MALTS AND MALTING

1. Introduction

Malting is essentially the same process as occurs when seeds fall to the ground or are planted, are moistened by water (qv), and germinate. During germination, rootlets (sprouts) and a nascent stem (acrospire) emerge; simultaneously, enzymes are produced or activated and the cellular structure and composition are modified, resulting in a product that can be used as a substrate for fermented beverages and as a food adjunct. The terms malt and malting can apply to any germinated grain; however, nearly all commercial malting involves barley. Because the brewing process and finished beer characteristics are a function of malt properties, malting is considered to be a part of the brewing process. Brewers' malt is designed to provide fermentable carbohydrates, assimilable nitrogen, as well as precursors for beer flavor (see BEER AND BREWING). Malt enzymes convert added carbohydrate, eg, corn grits or rice, into fermentable sugars.

Approximately 95% of the malt produced is used to make beer while small amounts are used as distillers' and food malts. Distillers' malt, which is used to convert starch-containing grains into fermentable sugars, is prepared almost exclusively for its enzymes, especially α-amylase (see BEVERAGE SPIRITS, DISTILLED). Food malts are sold for their flavor and/or enzyme contribution to food products.

2. Manufacturing and Processing

2.1. Raw Materials.

Two principal types of malting-grade barley are in use, ie, six and two row. Six-row barley has six kernels around the stalk, whereas the two-row variety has two kernels. Six-row kernels tend to be twisted, and the two-row grade is more symmetrical. Figure 1 is an illustration of a barley kernel and its key components. As barley is converted into malt, the acrospire for the embryo lengthens until it reaches the far end of the kernel, and rootlets also grow as if the seed is germinating into a new plant. A discussion of the structure and composition of barley can be found in Ref. 1.

The predominant growing areas for six-row barley are North Dakota, eastern South Dakota, and western Minnesota (Table 1). Two row is produced in Idaho, Montana, Washington, Colorado, Wyoming, and California. Less than one-half of the barley grown in the United States is processed by the malt industry; the remainder is used as animal feed. Two-row usage by the malt industry has increased significantly in recent years, and now account for about one-half of the industry's needs (see FEEDS AND FEED ADDITIVES, PET FOODS).

Barley varieties recommended by the American Malting Barley Association, Inc. (Milwaukee, Wisconsin) are used for producing brewers' malt. Anheuser-Busch supplements these varieties with some of their own malting barley varieties, whereas Adolph Coors primarily uses their own barley varieties (Moravian 14 and 37). The main malting-grade varieties for two-row barley are Harrington, Moravian 14 and 37, Conlon, Metcalfe, and B1202 and, for six-row barley, Robust, Lacey, Legacy, and Drummond (2). These varieties are purchased by maltsters based on kernel appearance, germination ability, and protein content. Kernels should be plump and uniform in size and free from mold or staining. At least 95% of the kernels must germinate. Historically, barley has been selected for low protein content and, implicit in the low protein content, high extract.

Most of the malting barleys in the world (Table 2) are two-row varieties; these are characterized by larger berries, lower protein content, lower enzyme activity, and higher extract than the predominant six-row varieties used in the United States. Six-row varieties, however, are well suited to the lighter beer styles that dominate the American marketplace.

Barley subjected to wet harvest conditions should be dried prior to storage. Too much moisture at harvest might result in unacceptable kernel staining, mycotoxin contamination, and poor storage stability. There is also the possibility that excess humidity from rains or heavy dews will initiate germination while the barley remains in the field. Barley that has pregerminated is unfit for the malting process.

2.2. Processing. The malting process consists of three basic steps: steeping, germination, and kilning (Fig. 2). Prior to steeping, barley is cleaned and then sized according to kernel width. After kilning, the malt is cleaned, stored, and blended with other malt to meet customer specifications. A typical material balance for the malting process, based on raw barley solids, is shown in Table 3.

2.3. Cleaning and Grading. Prior to malting, raw barley must be cleaned to remove tramp metal, dirt, debris, and other cereal grains, and be graded through slotted screens to produce a uniformly sized product. The grain first is passed over a magnet to remove metal, and then is aspirated to remove chaff, dust, and other light materials. Next, the grain is passed over slotted screens that retain corn and large seeds, whereas barley and smaller seeds pass through and are separated on another slotted screen. Finally, the very thin barley kernels (needles) are separated from the barley by aspiration.

United States barley grades are determined according to kernel width, eg, A>2.48 mm, 2.18 mm<B <2.48 mm, 1.98 mm<C <2.18 mm, 1.93 mm<D <1.98 mm, and throughs <1.93 mm. Grades A and B produce the highest extract and are used for brewers' malt. Because different size kernels absorb moisture at different rates, it is desirable to process uniform kernel sizes to improve product uniformity and quality. Smaller kernels have higher protein content and are malted primarily for high enzymatic activity to meet distillers' malt specifications or to be blended with other brewers' malt. Normally, throughs are not malted, but are sold with the clean-out grain. About 90% of the incoming grain is malted and the remainder is sold as animal feed.

2.4. Steeping. In steeping, cleaned, graded barley from storage is immersed in water, resulting in a rise in the moisture content to 41–45% and initiation of growth. A diagram of a typical cylindroconical steep tank is shown in Fig. 3. The size of steep tanks varies in the United States, with the smallest tanks holding $<$ 6 metric tons of barley and the largest tanks holding $>$ 40 t. The tank shown in Fig. 3 holds 26 t of barley. Most tanks are fitted with a 45° conical bottom to allow the barley to flow freely from the tank. Steep tanks normally are equipped with overflow chambers that allow floating kernels, chaff, dust, and miscellaneous material to be skimmed and floated out of the tank during an immersion, ie, a water change. The bottom conical section also will be fitted with external air rings so that the barley can be supplied with oxygen via compressed air during immersions. The objective of the aeration during immersions is to maintain a dissolved oxygen of 5–8 ppm. Compressed air also is used to provide mixing (rolling) during immersions, either via the aeration rings or an air line located at the bottom of the tank. During couches (periods during which tanks are drained and aerated), ventilation of the grain is achieved by drawing fresh air through the grain and exhausting the CO_2-rich air.

The industry has, however, started to move away from cylindroconical tanks. The majority of the new capacity in the industry utilizes large flat-bottom steeps. These vessels can steep batches in excess of 400 t of cleaned barley. Grain depth in these vessels is considerably shallower ($\sim$2 m). In this situation airflow is increased, is applied more evenly, and achieves more uniform attemperation. As a result, the grain leaves the vessel with more even hydration and at a more consistent level of germination.

Steeping was historically a long continuous process characterized by a single immersion. This was followed by a process of several shorter immersions with dry periods in between. During the 1970s, a process called spray steeping was implemented, in which the initial immersion is followed by intermittent spraying to hydrate the kernel. Although water usage and effluent volume are reduced in this method, this technology has not achieved significant use, as levels of modification tend to be lower and more variable as compared to conventional steeping.

The choice of steeping procedures depends on equipment limitations, process or product specifications, and company tradition. Typical values and ranges for key steeping parameters, regardless of process, are shown in Table 4.

After steeping, barley is either transferred with water by gravity pumping or dry transferred by gravity or conveyors to germination compartments. Although still practiced by some United States maltsters, the wet-transfer process inhibits barley respiration, resulting in a substantial increase in germination time (4).

2.5. Germination. A diagram of a typical germination compartment is shown in Fig. 4. Whereas water is used to control temperature during steeping, preconditioned air is used to control temperature during germination. Air is saturated with water and pulled or pushed down or up through the germinating bed. During summer, the spray water used to saturate germination air may be refrigerated. Depending on ambient conditions, up to 30% germination air may be recycled to conserve energy. The germination fans are designed to deliver 7–12-m^3 air/min/t barley. The grain is turned every 8–12 h to minimize temperature differences between the top and bottom of the germination bed and to prevent the roots from matting together. A watering device is mounted on the turner and is used to increase or control green malt moisture content. Capacities of germination compartments vary between 20 and 420 t. Typically, germination beds are 0.75–1.0-m deep.

Process parameters that are controlled during germination are included in Table 5. In general, lower temperature and moisture contents correspond to longer germination time and vice versa.

2.6. Kilning. Following germination, green malt is dried in a kiln until the moisture content is reduced to 4–6% (5). This allows for the malt to be stored safely and stabilizes the enzymes produced during the first two stages of the malting process. It is important to note that the malt kernel is still alive at the end of the kilning process. Important flavor- and color-producing reactions that are catalyzed by heat occur in addition to the cessation of growth and enzymatic processes. Kilning is a batch process; the kilns are single-, double-, or triple-bed compartments and hot air is circulated through each compartment to remove moisture from the green malt. A typical double-deck kiln is illustrated in Fig. 5. A number of U.S. maltsters also have fleximalt compartments, which are equipped for germination and kilning in the same compartment. More recently, tower malting facilities with circular kilns have been built (6).

In double-deck kilns, green malt is dried on the upper deck to 10–20% moisture with influent air temperature of 40–60°C during the first half of the cycle. The malt is then dropped to the lower deck and is dried at higher air temperature, eg, 60–85°C, to 4% moisture for brewers malt. Low temperatures, ie, 60°C, are used during the first portion of the kilning cycle while the green malt moisture is high in order to minimize color formation and thermal degradation of enzymes. Distillers' malts are dried at low temperature (60°C or less) to preserve maximum enzyme content; final moisture content is 6%.

To reduce drying time, maximum airflows are used during the first portion of the kilning cycle until the exhaust air is no longer saturated with moisture. Airflow then is reduced or recirculated to conserve energy. Fuel consumption for kilns in the United States ranges between 25 and 35 therms/t, with an industry average of 30 therms/t.

2.7. Storage, Blending, and Shipping. After kilning, malt is cleaned to remove sprouts and loose hulls; it is then stored in bins according to variety and malt analytical properties. Prior to shipping, malts from several bins are blended to satisfy customer specifications. Most of the malt is shipped in railroad hopper cars; small quantities are trucked to local customers and smaller breweries. Midwestern malt is sometimes barged to the Gulf Coast for export markets.

3. New Technology

3.1. Barley Breeding. The barley breeding programs involve conventional cross-breeding techniques and have resulted in barley varieties of better yield, disease resistance, and malt quality. In recent years, traditional breeding programs have begun to extensively utilize genetic engineering tools to improve the efficacy of their programs; the scope of this research has been limited, as the malting and brewing industries have not demonstrated an interest in the development of transgenic barley varieties. Traits such as disease and pesticide resistance and optimizing enzymatic properties are the early targets of genetic engineering efforts.

One example of improving malting quality through the use of mutagenic techniques is the development of experimental proanthocyanidin-free varieties, which can yield beer that is colloidally stable and thus does not require stabilization in the brewery (7–11). This technique shows promise of developing other important quality characteristics, eg, reduction of the β-glucan content of barley, which causes malting modification and beer filtration problems (12).

3.2. Processing. Another advance concerns increased understanding of the role of the natural plant hormone Gibberellic acid in the malt modification process (12–15). It occurs naturally in barley at 20–150 ppb, and is obligatory for the *de novo* synthesis of α-amylase. When small amounts are added, eg, 0.01–1 ppm dry barley basis α-amylase content can be increased by at least 50% (16,17). The use of Gibberellic acid is not common for the manufacture of brewers' malt, and is generally restricted to the production of very high enzyme malts for distilling.

N-Nitrosamines are carcinogenic by-products of the reaction between certain amino acids in the fully germinated barley and nitrogen oxides. Nitrogen oxides are combustion gases, and the introduction of indirect heating of kiln air has significantly reduced the formation of *N*-nitrosamines in the malting process. The introduction of small amounts of sulfur dioxide during the early stages of kilning further inhibits the formation of *N*-nitrosamines.

Heat exchangers are now used routinely in the industry to recover the sensible heat content of water-saturated exit kiln air. When this sensible heat is transferred to the incoming fresh air fuel savings of ~30% are being achieved.

The amount of distillers' malt produced in the United States decreased substantially in the 1950s when the U.S. consumer switched to white goods (vodka and gin), which require less malt. A shift in the early 1970s to lighter and lower calorie beers has also decreased the United States demand for barley malt. However, brewers' malt still comprises >50% of the grain bill for beer production. Malt substitutes and alternative brewing technology have the potential to further lower brewers malt usage in favor of lower cost grain bills and processes, but no significant trends among large U.S. brewers to dramatically lower malt usage have been detected.

4. Economic Aspects

4.1. Malt Production and Producers. World and U.S. beer and malt production are shown in Tables 6 and 7. Because ~95% of malt manufactured is used to make beer, malt production follows trends in beer production. World brewers' malt and beer production in 2003 was ~12 million tons and 1.4 billion hectoliters, and was growing at 3%/year.

U.S. and Canadian maltsters are shown in Table 8, along with a range of estimated annual capacities. Since the 1970s, the number of malting companies in the United States has decreased due to mergers, acquisitions, and the closing of smaller malting companies and individual malthouses. U.S. brewers' production in 2003 was 210 million hectoliters (Table 9), but demand has been stagnant or decreasing since 1982. Distillers and food malts account for approximately 5% of the U.S. and world malt production.

A significant impact on the economics of the malting industry has been the decrease in malt usage per unit of beer produced. In 1934, 0.146 kg of malt was required to produce a hectoliter (hL) of beer in the United States (20). By 1978, malt usage had dropped to 0.110 kg/hL, and it has decreased even further to 0.092 kg/hL in 2001. Unless changes in malt composition, brewing technology, or beer products develop, it is probable that the unit usage will not decrease substantially below the current level. If too little malt is used, the low husk content in the brewers' mash results in slow lautering or mash filtration. Since malt is the only source of assimilable nitrogen, too little malt could cause variable fermentations and corresponding beer flavor problems. However, continued growth in lower calorie beer, cost pressures to substitute lower cost adjuncts for malt in the brewing process, or changes in high gravity and other brewing technology could reduce usage.

Commercial information on the U.S. malting industry can be obtained from the Beer Institute (Washington D.C.). Data on barley can be obtained from the American Malting Barley Association, Inc. (Milwaukee, Wisconsin). Canadian statistics are available from the Canadian Grain Commission (Winnipeg, Canada) and the Brewing and Malting Barley Research Institute (Winnipeg, Canada).

4.2. Investment, Costs, and Prices for Barley and Malt. The investment required to construct a new facility depends on several factors. Some of the more important considerations are

1. Style of plant	Tower, Mini Tower, or Flat construction
2. Batch size	Typically larger than historical, from 250 to 450 MT
3. Vessel materials	Concrete, Mild Steel, or Stainless Steel
4. Storage amount/type	Typically 1–2 months barley and 1.5–2 months malt
5. Project management	Turnkey, General Contractor, Multiple primes

After a long period without any new construction in the United States, three plants have been started in recent years, with one of these commissioned in 2004 and two coming on line in 2005. There has been a marked increase in new capacity worldwide, especially in Russia and the Ukraine. All of the above activity will result in an overcapacity situation in the global marketplace. Costs for greenfield plants completed has ranged between $400 and 650/metric ton produced. A summary of running costs in USD/metric ton malt appears below.

Operating labor	6–10
Supervision	2–6
Corporate administration	6–10
Kiln heat	12–20
Electricity	7–12
Water and sewer	7–10
Repairs and maintenance	3–5
Laboratory services	1–2
Depreciation	1–22

5. Specifications

Typical ranges of U.S. product specifications for brewers' malt are listed in Table 10. Moisture specifications define the drying process and imply a limit of economically undesirable material; extract is a measure of the amount of water-soluble extract in malt, which defines the amount of beer that can be made from a given amount of malt; fine-coarse difference is a measure of predicting how efficiently the extract can be obtained in the brewery; diastatic power and alpha-amylase are indirectly related to the fermentability of the wort; color is directly related to the color of the finished beer; soluble protein is related to yeast growth and flavor metabolites as well as foam stability of the finished beer; beta-glucan is a measure of the desirable breakdown of endosperm cell wall components; and assortment uniformity is necessary for predictable milling in the brewery. The analytical procedures for these parameters are given in Ref. 21. Large U.S. breweries also specify all or at least part of the process conditions for manufacturing their products. Typical examples of process specifications are kiln finishing temperature and the germination time for certain malt varieties. Additional malt specifications are likely to be added in the future, primarily in response to resolving or minimizing brewing problems (22–26).

These rigorous specifications have created a complex blending problem, since each brewer has their own list of specifications. In order to meet such specifications, large commercial maltsters produce and store different types of malt and then carefully blend from several bins at a time.

5.1. Health and Safety Factors. Dust-control systems and good housekeeping are employed in the barley and malt elevators, steephouse, and other processing areas to eliminate or minimize the potential of dust explosions and inhalation. Although low levels of sulfur dioxide are employed (0.1–2.0 g S/kg malt), the potential of toxic sulfur dioxide concentrations resulting from process or operator error does exist. Fumigants and various cleaning agents are used routinely in the malting industry in accordance with safe operating practices.

6. Specialty Products and By-Products

A wide variety of special malts are produced which impart different flavor characteristics to beers. These malts are made from green (malt that has not been dried) or finished malts by roasting at elevated temperatures or by adjusting temperature profiles during kilning. A partial list of specialty malts includes standard malts, ie, standard brewers, lager, ale, Vienna, and wheat; caramelized malts, ie, Munich, caramel, and dextrine; and roasted products, ie, amber, chocolate, black, and roasted barley.

These malts vary in flavor characteristics and color among suppliers (27–29). Manufacturing protocols for specialty malts vary widely (30), with some malts being prepared in full-scale conventional kilns and others in roasters. Specialty malts for distillers have been made from rye and oats in the past, whereas wheat and sorghum (31) have been malted for wheat beers in Europe and the United States, and sorghum beer in Africa. Although the majority of cereal grains can be malted, only barley has been bred to be a good quality malting grain.

Very few companies produce specialty malts in roasters or specialty kilns in North America. Other malting companies produce high dried malts in conventional kilns that are used by brewers for color or flavor purposes. Specialty malts represent $< 2\%$ of malt sold in North America.

Malt syrups, which are extracts of conventional or specialty malts, are produced by three companies in the United States: Breiss Malting Co., Malt Products Corp., and Chr. Hansen, Inc. Malt extracts are used in a variety of food applications and by microbrewers and home brewers.

The main by-products from the malting industry are malt sprouts, cleanout material, and small-kernel barley. Malt sprouts are primarily dried malt rootlets, containing 24–26% protein, 2–3% fat, and 12–14% fiber. Since the protein is readily available, malt sprouts are used in various animal feed blends. Occasionally, malt hulls and barley chaff are blended with malt sprouts. The remainder of the cleanout material and small kernel barley is sold as feed.

BIBLIOGRAPHY

"Malts and Malting" in *ECT* 1st ed., Vol. 8, pp. 705–718, by A. D. Dickson, U.S. Dept. of Agriculture, and E. Kneen, Kurth Malting Co.; in *ECT* 2nd ed., Vol. 12, pp. 861–886, by E. Kneen, Kurth Malting Co., and A. D. Dickson, U.S. Dept. of Agriculture; in *ECT* 3rd ed., Vol. 14, pp. 810–823, by M. R. Sfat and J. A. Doncheck, Bio-Technical Resources, Inc.; in *ECT* 4th ed., Vol. 15, pp. 947–962, by J. A. Doncheck, Bio-Technical Resources, L. P.; "Malts and Malting" in *ECT* (online), posting date: December 4, 2000, by J. A. Doncheck, Bio-Technical Resources, L. P.

1. A. W. MacGregor and R. S. Bhatty, eds., *Barley: Chemistry and Technology*, American Association of Cereal Chemists, Inc., St. Paul, Minn., 1993.
2. *Gleanings, September 30, 2004*, American Malting Barley Association, Inc., Milwaukee, Wis., 2004.
3. Unpublished research, International Malting Company, 2004.
4. D. E. Davidson and N. O. Jangaard, *J. Am. Soc. Brew. Chem.* **36**, 51 (1978).
5. M. R. Sfat, *Brew. Dig.* **40**, 50 (1965).
6. S. J. O'Donnell, C. Giarratano, and D. Burczyk, *Brew. Dig.* **60**, 13 (1985).
7. D. von Wettstein and co-workers, *Carlsberg Res. Commun* **42**, 341 (1977).
8. J. D. C. Figueroa, M. A. Madson, and B. L. D'Appolonia, *J. Am. Soc. Brew. Chem.* **47**, 44 (1989).
9. K. Erdal, *J. Inst. Brew.* **93**, 3 (1986).
10. D. M. Wesenberg and co-workers, *J. Am. Soc. Brew. Chem.* **47**, 82 (1989).
11. D. von Wettstein and co-workers, *Tech. Q. MBAA* **22**, 41 (1985).
12. A. M. MacLeod, *Proceedings of the 16th Congress, European Brewery Convention*, Amsterdam, the Netherlands, 1977, p. 63.
13. J. G. Dickson, *Tech. Proc. Master Brew. Assoc. Am.* **64** (1960).
14. C. M. Hollenbeck, *Cereal Sci. Today* **10**, 368, 392 (1965).
15. W. J. Pitz, *J. Am. Soc. Brew. Chem.* **48**, 33 (1990).
16. U.S. Pat. 3,159,551 (Dec. 1, 1964), E. Sandegren and H. Beling.
17. U.S. Pat. 3,116,221 (Dec. 31, 1963), M. R. Sfat and co-workers (to Rahr Malting Co.).
18. *Impact* **34**, 17 (2004).

19. *Modern Brewery Age* **55**, 13 (2004).
20. Department of the Treasury, Internal Revenue Service, Bureau of Alcohol, Tobacco and Firearms, Annual Report, Alcohol and Tobacco Summary, U.S. Government Printing Office, Washington, D.C.
21. American Society of Brewing Chemists, *Methods of Analysis*, 9th ed., St. Paul, Minn., 2004.
22. J. Britnell, *Tech. Q. MBAA* **23**, 115 (1986).
23. B. Axcell and co-workers, *Tech. Q. MBAA* **21**, 101 (1984).
24. G. H. Palmer, *J. Am. Soc. Brew. Chem.* **50**, 121 (1992).
25. S. Aastrup, *J. Am. Soc. Brew. Chem.* **46**, 37 (1988).
26. C. E. Giarratano and D. A. Thomas, *J. Am. Soc. Brew. Chem.* **44**, 95 (1986). M. J. G. Minch, *Brew. Guard.* **105**, 31 (1976).
27. *Brew. Techniques* **45** (Jan.–Feb. 1994).
28. M. Griffiths, *Brew. Guard.* **121**, 29 (1992).
29. M. A. Gruber, *Tech. Q. MBAA* **38**, 227 (2001).
30. P. Blenkinsop, *Tech. Q. MBAA* **28**, 145 (1991).
31. J. P. Dufour and L. Melotte, *J. Am. Soc. Brew. Chem.* **50**, 110 (1992).

GENERAL REFERENCES

A. W. MacGregor and R. S. Bhatty, eds., *Barley: Chemistry and Technology*, American Association of Cereal Chemists, Inc., St. Paul, Minn., 1993.

D. E. Briggs and co-workers, *Malting and Brewing Science*, Vol. 1, 2nd ed., Chapman and Hall, New York, 1981.

E. B. Adamic, *The Practical Brewer*, Master Brewers Association of the Americas, Madison, Wis., 1977, pp. 21–39.

A. H. Cook, *Barley and Malt*, Academic Press, Inc., New York, 1962.

J. S. Hough, D. E. Briggs, and R. Stevens, *Malting and Brewing Science*, 1st ed., Chapman and Hall, London, 1971.

K. Schuster, *Die Technologie der Malzbereitung*, Ferdinand Enke Verlag, Stuttgart, Germany, 1963.

J. Inst. Brew. **77**, 181 (1971), describes methods of analysis for barley and malt according to British Standards.

European Brewery Convention, *Analytica-EBC*, 3rd ed., Schweizer Brauerei-Rundschau, Zurich, Switzerland, 1975, describes methods of analysis for barley and malt according to European standards.

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Table 1. **U.S. Barley Production in Metric Tons, 2004**[a]

	Midwest	Western	Total
6-row total	2,029,650	192,150	2,221,800
6-row malting	1,360,750	26,150	1,386,900
2-row total	225,500	3,651,150	3,876,650
2-row malting	141,500	1,271,500	1,413,000
total U.S. barley	2,255,150	3,843,300	6,098,450
total U.S. malting	1,502,250	1,297,650	2,799,900

[a] See Ref. 2.

Table 2. **World Barley Production in Metric Tons, 2003**[a]

Country	Total barley	Malting barley	% Malting	% of World malting
North America	18,300,000	5,000,000	27.3	21.7
South America	1,500,000	1,000,000	66.7	4.3
Europe	46,800,000	9,200,000	19.7	40.0
Asia	42,800,000	4,400,000	10.3	19.1
Oceania	7,740,000	3,410,000	44.1	14.8
other	19,860,000			
total	137,000,000	23,010,000	16.8	

[a] See Ref. 3.

Table 3. **Typical Material Balance for Malting Process**

Material	Range	Typical U.S. percentage
barley cleanout	5.0–15.0	10
steepwater chaff and solubles	0.5–1.0	0.7
respiration losses	2.5–4.5	4
hulls and sprouts	2.5–6.5	3.5
finished malt	77.5–83.0	81

Table 4. **Typical Steeping Parameters**

Parameter	International range	Typical United States
steeping time, h	20–50	40–48
water temperature, °C	10–18	12–16
barley steepout moisture, %	35–45	41–45
barley steepout temperature, °C	12–22	15–18

Table 5. **Parameters Controlled During Germination**

Parameter	International range	Typical United States
germination time, day	3–6	4
germination temperature, °C	12–25	16–20
load-to-kiln moisture, %	42–48	41–45

Table 6. **World Malting Capacity in 1000 Metric Tons, 2003**[a]

Groupe Soufflet	1387
Cargill Malt	1245
ConAgra Malt	1191
Groupe Malteurop	1124
International Malting Co.	845
Greencore Group	613
Rahr Malting Co.	525
Weissheimer Malt	520
Boortmalt	403
Ausmalt/Joe White	403
All Others	3426
Total	*11,682*

[a] See Ref. 3.

Table 7. **World Brewing Production in 1000 Hectolitres, 2003**[a]

Anheuser-Busch	152,300
SABMiller	132,600
Interbrew	116,000
Heineken	101,000
AmBev	75,800
Carlsberg Breweries	54,300
Scottish Courage	48,200
Grupo Modelo	41,700
Coors Brewing Co.	38,400
KirinBrewing Co.	34,300
All Others	622,500
Total	*1,417,100*

[a] See Ref. 18.

Table 8. **North American Malting Capacity in 1000 Metric Tons, 2005**[a]

	United States	Canada	Mexico	Total
Briess Industries	37			37
Busch Agricultural Resources, Inc.	555			555
Cargill Malt	463	235		698
Conagra Malt	248	390		638
Coors Brewing Co.	227			227
Cuauhtemoc Moctezuma			136	136
International Malting Co.[b]	653	88		741
Grupo Modelo[b]	100		290	390
Rahr Malting Co.	347	138		485
Total	*2,630*	*851*	*426*	*3,907*

[a] See Ref. 3.
[b] Includes capacity commissioned in 2005.

Table 9. **U.S. Brewing Production in 1000 Hectolitres, 2003**[a]

Anheuser-Busch	118,755
Miller Brewing Co.	43,629
Coors Brewing Co.	26,178
Pabst Brewing Co.	9,243
D. G. Yuengling & Son	1,521
Boston Beer Co.	1,438
Latrobe Brewing Co.	1,287
City Brewery	1,109
High Falls Brewing Co.	878
Sierra Nevada Brewing Co.	673
All Others	5,188
Total	*209,899*

[a] See Ref. 19.

Table 10. **Typical United States Malt Specifications**

Property	6-Row	2-Row
moisture, wt%	3.7–4.3	3.7–4.3
fine grind extract (dry basis), wt%	>78.5	>80.0
coarse grind extract (dry basis), wt%	>77.5	>79.0
fine–coarse difference (dry basis), wt%	1.0–1.5	1.0–1.5
color, ASBC	1.7 – 2.3	1.5–2.1
diastatic power (dry basis), °Lintner	>140	>110
alpha-amylase (dry basis), 20° dextrinizing units	>45	>45
total protein (dry basis), wt%	12.0–13.5	11.0–12.5
soluble protein (dry basis), wt%	5.2–5.7	4.8–5.5
beta-glucan, mg/L	<150	<130
assortment, % kernel width >2.38 mm (6/64 in.)	>80	>85
assortment, % kernel width <1.98 mm (5/64 in.)	<1.5	<1.5

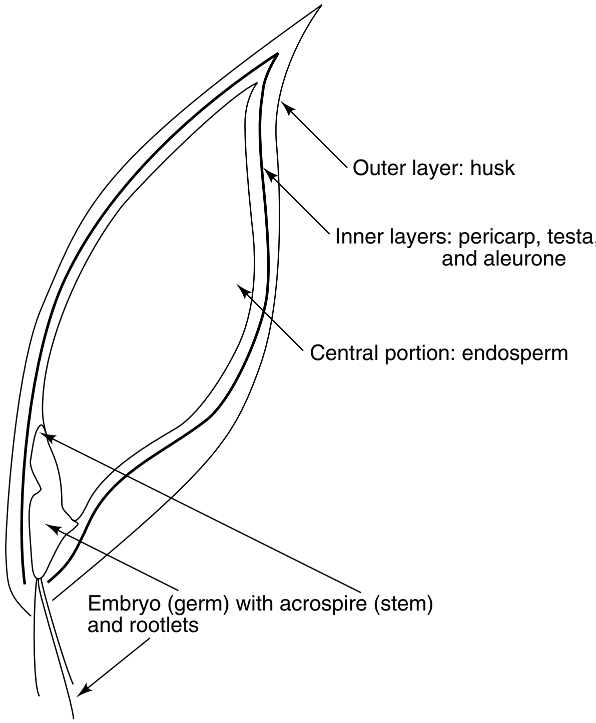

Fig. 1. Barley kernel and key components, shown in early stage of malting process.

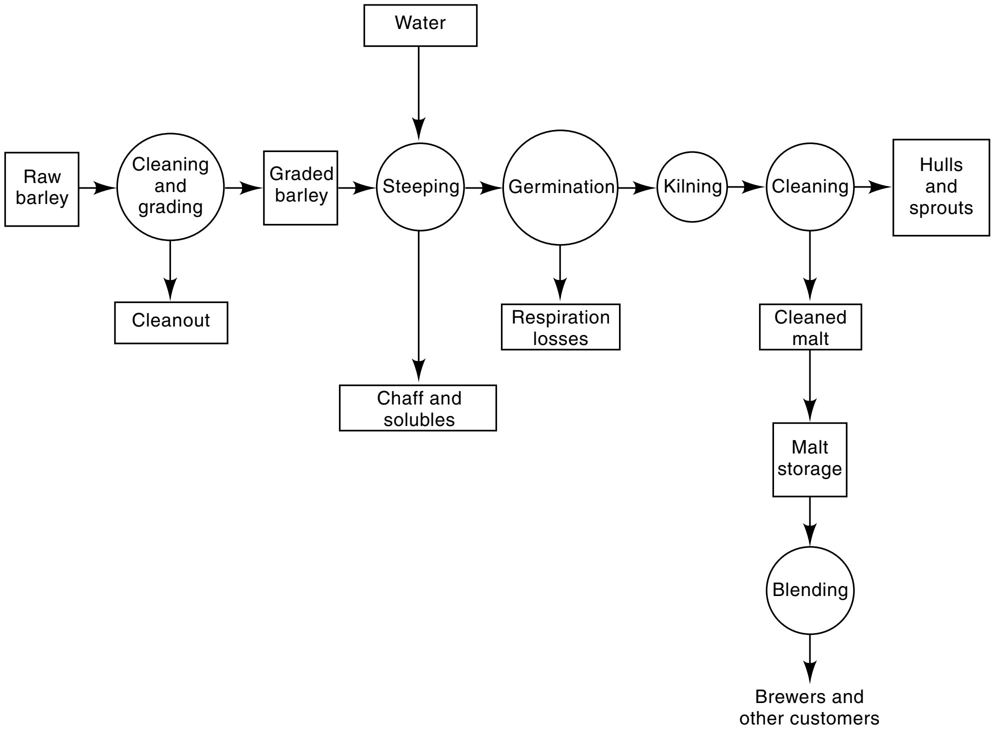

Fig. 2. Malting process.

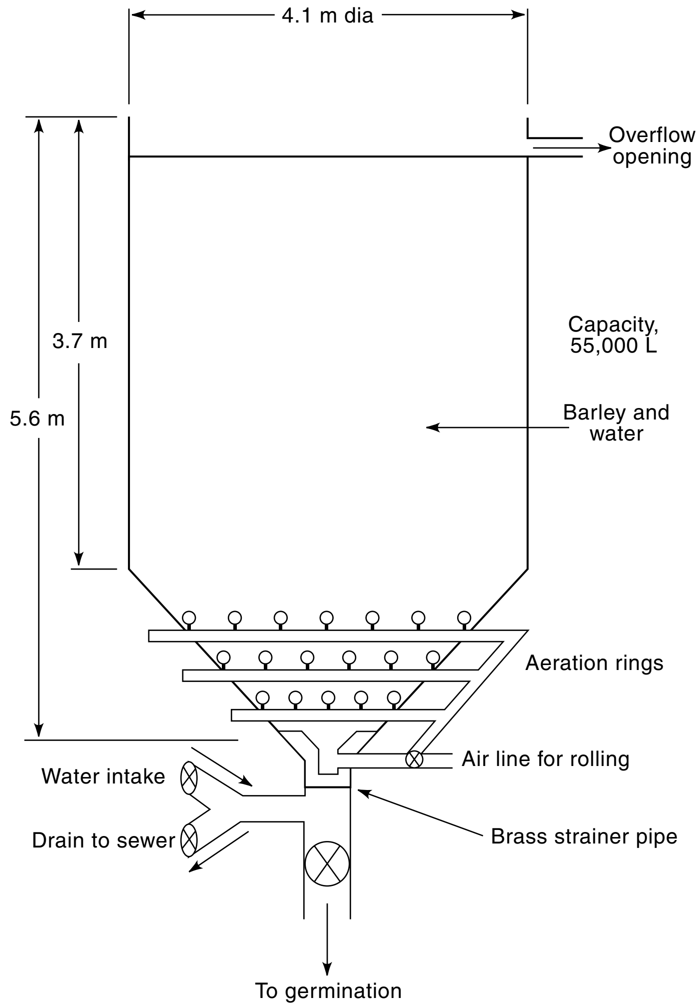

Fig. 3. Steep tank.

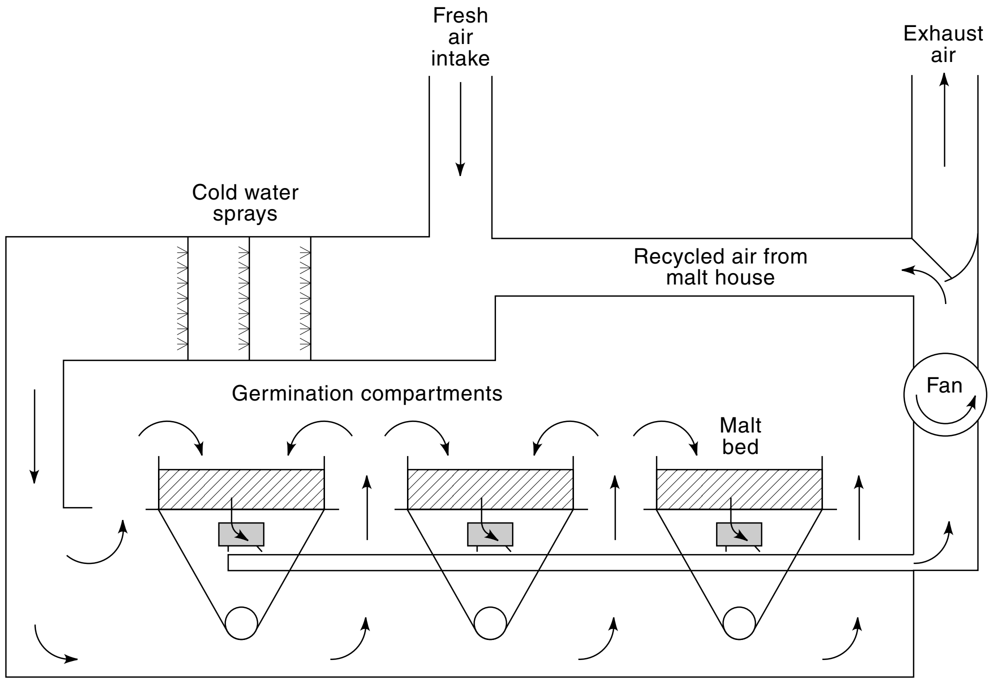

Fig. 4. Germination compartment.

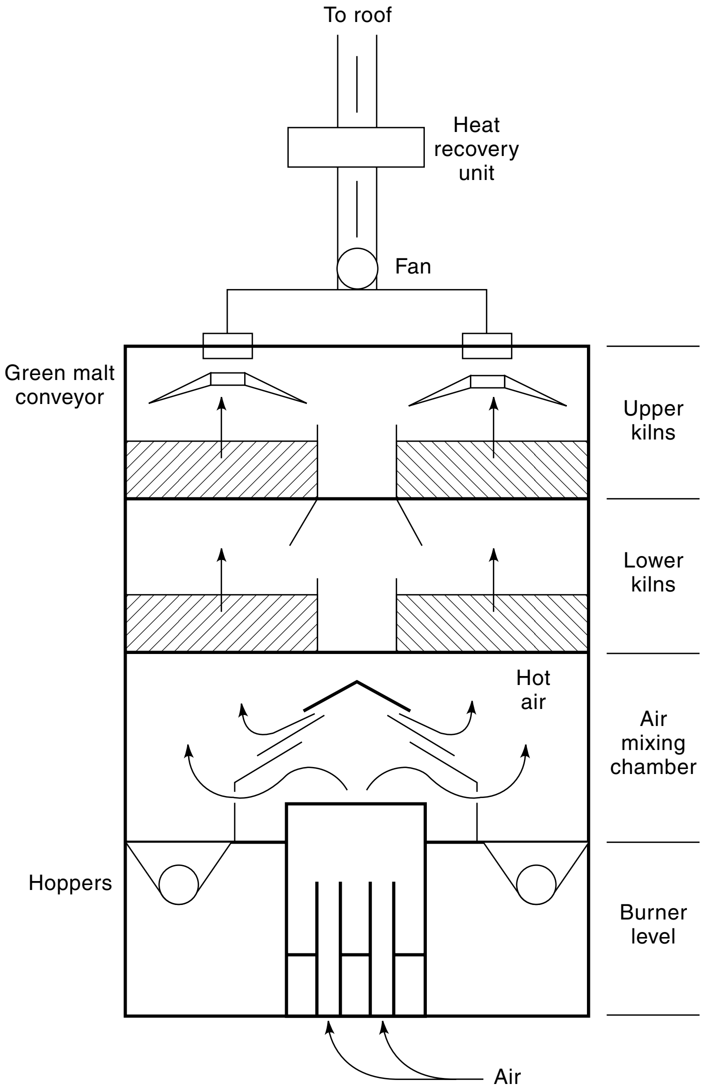

Fig. 5. Double-deck kiln.