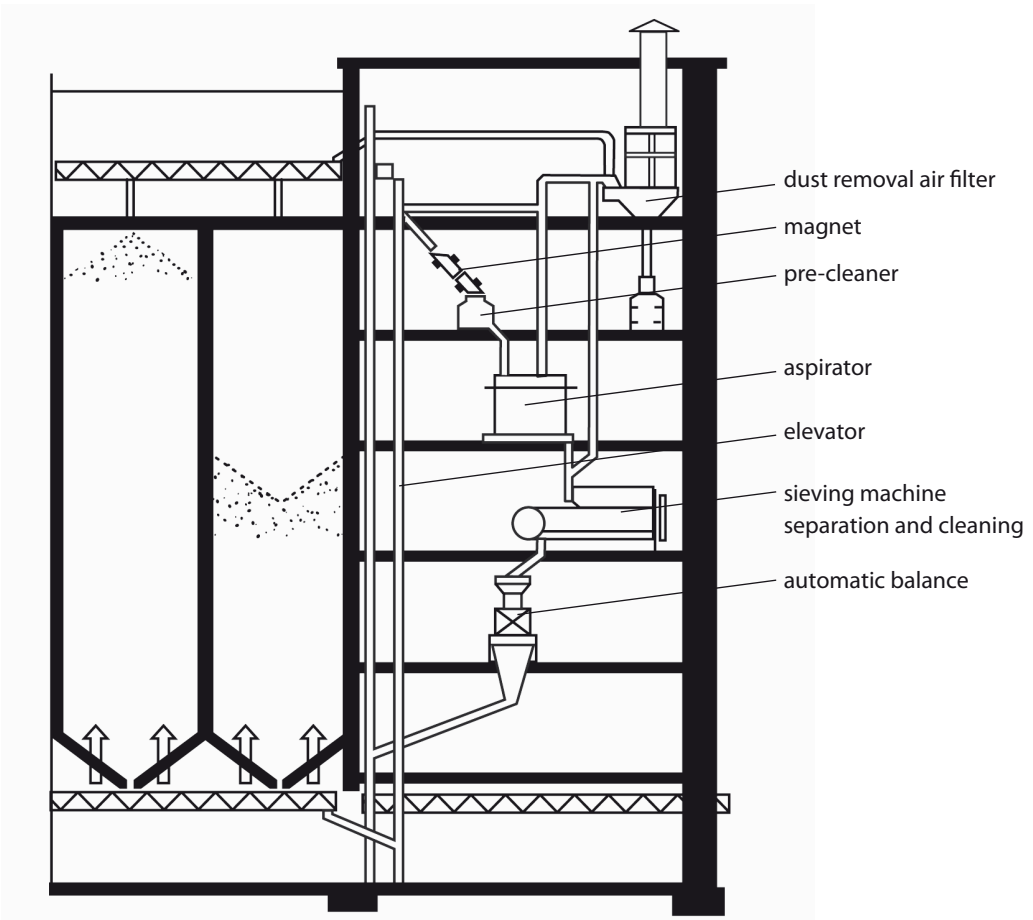
Malt can be produced from the hybrid cereal, triticale, which was bred through crossing rye (*Secale* ssp.) with wheat (*Triticum aestivum*, L.). Triticale malt contains more protein and is darker in color than conventional malt. A special malting process is required to ensure that the enzyme activity is optimal. This involves germination and kilning temperatures lower than those used in the production of conventional pale malt [Pomeranz et al., 1970].

Malt is created from sorghum (*Sorghum* Moench, L.) primarily in African countries, such as South Africa, Nigeria, etc. It is used to brew indigenous beverages like Kaffir beer. Maize (*Zea mays*, L.), rice (*Oryza sativa*, L.), oats (*Avena sativa*, L.), rye (*Secale cereale*, L.), millet (*Panicum miliaceum*, L.), and other cereals are not generally made into malt, and if so, only for the production of unconventional beers confined to narrow geographical areas [Moll 1994].

1.1.3 The effect of storage on the quality of malt

Freshly kilned malt is not suitable for immediate usage in a brewery. It is necessary to first allow this raw material to rest for three to four weeks. Cleaned malt is stored in lofts, bins, or silos (Figure 1.3). Silos are the most common storage receptacles for malt today. Silos often have automatic temperature and humidity controls, and the malt can be mixed within the silo as well.

Figure 1.3 Schematic diagram of a malt and barley storage silo with a cleaning station [Basařová and Čepička 1985]



Significant structural and enzymatic changes occur in the barley kernels during germination and kilning [Autio et al., 2001]. Other, less intense, changes in the physical and chemical properties of malt take place during storage, which improve the malt's attributes as a raw material for brewing [Narziss 1976; Rennie and Ball 1979]. The moisture content rises slightly (by approximately 1.6 to 1.8%) due to hydration of the

kernels. This increases the volumetric weight and improves husk elasticity, both important criteria in malting. The fine-coarse grind difference in extract and the activity of important malt enzymes (particularly proteolytic ones) also increase. Raising the moisture content excessively can cause problems during milling, and the stored malt must therefore be protected from moist air. The aroma of dark malt changes slightly after storage periods longer than three months. Storing raw materials under inappropriate conditions can significantly reduce their quality. For instance, Strecker aldehydes can form, adversely affecting sensory characteristics (especially flavor stability) [Methner et al., 2003].

1.1.4 The attributes of malt affecting quality

A large number of mechanical, physical, chemical, and biochemical properties are assessed when the quality of malt is evaluated. These properties are good indicators of a malt lot's processability, and they provide information concerning the fundamental characteristics of standard beer styles and some specifics regarding brands of specialty beer. Malt quality is a function of barley variety, the parameters of the malting process, and storage conditions. It influences the trajectory of the brewing process as well as the basic physico-chemical, biochemical, and organoleptic properties of the finished beer. It also influences the colloidal and flavor stability of beer, as well as beer redox potential. A sufficient redox potential reduces the impact of undesirable oxidative processes on the beer during production and storage [Waesberghe 2001; Back 2002; Urban 2002].

Methods available for malt quality control are constantly expanding. The basic range of quality control methods can be found in many specialized publications such as the regularly supplemented Analytica-EBC, Analytica ASBC, MEBAK, etc.

1.1.5 The mechanical and physical attributes of malt

Mechanical and physical properties of a given batch of malt significantly affect its processability, the optimal utilization of its extract, and the trajectory of the beer production process.

1.1.5.1 Hectoliter (volumetric) weight and thousand kernel weight

Volumetric weight (hectoliter weight) is a measure of the mass of one hectoliter of barley or malt. The measurement is performed using a special volumetric balance with a container size of one-quarter liter or one liter and is measured in kilograms [Basařová a kol 1992]. The volumetric weight of malt depends on the size, shape, and mass of the kernels. Barley kernels are composed predominantly of starch, and barley rich in starch has a higher volumetric weight. This characteristic is a good indicator of the suitability of a given lot of barley for malting. The degree of malt modification can be roughly estimated from the difference between the volumetric weight of barley (72 to 74 kg on average) and that of malt (54 to 60 kg for pale malts and 52 to 55 kg for dark malts). The greater the difference, the more extensive the degradation of the high molecular weight compounds (non-starch polysaccharides and proteins) in the grain during malting. This degradation makes starch in the endosperm accessible to malt enzymes that break it down during mashing (see Chapter 2).

Thousand kernel weight is a function of the shape and density of the kernels. It is given in grams of dry matter and ranges from 38 to 42 g of dry matter for barley and 30 to 38 g of dry matter for malt [Psota and Vejražka 2006]. As the average thousand kernel weight of the malt decreases, the better modified the malt is, and the higher the rate of fermentation - at least within certain limits.

1.1.5.2 Floating test

Density is also a measure of the degree of modification of malted grain. The structures comprising the endosperm are more highly modified in friable grains and therefore are less dense [MEBAK 2002].

1.1.5.3 Mealiness and glassiness

The mealiness or, conversely, the glassiness of a malt kernel characterizes the properties of the endosperm. It corresponds to the degree of modification (particularly concerning the proteins and starch). It describes the textural properties of endosperm, which change as a result of enzymatic degradation during malting. Mealiness depends primarily on the genetic traits of the barley variety used for malt production. Glassiness is heavily influenced by barley growing conditions, harvest, and post-harvest treatment. The mealiness of the malted grain can be assessed subjectively by cutting the grains transversely using either a Heinsdorf or Grobecker farinator or longitudinally using a Kickelhaym farinator. Malting barley high in protein produces less friable malt. This relationship is not entirely clear; however, malt with similar percentages of friable grains can be produced from barley varieties exhibiting different levels of nitrogenous compounds.

Mealiness can be assessed objectively by illuminating the grains with a diaphanoscope. Grains with mealy endosperms are more opaque and absorb more light than glassy grains. Modern instruments for measuring mealiness employ a laser beam for measuring the opacity of malt kernels and also evaluate the endosperm structure using electron microscopy [Wheaton et al., 2001]. Malt with a lower mealiness can lead to lower brewhouse yields and greater difficulty in carrying out brewhouse processes.

1.1.5.4 Determining the friability of malt

Malt friability relates to the degree of malt modification achieved during germination. Modification refers to the breakdown of starch granule walls, which consist predominantly of non-starch polysaccharides and a protein matrix. Well-modified grains are friable and easy to mill. A number of instruments have been developed to measure friability or, conversely, the hardness of malt. Older instruments relied on measuring the resistance of the kernel as it was cut with a knife mounted on a weighted lever arm with an adjustable load (a device according to Vítek; Vilikovský's device works on a similar principle). Chapon's instrument measures the hardness of the kernel using a dynamometer connected to a computer, which registers the force needed to perforate the grain with a needle [Psota and Vejražka 2006]. Today, malt friability (which provides information regarding the degree of malt modification) can be determined using a friabilimeter, a sclerometer or a murbimeter. The distribution of milled malt particles can also be evaluated using particle size analyzers.

Friability or malt fragility is determined using a friabilimeter under standard conditions. This device presses the malted grain against a sieve and afterwards the material that falls through the mesh is weighed. Friabilimeters return three values: malt friability, percentage of partially glassy grains, and percentage of completely glassy grains. The value of friability (expressed as a percentage) reflects the degree of malt modification. The percentage of completely glassy grains is a measure of the ungerminated kernels and of the so-called homogeneity or uniformity of malt modification [Baxter and O´Farell 1983]. Values of friability, homogeneity, and an overall assessment using a friabilimeter are given in Table 1.2 [Basařová a kol 1992].

Table 1.2 Assessment of malt friability with a friabilimeter

Friability (%)	Homogeneity (%)	Assessment
81-100	up to 1	very good, +++
71-80	up to 2	good, ++
65-70	up to 4	satisfactory, +