

1

A Comprehensive History of Beer Brewing

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1.1

Introduction

Brewing has been a human activity ever since the beginning of urbanization and civilization in the Neolithic period. Beer is a product valued by its physico-chemical properties (i.e. quality) as much as by its entanglement with religious, culinary and ethnic distinctiveness (i.e. tradition). Accordingly, the history of beer brewing is not only one of scientific and technological advancement, but also the tale of people themselves: their governance, their economy, their rites and their daily life. It encompasses grain markets as well as alchemy.

There exists a vast literature on beer and brewing. Among the most comprehensive reviews are the books by Arnold [1] and Hornsey [2]. Some aspects have recently been covered by Unger [3] and Nelson [4]. A major problem is posed by language—there is an abundance of information available in, for instance, English, German, Dutch, French, Danish or Czech, which, due to insufficient command of the various languages, is not acknowledged by other authors. If evaluated in a broader context these publications would yield very interesting insights.

There are two fundamental limits to any history of beer brewing. First of all it is the unambiguous definition of its object, namely beer. Does 'beer' broadly refer to fermented beverages based on grain or does it designate the hopped drink obtained from liquefied starch after fermentation with specific strains of *Saccharomyces* yeasts, which is understood to be beer in our times? Although including the history of all grain-based fermented beverages would exceed the scope of this chapter, a consideration of hopped beer only would be too selective, and would ignore the fundamental roots of brewing technology and beer culture. Therefore, this chapter follows the approach taken by many previous authors—illustrating the process leading from the beginning of agriculture in the Neolithic period to today's beer. This approach necessarily limits the scope to Mediterranean, European and North-American developments. This does not imply, however, that development elsewhere is inferior. In contrast, the dissemination of European/American beer culture all over the world and the recent trend towards

globalization generates new variants of beer-like beverages that follow regional traditions and preferences.

A second difficulty arises from the availability and reliability of sources. Our knowledge about brewing comes either from archaeological artifacts or written documents. Thus, grain residues and the presence of oxalate, respectively, have been used as archaeological evidence for beer. This is certainly appropriate if the surroundings indicate conditions favorable for beer production [5]; however, it is not proof in itself. Difficulties might also arise from the interpretation of written documents. As brewing consists principally of at least three distinct processes (germination/drying = malting; enzymatic hydrolysis of natural polymers = mashing; microbial transformation of amino acids, sugars or oligosaccharides = fermentation) one is tempted to apply modern technical concepts to earlier technology. This might not always be appropriate and may result in misinterpretations. Also, terms and definitions might change over the times, complicating the correct interpretation of texts. For instance, the Indo-Germanic terms *beor*, possibly etymologically related to our word 'beer', and *alu*, the likely origin for the word 'ale', might both have been used at times not for grain-derived beverages, but for mead and fermented fruit juices, respectively [4, 6].

This uncertainty arising from the meaning of terms is further complicated by the high ideological significance of beer and brewing. Ever since antiquity beer drinking has also implied a cultural, national and ideological affiliation, and publications have served not only the documentation of technological or economical facts, but also the satisfaction of cultural pride. From antiquity to modern times many authors have approached the theme with considerable bias. Accordingly, while beer and wine probably coexisted in most societies, frequently attempts have been made to mark a civilization as 'wine' or 'beer' drinking. This chapter tries to avoid valuations as far as possible, and to focus on the economic, technological and cultural developments that enabled men and women to provide their fellow men with a nutritious, healthy and joyful drink for over 6000 years. However, it follows the advice of Professor William Whewell from Cambridge (who coined the term 'science' around 1840) that new insights should not be taught until 100 years have passed to avoid scientists ridiculing themselves. It ends therefore with the advent of World War I.

1.2

'The Truly Happy Man Has His Mouth Full of Beer' [7]: From Prehistory to the End of the Roman Empire

1.2.1

Advent of Agrarian Societies

'Very deep is the well of the past. Should we not call it bottomless? Bottomless indeed, if-and perhaps only if-the past we mean is the past merely of the life of mankind, that riddling essence of which our own normally unsatisfied

and quite abnormally wretched existences form a part; whose mystery, of course, includes our own and is the alpha and omega of all our questions, lending burning immediacy to all we say, and significance to all our striving. For the deeper we sound, the further down into the lower world of the past we probe and press, the more do we find that the earliest foundations of humanity, its history and culture, reveal themselves unfathomable. No matter to what hazardous lengths we let out our line they still withdraw again, and further, into the depths.' THOMAS MANN, *JOSEPH AND HIS BROTHERS*, *Translated by H.T. Lowe-Porter*, ALFRED A. KNOPE, New York, 1945.

These sentences written by Thomas Mann at the beginning of his novel *Joseph and his Brothers* describe the dilemma of defining the beginnings of brewing. While humans might have used intoxicants at all times and even fermented ones in Paleolithic times [8], three prerequisites must be met for brewing: (i) the availability of suitable grains, (ii) a controllable source of energy (i.e. a fireplace) and (iii) suitable brewing vessels (i.e. pottery or metal kettles). Most probably some experience with handling and processing grain (storage, controlled germination and milling) was also to be acquired before a fermented beverage could be made from cereals. These prerequisites were met on a wider scale not earlier than 5000 BC.

The end of the ice age as result of climate change around 12 500 BC had induced changes to human societies as well. As a consequence, the small groups of 25–50 humans who dotted the country (0.1–0.2 humans/km²) and made their living from hunting and gathering began to build up supplies. They developed simple harvesting utensils as well as the means to grind seeds. As population growth rates increased, the first permanent settlements emerged. This development occurred independently in the so-called Fertile Crescent (Israel/Jordan/Syria/Turkey/Iraq), Southern and Northern China, Sub-Saharan Africa, the Andes region, and Middle and North America. Concomitantly, humans began to adapt other species to their needs (i.e. to domesticate plants as well as animals). Among the plants selected and bred were einkorn [9], wheat [10, 11] and barley [12]. As these grains provide a useful source of carbohydrates and protein, are easy to handle, and can be stored over long periods, they quickly became a major object of interest and innovation. It is no surprise, therefore, that the first evidence of grain-based fermented beverages mainly originates from the regions where grain cultivation first flourished—the Fertile Crescent, Mesopotamia and Egypt. However, the oldest evidence for such drinks comes from China. Chemical analyses of ancient organics absorbed into pottery jars from the early Neolithic village of Jiahu in Henan province revealed that a mixed fermented beverage of rice, honey and fruit was being produced as early as the seventh millennium BC [13]. Even the first pictorial and chemical evidence for grain-based fermented beverages from the near east dates from times when the last mammoths became extinct and the iceman 'Özi' traveled the Alps, namely from the fourth millennium BC [14, 15]. Thus, at the very beginning of scientific (i.e. recorded) history, beer-like drinks were already part of

human life. It has even been argued that the development of fermented cereals acted as a driving force of human development [16].

While cereals as a source for alcoholic drinks offer the great advantage of being available all year around if stored appropriately, they have two great disadvantages: (i) the starch content of the cereal must somehow be modified and converted into fermentable sugars, and (ii) the few yeasts suitable for effectively transforming carbohydrates to ethanol [17] do not settle on grain surfaces [18]. Thus, the brewing yeast must come from another source. As at the beginning of civilization and under Mediterranean climate conditions suitable airborne yeasts might have been rather scarce, plants can be assumed to have been the source of the earliest brewing yeasts. Certain fruits, such as grapes or dates, host appropriate wild yeast on their skins.

Brewing beverages from starch can be performed by different processes; however, these are always composed of a few invariable modules (Table 1.1, modified from [19]).

As conversion of starch to sugars (malting) was poorly perfected initially, either additional fermentable sugars had to be added in the form of juices or honey and/or microorganisms capable of liquefying starch with exoenzymes had to be present to ensure fermentation. Moreover, contamination with harmful microor-

Table 1.1 Basic modules of brewing.

Sugar source		Yeast conservation/ starter culture	Reduction of Contamination	Fermentation	Storage
Grain starch modification	Other source				
Heating/boiling	honey/mead	unmodified plants (fruits/berries)	plants/herbs	heterofermentation	clay bottles
Soaking/ germinating/ malting	fruit syrups	leavens/bread	lactic acid bacteria	homofermentation	glass bottles
Dough/baking (beer-bread)	wine	sugar solution (wort, honey)	ethanol formation or addition (wine)	immobilized yeast	barrels
Enzymatic saccharification in solution (wort)		fermentation broth	wort boiling		
Enzymatic saccharification in solid state (mold amylases)		pure cultures	filtering		

ganisms had to be minimized by lowering the pH through lactic acid fermentation and the addition of suitable plant components. Thus, a great variety of beverages became available from grains shaped by climatic and cultural peculiarities. Mixed beverages were widespread throughout Roman–Hellenistic times [20] and the Middle Ages, and live on in some of the Belgian lambic and geuze beers [21]. The ‘barley wines’ mentioned by several ancient authors [22] might be such products as well. The complexity and long fermentation times of such beverages result in a wine-like drink [23].

1.2.2

Mesopotamia and Egypt

As the life of settled humans became increasingly stratified in social classes organized by administrative structures in urban centers and an exchange of goods evolved, both developments were accompanied by the development of writing in the Sumerian states and Egypt (3300–3100 BC) as well as in Akkad (2500 BC). Even the earliest written documents provide information about beer, stressing its key role in those societies. In the *Epic of Gilgamesh*, king of Ur, the savage Enkidu is ‘civilized’ by a woman teaching him to eat bread and to drink beer (second table), revealing brewing as one cornerstone of civilization.

Most of our scant knowledge about brewing in early Mesopotamian cultures originates from administrative and literary texts, the best known of which is the ‘Hymn to Ninkasi’ [24]. This poem has come to us in copies from the Old Babylonian period (about 1800 BC) and—in spite of many ambiguities—details the brewing process. It specifies as basic ingredients of the beverage: *bappir* (often translated as beer-bread, a cooked or fermented mixture of leaven and aromatic herbs), *munu* (a hulled cereal that is malted during the brewing process) and *titab* (probably a mash prepared from malted grain that is dried after cooking). Honey and wine are added to the mixture before fermenting.

Beer and other alcoholic drinks played a vital role in early societies. Ecstasy was considered an indispensable spiritual exercise and a state of unification with the gods, while banquets and ceremonial dinners served as divine service and to foster tribal allegiance. In the form of libations, beer served as an offering to the gods, believed to be an essential constituent of their divine diet as it was of that of their worshippers. As disease was believed to result from ‘banes’ or ‘numinous anger’, magic and ritual were integral parts of medical therapy. It is no wonder that beer was important as a basic element of the medicines as well as of magic evocations. Thus, to implore Nergal, the god of plague, to spare the city one had to recite: ‘O lord, do not enter this beer-house, do not slay those sitting at the place of beer!’, while a snake dissolved in beer was considered a remedy for jaundice.

Moreover, beer, malt and ‘beer-bread’ were a common element of tributes and tithes, as well as an integral part of the daily remunerations of magistrates, servants, priests or workers. Given the vast commercial and social importance of brewing intermediates and beer in early societies it is not surprising that immense efforts were made to adapt to changing consumer preferences and to optimize brewing

technology to improve efficiency and profitability. There is no doubt that brewing techniques as well as ingredients changed dramatically over a period ranging from the fourth millennium BC (late Uruk period) until the fifth century BC (New Babylonian Empire) [25]. While originally at least nine different beer types had been produced from barley and barley malt [26], in Babylonian times up to 70 different types of beer were manufactured from (white) emmer, barley and intermediates thereof [27, 28]. The cheapest beverage was a ‘black’ beer prepared from barley only [29]. The color probably results from the grain as the wild barley varieties commonly found in Syria and Mesopotamia exhibit a purple color [30]. Unfortunately, details of technical improvements are prone to speculation, as our knowledge depends on the differing specialist interpretation of cuneiforms and sparse illustrations on seals. The latter often indicate that, in particular, in the northwest of Mesopotamia a specific brewing technique yielded a beer that had to be sipped through a reed or metal tube in order to avoid swallowing husks and other insoluble plant constituents. Xenophon, the Athenian historian and soldier, encountered such a beer in the fourth century BC in Armenia and found it quite tasty [31]. However, bone and metal straw-tip beer-strainers have also been found in the central Jordan valley [32], indicating a broader distribution of this brewing technique.

It is assumed that the Jewish elite learned to prepare beer during their exile in Babylon. Although there are controversies about brewing in ancient Israel, evidence for beer and beer consumption can be found in the scripts [29, 33–35]. The designation *shekar* (strong drink) is certainly related to the Akkadian *sikaru* and the Babylonian *shikaru*, both meaning beer, although at times *Shekar* might have also been used for other beverages. It is interesting to note that one of the earliest references to hopped beer, a list of tithes owed to the abbey of Fontanelle from the early ninth century AD, refers to this drink using the Carolingian term *sicera* [4], an analog to *Shekar* and *sikaru*. It had been postulated that *Shekar* was a hopped beverage [34].

There is better knowledge about brewing in the other great early civilization—Egypt—since the Egyptians displayed the brewing process on the walls of their tombs and supplied their dead with clay figures of laborers (*uscheptis*) to ensure provisioning with indispensable victuals in the afterlife. Beer was a crucial staple and played as dominant a role in cult and medicine in ancient Egypt as it did in Mesopotamia [36]. There were a variety of beer styles differing in raw materials, ingredients, alcohol content and taste. Some beers were brewed for religious purposes only, like the ‘beer of truth’ reserved for the 12 gods who guarded the shrine of Osiris or their priests [29]. The god Osiris, in Hellenistic times equated with Dionysus, was considered the one who had taught humans to brew beer. This legend lived on for centuries. As late as 1536 AD the German humanist A. Althammer informed his readers that the god Osiris and his wife Isis had taught the Thuisikon chief Gambriivius how to cook beer [37]. The legend of Osiris—a god murdered and dismembered by his brother, and then reconstructed and reanimated by his wife—served not only as a template for later theological paradigms, but also for much of the alchemistic theory. One reason for this was that the Egyptians had not only developed an alloy named electron, which resembled gold in appearance and properties, but also their mastery of fermentation.

The first evidence of beer in Egypt dates from about 3500 BC [38]. Excavations from two pre-dynastic sites at Abydos and Hierakonpolis uncovered large, fixed vats, supported by distinctive firebricks, which are considered the remains of breweries [39]. Later, in the New Kingdom times and probably earlier, brewing took place in smaller moveable pottery vessels. The majority of ancient Egyptian beer residues contained barley, whereas only some were made entirely from emmer. Occasionally, both cereals were mixed together [40]. In most Egyptian beers presumably a special type of bread [41] or sour dough was used as a source of yeast and lactic acid. Scanning electron microscopy analysis of desiccated bread loaves and beer remains suggest that bread was made not only with flour from raw grain, but sometimes also with malt and with yeast. Brewing blended cooked and uncooked malt with water; the mixture was strained free of husk before inoculation with yeast [42]. It is natural that the Egyptian brewing technology did not remain the same over the centuries, but was adapted to market trends and technological progress [19, 40, 43]. Moreover, there is evidence that different brewing processes were used in Upper and Lower Egypt [19]; this is not surprising as Egyptian texts also differentiate between the six-rowed barley from Upper and Lower Egypt [19].

Many hundreds of years of brewing resulted in a process that has been preserved in the writings of the fourth-century alchemist Zosimus of Panopolis. He described malting by soaking and germinating barley before drying it in the sun and air, and subsequently grinding it. The malt was made into leavens which were briefly heated (baked/fermented?) and crumbled into water, slightly heated for mashing, and subsequently fermented. This Egyptian beer, called *Zythos*, was generally synonymous for beer in Hellenistic times. Beverages made by the recipe of Zosimus were consumed even in Islamic Egypt and a drink named *bouza* was prepared by Fellaheen in modern times from wheat according to Zosimus' recipe [4].

1.2.3

Hellenistic Period: Greeks, Romans and Their Neighbors

The Greeks under Alexander the Great conquered Egypt in 331 BC and established the Ptolemaic dynasty there. The Ptolemeian rulers introduced wine in Egypt, which was soon to become the favorite drink of the upper classes. In contrast, beer production and sale was tightly regulated, and ultimately beer making became a state monopoly. Under the pretext of combating the public abuse of alcoholic beverages, a tax was imposed on beer—unheard of during the millennia before.

One reason for this was that Greeks (as well as Romans later on) were determined wine drinkers for cultural, not to say ideological, reasons. For once, they were surrounded by hostile beer-drinking nations. Their rivals for the trade in the Eastern Mediterranean from Egypt and Mesopotamia were beer drinkers as well as the Thracians, the Illyrians, the Scythes, the Phrygians and the Gauls, who obstructed their territorial expansion. Although the Greeks had been originally beer drinkers too, their term for beer *methou* being closely related to our word mead, the tragedian of Aeschylus in the fifth century BC let one character exclaim

in the *Danaids*: ‘Truly, you will find that the dwellers of this land are men indeed, not beer drinkers’. This prejudice against beer in Greek culture originates not only from the necessity to distinguish themselves as men of culture and knowledge from the uncultivated barbarians, but also from philosophical considerations [4]. First, they had developed the theory of the four elements into a universal concept, attributing to substances properties like cold, hot, dry or humid. While wine was considered a ‘hot’ drink suiting the ‘hot’ male principle, beer was thought to be ‘cold’, matching the female essence. Beer drinkers therefore had to be effeminate. Second, the nature of fermentation was regarded with suspicion. The excretion of yeast indicated an unnatural and impure process. Cicero called the proletariat ‘*faex populi*’ (yeast of the people) and Theophrastus of Lesbos specified in the late fourth century: ‘They even turn into drinkable juices some [products] which they have caused to depart from their nature and have somewhat rotted’. The Greek prejudice was absorbed by the Romans who encountered hostile beer drinkers in Hispania, Britain and Germany. However, the necessity to accommodate their legions in regions without viticulture with suitable drinks required the provision of beer. This they organized with their typical thoroughness and beer can be found on the shopping lists of Roman pursers in England [44]. Remains of Roman breweries at the border forts Loesnich, Xanten and Regensburg as well as at a villa in the hinterland at Namur point to a high degree of professionalism. Moreover, inscriptions from tombstones indicate that brewers and beer dealers were organized in distinct guilds (e.g. ‘*ars cervesaria*’ or the ‘*cervesa*’ guild) [4]. The different beer styles known to the Romans are also mentioned in the commentaries on civic law by Sabinus in the first century AD and Ulpian in the third century AD.

1.2.4

Celts and the Germans

The cultivation of grain did not spread to Northern Europe until the start of the Neolithic period, about 6000 years ago. Afterwards, a distinct beer manufacturing tradition emerged there that differed significantly from that developed in the Mediterranean. First of all, except for rare examples [45], leavened bread was not widespread in the northern regions. Moreover, air-drying of soaked cereals would not yield malt, but mold contamination. Therefore, kilning, as shown at a Celtic brewery site [46], had to be established in malting.

The Celts had been around since at least 700 BC in Central Europe. During the fifth to third centuries BC they expanded south towards Italy, west to Gaul and Iberia, and east into Hungary, Greece and Turkey. The Celts had certainly acquired great experience in brewing; however, we have only the testimony of Pliny who remarks in his *Natural History* (XXII, lxxxii): ‘from grain they make beverage, which is called “*Zythos*” in Egypt, “*Caelia*” and “*Cerea*” in Spain, *cervesia* in Gaul and other countries’. He also mentions (XIV, xxix) that ‘the populace of the west of Europe have a liquid with which they intoxicate themselves, made from grain and water. The manner of making this liquid is somewhat different in Gaul, Spain and other countries, and it is called by different names, but its nature and proper-

ties are everywhere the same', and states (XVIII, xii) that a Spanish beer is made from wheat and very stable. In spite of this apparently sophisticated brewing technology, the Gauls soon turned to wine. The Celtic beer culture, however, survived in Ireland and was brought back to the continent by Irish missionaries 500 years later.

Even less is known about the brewing technology of the German tribes, who slowly rolled back the Celts in Central Europe between 300 BC and 100 AD. The early Germanic tribes spoke mutually intelligible dialects, and shared a common culture and mythology, as is indicated by *Beowulf* and the *Volsunga* saga. We know that they drank beer in considerable quantities from a report by Tacitus who wrote (*Germania*, 23): 'they make a liquid from barley or wheat, which, if fermented [rotted], resembles wine'. Archaeological evidence indicates that germinating cereals was a step in Germanic brewing [47]. These were not dried, but squashed immediately and the resulting mash was fermented with airborne yeasts, and eventually contained plants and honey [48]. From the poetic *Edda*'s tale of the allwise dwarf *Alvíss* we come to know that there were different names for beer or beer styles: *bjórrr*, *veig*, *oel*, *hreinna lögrr* or *mjöð*, probable reflecting various beer/mead drinks.

In the third and fourth century the Germanic tribes approached the Roman fortifications. Germanic preference for beer would meet with Roman technology and herald a new chapter in brewing.

1.3

'I Would Like to Have a Great Lake of Beer for Christ the King' [49]: The Christian Middle Ages

Thus ended Roman rule in the Western parts of the empire. Germanic tribes overran the Roman defenses and roamed the country. Military commanders, already of German ancestry, added to their Roman titles of *magister* or *consul* that of 'king' and parted with their Germanic kin. However, some continued to cooperate with the gentry and the administration of state and church. In continental Europe the Franks were the most successful, not least because they accepted the Roman Catholic religion, thus allying themselves with the old system. Their cavalry finally accomplished what the Roman legions had failed to enforce for so long—to subordinate the Northern German tribes.

1.3.1

Monasteries

The church acquired a predominant position in those turbulent times, and managed to conserve some of the immense medical, scientific and technical knowledge compiled in Roman times. This applied to brewing too. The early Christians, standing in the Hellenistic/Judaic tradition, scorned beer and beer drinkers. In Ireland, however, which was never under Roman rule, a quite inde-

pendent church and monasticism had developed. Here, beer played a significant role as exemplified by Saint Brigid of Kildare who is reported to have worked several beer wonders. Irish missionaries like St Columbanus spread the Celtic predilection for beer as well as the Christian faith in Europe. St Columbanus' hagiographer, Jonas of Bobbio, remembered around 643 that 'as their drink they brewed beer (*cerevisia*) from grain (wheat) or barley-juice, which at that time was not only common at the Skordic and Dardaneic people but also in Gallia, Britannia, Ireland and Germania and their kin' [50]. St Columbanus also worked beer miracles, as did other holy men at that time. Thus, the attitude of the church towards beer changed during the sixth and seventh centuries as a consequence of the predominance of Germanic traditions and the Celtic mission among Gallic and Germanic tribes. The documented recognition of beer by the church, however, only came in the year 816 at the synod of Aachen where a standardized binding order of monastery life was deliberated. It was decided that a monk should receive daily one beaker (*hemina*, 0.273l) of wine or, where no wine was available, twice as much (one *sextarius*, 0.546l) of 'good beer' [4].

In the Christian culture, the aspect of 'holy drunkenness' never had the significance attributed to it in the Roman–Hellenistic and particularly the Celtic–German cultures. Therefore, missionaries and clergy had little compassion with their flock's view of Christ as highest chieftain and its church as mead hall. Ordinances of archbishop Dunstan of Canterbury, however, prove that such an association was not so far from reality. Dunstan decreed (Canon 26) 'Let no drinking be allowed in church' and (Canon 58) 'Let no priest be an ale scop nor in any wise act the gleeman' [51]. Thus, consumption of alcoholic beverages was observed with utmost suspicion by the church. Accordingly, King Edward of England, instigated by Dunstan, ordered alehouses to close. Proof that this had at best a temporary effect comes from the canons of his successor Aelfric, who ordered (Canon 35) 'Nor ought men to drink or eat intemperately in God's house ... yet men often act so absurdly as to sit up by night and drink to madness within Gods house and to defile it with scandalous games and lewed discourse'. These tenth-century examples from Britain characterize a situation to be found all over Northern European Christianity.

At that time the prospering Northern monasteries had become brewing centers. Nothing exemplifies this more than an outline of a Carolingian monastery drawn around 830 and known as the plan of St Gallen. There, three different brewhouses are designated: one to provide beer for noble guests, one for the daily consumption of the monks, and another one to grant beer for the pilgrims and paupers. The brewing process apparently consisted of crushing malted and unmalted grain (a kiln is depicted) with mortars (presumably water propelled) and mills. The brewing facility consisted of a central room with a hearth, and a second room for cooling and filtering the beer. The storage room contained 14 barrels of different size with an estimated capacity of 350hl [2, 52].

It was also the monasteries that documented the first evidence of using hops in brewing. It is assumed today that hops originated in China. The closely related hemp was in use by the bell-beaker people and the Scythes [2], and spread to

Middle Europe in the early Middle Ages. It is assumed that Caucasian people brewed hopped beer before our times, and that this technology came with their migration to Northern and Eastern Europe [53]. It is interesting to note that a hop garden in Geisenfeld near Freising mentioned in 736 AD is said to have been set up by Wendic prisoners of war. That the Wendes, a tribe living on the shores of the Baltic Sea, were especially familiar with hops confirms a customs ordinance of Lübeck from around 1220 stating that hops is carried by a Wende into the city were free of duties.

The first evidence of the use of hops in brewing in Europe originates from the ninth century. In 822 AD, Abbot Adalhard of Corbie issued a set of instructions for his abbey. Corbie counted among the most important monasteries of the empire and was the location of the imperial library, and Abbot Adalhard was a member of the royal family, a cousin to Emperor Charlemagne. In his *Consuetudines Corbeiensis*, Adalhard decreed that the porter of the monastery might receive a fraction of the hops given as tithe to the abbey to make beer thereof [54]. The use of hops in Western monasteries has been further documented in Fontanelle and St. Denis during the eighth and ninth centuries AD [4]. Another monasterial statute, the Polyptychon of St Germain (Paris) from the early ninth century, names hops as tithe. Moreover, at the same time (822 AD) that Adalhard enacted his *Consuetudines*, he founded the monastery Corvey (*Corbeia nova*, near the river Weser in Central Germany) and it is safe to assume that his regulations were, if not destined for it, at least followed there also. Cultivation of hops is also documented in the diocesan records of Freising (Bavaria) between 859 and 875 [55]. Thus, it seems likely that hops were used for brewing in at least some monasteries.

Evidence of the use of hops for brewing in the ninth and tenth centuries comes also from archeobotanical evidence. The remains of Haithabu, one of the most important Viking trading places on the Schleswig coast, confirm the frequent use of hops [56]. Moreover, hop residues were detected in high numbers in the remains of a cargo vessel from the ninth century at Graveney on the English coast [54]. Thus, it can be assumed that hops were in use outside the monasteries, and even traded between the continent and the British Isles. References to hops (*hymele*) are somewhat later found in a ninth- or tenth-century English version of Pseudo-Apuleius's Herbarium, where it is recommended 'that men mix it with their usual drink' [4, 57].

Hops were also—at least at some times—part of another beer additive—*Gruit*. There is some of confusion about *Gruit* as it designates a brewing privilege, beer additives, a beer type, or even flour or something baked, respectively, depending on the context, the time and the place. *Gruit* is known first as a brewing privilege. In Germanic societies brewing was a right that every free member possessed. However, by his *Capitulare de Villis* from 811, Charlemagne made the right to brew (for more than one's own needs) a royal prerogative. The edict limited the right to brew for the surrounding territory to the royal manors and imperial homesteads. Thus, brewing changed from a common law to a privilege linked to a place. Consequently, it became a general privilege of the king who later bestowed it to his lords [58]. Thus, the German emperors Otto III and Heinrich mention a brewing

right and brewing ingredient called *fermentum*, stating it is synonymous with *Gruit*. The brewing privilege was of commercial interest particularly to the cities, where a relatively large population increasingly depended on beer produced by professionals. Before the thirteenth century the majority of the few cities in Central Europe were of Roman origin and under the rule of bishops. The bishops—and probably other lords owning cities—excised their brewing privilege by compelling the municipal brewers to buy essential brewing ingredients from their administration. At least in the case of the bishop of Magdeburg, we have written evidence that he had the privilege to provide the yeast for the brewers in his entire diocese. That meant that brewers as far as Hamburg or Halle had to buy their yeast (*bärme*) from the Episcopal *Bärmamt* (Yeast Administration) [59]. *Fermentum*, always synonymous with ‘*Gruit*’, could indicate the physical form in which yeast was kept. Pliny had already mentioned that yeast for wine making was preserved in antiquity by mixing flour and must at harvest time and baking little cakes thereof [60]. As *fermentum* originally had designated the particle of the eucharistic bread sent by the Bishop of Rome to the bishops of the other churches as a symbol of unity and intercommunion (until the Council of Laodicea forbade the custom), *fermentum* = *Gruit* could have originally meant a bread-like substance containing viable yeast. It is noteworthy that Robert Boyle writing on digestion in the seventeenth century concludes that something in a dogs stomach ‘boild flesh, bread, gruit, &. to the consistence of a fluid Body’, thus putting *Gruit* next to bread [61].

Later, *Gruit* designated the ready mix for brewing, to be exclusively purchased from the local authorities (bishop, count or city council) or from their representatives. This was an early form of taxation as the price of *Gruit* included a fee for the authorities. *Gruit* contained malt, herbal ingredients like sweet gale (bog myrtle), marsh (wild rosemary), coriander, yarrow and milfoil; and probably yeast, attached to straw. The use of straw as a means to concentrate and preserve yeast was widespread [62, 63]. Moreover, it had been common in monasteries to add herbal ingredients like *Myrica*, *Ficaria* and *Iris* to the yeast [64], probably as a bactericide to protect the cultures against contamination. Apart from their bactericidal and fungicidal properties, *Gruit* herbs also produces flavor and psychotropic effects. As Lobelius put it later in 1551: ‘the same plants [*Myrica gale*] are added at times of lacking hops/to the beer in the Nordic countries: sometimes only in order to make the drinker happy/since gale goes up to the head and its spirit pleasures the limbs...’ [65]. Thus, almost all drinks, including malt liquors and wine, had been spiced since antiquity and the medieval preference for spiced food included drinks, too. Therefore, condiments were regarded as essential constituents of beer, and their type and quantity contributed to its valuation. In many locations hops were used as a constituent of *Gruit* before it became the sole beer additive due to commercial and fiscal necessities.

1.3.2

Beginnings of Professionalism

Professionalism means not only mastering a technology, but also developing brands and markets. In the latter respect, medieval brewers differed from their

predecessors in ancient times. The emergence of professional brewers can be traced back to the times of Charlemagne, when he admonished governors in his administrative instructions *Capitulare de Villis* to always have a sufficient number of experienced craftsmen at hand, among them brewers (*siceratores*). This referred probably to the profession already known as *braxatores* in Roman times. *Brassatores* and *cervisarii* are also mentioned next to bakers, cooks and tailors in the Domesday Book of 1086 in England [51]. In cities, the presence of brewers (*brassatores*) is recorded as early as the eleventh and twelfth centuries (Aachen, Bamberg, Huy), most likely denoting a specialist in the service of the overlord. It was in the cities, however, where professional brewing began to flourish.

The cities founded in Roman times had been gradually abandoned during the early Middle Ages. However, when trade and commerce slowly resumed after the crusades, cities regained their function as intersections of trading routes and administrative centers. In the twelfth century, new words began to appear in urban records, both in Latin and in vernacular languages, to designate brewers and brewing, indicating that a change in the status of brewers had occurred [3]. This is illustrated in a thirteenth-century manuscript of the Bibliotheque de Bourgogne in Ghent that depicts typical urban craftsmen with their professional tools: butcher, blacksmith mason and the brewer with a stirring paddle [66]. This display in an expensive manuscript shows that the craftsmen had gained a position previously reserved for overlords or bishops, and indicates the economic and political significance of their cities, many of which managed to gain more or less independence from their overlords during the eleventh to thirteenth centuries. As a consequence, most cities acquired special liberties, among them the brewing privilege. This included the right to grant brewing permits and regulate beer production and distribution. Brewing was regarded as a ‘civic aliment’ (mode of subsidy), indicating that commercial brewing was restricted to the inhabitants of cities. Moreover, many cities obtained additionally a right of precinct (*Bannmeile*, *Banlieux*), giving them a monopoly for their products within a specified parameter around the city.

Although in the beginning every citizen was entitled to brew, this right was soon confined to homeowners. The increasing demand required specialization and professionalism, as larger production volumes required high investment in equipment and raw materials. Moreover, the ever stricter fire prevention legislation could be more easily enforced on homeowners. As cities grew and brewing turned out to be quite profitable, the group of brewing citizens had to be constricted further. This was accomplished by restricting the period of time during which each brewer was permitted to produce, establishing the chronological order by lottery and by complicating admission to brewing [67].

Division of labor and specialization is one of the most significant features of urban economies. The expert artisans and traders were the pillars of urban economy. The craftsmen were quick to organize into corporations—autonomous guilds responsible for the admission to brew, training, product quality, and pension provision and fraternities for charity. Guilds had a considerable political influence as they represented all brewers, and could decree binding regulations and impose fines. Records of brewer’s guilds exist as early as 1200 for London, 1230 for

Regensburg, 1267 for Ypern and 1280 for Munich. Separate maltster's guilds existed in several cities, such as Brunswick. Slightly later, the laborers also organized. In 1447 at Bruges (Flanders) the first association of brewery workers (*fraternitas sancti vincenti*) convened to protect themselves against 'innkeeper, women and provost' [68]. The emergence of brewer's guilds is an indicator of the transformation from home brewing to professional (and profitable) brewing. By the sixteenth century, brewers guilds were found in most cities all over Europe and continued to exert considerable influence in many states until the early nineteenth century.

Concomitantly, the display of guild emblems came into use. Until the late Middle Ages, emblems (e.g. a coat of arms) were strictly confined to the nobility. Now craftsmen who were certainly not entitled to armorial bearings used the symbols of their trade to distinguish themselves from other citizens. Moreover, the display of a guild emblem soon served as a certificate that a professional was at work. The tools used by professionals were therefore commonly displayed in the guild's emblem. In addition, the signs were soon customized by serving as an early version of a trademark.

The guilds of the staple food producing professions not only had an impact on the urban economy, but also greatly influenced the health and satisfaction of the citizens through the quality and the price of their respective product. Thus, city governments enacted regulations concerning the measure and quality of food. When taxation of food—in particular, beer—had become an important source of income for the city treasury, such legislation became even more substantial. Brewing ordinances are recorded as early as 1156 from Augsburg, 1268 from Paris and 1293 from Nuremberg. Those urban 'purity laws' dealt with [69]

- Consumer protection (beer additives, brewing seasons, attenuation, technology).
- Security of supply (grain used for brewing, pricing, obligation to brew).
- Organization of brewing (guilds, training, authorization to brew).
- Implementation of regulations (beer inspection).
- Trade (sale and taxation of foreign beers).

Thus, one main concern was to ensure the supply of grain. The adoption of the undemanding rye in Central Europe between the eighth and tenth centuries and the corresponding implementation of the three-field economy had shifted human nourishment unidirectionally towards grain-based diets [70]. In the Middle Ages, rye (*Secale cereale*), bread wheat (*Triticum aestivum*) and spelt wheat (*Triticum spelta*) were the dominant winter cereals, oats (*Avena* spp.) and to a lesser extent barley (*Hordeum vulgare*) being in general the preferred spring grains; although local variations occurred [71]. As the ratio between seed and crop yield amounted to 1:3 on average, there was no chance to accumulate stocks and supplies lasted only for 1 year. Famines ravaged Europe—there were 29 major ones alone between the years 750 and 1100 and the great famine of 1315 is still remembered. Even locally restricted crop failures severely affected regions without connections to waterways, as transport was extremely poor. As the grain demand for beer

accounted for some 25–45% of the grain demand in towns [3] (and hardly less in the countryside), regulating the less important consumption of beer to ensure the supply of indispensable bread appeared reasonable. During severe famines brewing was interdicted altogether, as in London during the great famine of 1315. At other times, the type of grain for brewing could be dictated (e.g. barley in 1325 in Nuremberg). The most widespread brewing grain in the Middle Ages, however, was oats—a summer cereal; wheat, barley and rye being also in use. The type of grain or the ratio of different grains could change annually depending on their availability [72]. Many urban brewing ordinances also specified the amount of grain to be used for a given volume of beer.

The other major concern of urban ordinances was beer additives. Constituents of more than 40 different plants are known to be used as beer supplements and 14 additional ones were employed in beer for medical application [55]. As the properties of medieval plants might differ from today's plants, and in most cases the part of the plant used and the point of addition (before or after boiling) it is unknown, conclusions about the reason for their use and physiological effects remain speculative. However, much of the vast ancient information about plants and the insights of Islamic scholars as well as the popular knowledge was available to the educated upper classes. On the other hand, medieval beers contained only little alcohol in normal times and were diluted even more in times of scarceness. Therefore, the temptation to enhance the psychotropic effects of beers by the addition of eventually harmful herbs was always great. The ordinances therefore constitute an early legislation to protect consumer's health. However, they also reflect attempts to confine brewing to professionals using *Gruit* (which was not harmful) and hops.

As soon as brewers became organized professionals, they tried to develop their markets. Taverns were originally part of the brewer's premises. However, producing and serving beer soon became separate occupations, although linked by manifold financial interests. During the fourteenth and fifteenth centuries taverns differentiated further, the various types recognizable on their sign. In Roman times taverns along the roads were already marked with a pole and British ale-houses as well as European inns retained a pole or a broom as their emblem. As traffic increased and taverns offered food and accommodation, such hostels distinguished themselves by sophisticated signposts. In Central Europe such signs were only allowed to be exhibited as long as the innkeeper had beer in stock.

Accordingly, a foreigner could get all of the necessary information about a place, like the types of beverages served, the price category, and whether food and accommodation were available, by looking at the sign outside.

The typical emblems of beer-serving premises had in part developed from the trade signs. This was exemplified by the drawings in the books of the Mendel and Landauer charities in Nuremberg [73]. The earliest known depiction of a professional brewer can be found in the Mendel charity book. It dates from 1425 and shows Herttel, the brewer, together with his brewing utensils. Interestingly, a hexagram is depicted above the brewing scene, indicating the use of this symbol in connection with beer brewing. It has been assumed that the use of the hexagram

as a icon for beer brewing and selling originates from its ancient meaning as a protective symbol and has little in common with the same symbol used by the alchemists or the Magen David used for the first time by the Jewish militia in neighboring Bohemia in 1350 [73]. Brewers' emblems others than the hexagram are also depicted in the charity books, for example, together with Jorg Prewmaister in 1437 (gate) and Hans Franck in 1506 (star). These symbols were soon used not only to indicate a professional brewer, but also the availability of beer.

This trend was strengthened further when Guilds built drinking parlors of their own and city councils furnished cellars in the town hall. This process favored the professional brewers who could offer beers of much superior quality in comparison to country brewers or brewing victuallers. Hence, professional brewing emerged in the medieval cities. It was the cities along the shores of the Baltic and North Sea where brewing technology was perfected further.

1.4

'Woar Volk Is, Bint Klaantn' [74]: Hopped Beer and the Seaports

1.4.1

Hanseatic League

After the downfall of the Roman Empire, several seaborne empires arose successively on the shores of the North Sea, based on powerful navies and international trade. The first was that of the Vikings/Normans followed by the German Hansa, the Dutch and finally the Britons. All had in common the fact that beer was an indispensable prerequisite for their seaborne ventures and constituted a trading commodity that contributed much to their wealth. The beer of course had to be particularly nutritious and stable in order to suit the necessities of sea voyages. Strong hopped beers proved to satisfy these requirements.

It is not certain that the inhabitants of the Viking settlement of Haithabu (Schleswig) already brewed beer with hops. The Vikings at Haithabu were neighbors of the Wendes, who certainly knew of hops. Moreover, large quantities of hops found at Haithabu can only be explained by invoking brewing [56]. Beer had been recorded as a trading good in the North as early as the mid-eleventh century [66]. Certainly, the citizens of Bremen brewed a hopped beer, about 100 years after Haithabu had been destroyed by the Wendes in 1066, and exported it overseas [75]. Beer from Bremen is mentioned at Holland in 1252 and Groningen (The Netherlands) in 1278. Soon, however, nearby Hamburg overtook Bremen as a brewing center, eventually because beer in Hamburg was brewed with wheat and barley malt instead of the common oat malt. The commerce in beer flourished and Hamburg was soon known as 'the Hanseatic League's Brewhouse'. In 1376, 475 of Hamburg's 1075 manufacturers were brewers who had exported some 133 000 hl in 1369 [75].

A confederation of Hamburg and Lübeck in 1241 served as a starting point for a much broader League of up to 170 cities, which was formalized in the first

general Diet of the Hansa held in 1356. There were now other important brewing centers associated with the League: Wismar, Rostock, Lübeck and Danzig. Commanding at the height of its power about 1000 ships, beer consumption by its own fleet might have amounted to over 250 000 hl annually if the quantities consumed at the time are considered [76]. However, most of the beer was exported; at its height the Hansa sold abroad well above 500 000 hl annually [75]. The League traded its famous hopped beer from Hamburg mainly to The Netherlands, where the little village of Amsterdam had been named as one of two exclusive custom places for beer from Hamburg in 1323. Another trade was established from the ports at the Baltic Sea (Lübeck, Wismar or Danzig) that exported what was often referred to as German or Prussian beer to Denmark, Norway and Sweden. In the period from 1562 to 1596, when the peak of the beer trade had already passed, Hansa ships still carried an average of 40 000 hl of beer annually through the Danish Straits [77].

Apart from its large trading network for beer exports, the League offered safe access to raw materials. Hops were no longer collected in the thirteenth century but planted in hop gardens in and around cities. Such hop gardens are reported from Wismar in 1250 and many other Hansa cities thereafter. Moreover, Hamburg had developed into the leading trading center for hops in Europe where hops were shipped to on the Elbe River even from Bohemia. This far-reaching trade allowed compensating for regional crop failures. Even more significant was the League's trade in malt. As it patronized the eastern granaries of Prussia, Pomerania and Mecklenburg, Hansa's brewers were independent of local grain supply, and could afford to always use choice grain and brew a strong beer of constant quality. Moreover, cities like Stralsund had specialized in malting and exported large amounts of malt [77].

The large-scale production of hopped 'export' beers of course required special production methods. Oats as the traditional brewing cereal were replaced during the fourteenth and fifteenth century by barley [72]. Some beers like that from Hamburg contained considerable amounts of wheat malt. Malt was air dried or kilned, resulting in 'white' or 'red' beers, the latter constituting the majority. Moreover, the amount of malt per brew varied considerable. Thus, taking the variation in brewing waters and technological variants into account, an astonishing diversity of beer styles emerged in Central and Northern Europe during the fifteenth century [75].

The manufacturing technology also changed. This started with brewing water, which was pumped and delivered by water mills as early as 1291 in Lübeck. As hops had to be boiled to benefit from their use, boiling vessels and heating technology had to be optimized. Until the early fourteenth century wooden vats had prevailed in rural brewing and iron pots with a capacity never exceeding 600 l were in use in the cities [75]. Wort preparation and fermentation were often conducted in the same vessels. Soon, however, larger copper kettles came into use with capacities of several thousand liters. This resulted not only in a significant increase in quality, but also in higher profitability. The urban kettles outclassed in their capacity particularly those of the monasteries—the greatest competitors of urban

brewers. The corresponding mashing technology ensured yields of 1.05–1.80l of beer per liter of grain, while aristocratic household in fourteenth-century England got 0.77–1.16l of ale per liter of grain [72], which can be assumed as pretty much the average for European brewing at that time. Of course, malting, fermenting and storage facilities had to be adapted to such volumes, which consumed 800–3000 kg of malt per brew [75]. Moreover, copper brewing kettles required significant capital expenditures. Therefore, the large kettles were first bought by the community and carried from house to house upon demand. Later, when the revenues justified the investment, brewers bought kettles themselves. While at first hung from the ceiling fixed to huge timbers, they were later integrated in furnaces to enhance fuel efficiency. Bricked ovens under copper kettles with fixed equipment to move the liquids in and out had become the standard of urban brewing by the sixteenth century [72].

The expansion of Russia and the loss of privileges in London initiated the downfall of the Hansa. After the Thirty Years War, the grain and malting region of Pomerania was lost to the Swedes. Their successors became the Dutch seaborne empire, which was better organized and commanded superior financial instruments. However, the Hansa brewers had been the first to develop a beer that could be transported over great distances overseas. Thereby they went far beyond the magnitudes handled by rural home brewers and urban victuallers until then. The limits they set were only surpassed by the London breweries of the eighteenth century.

1.4.2

Rise and Decline of the Cities in Central Europe

The overall conditions for brewing and selling beer changed dramatically at the end of the fifteenth century. Several factors contributed to this change.

First of all, the overall climate changed. Average temperatures dropped [78], although the actual levels varied regionally [79]. A decline in wine yields and a consecutive price rise resulted in an increased demand for beer [80]. The transition of Bavaria from a wine to a beer country must be seen in this context. This move had wider consequences, however. Next to grain, wine was the most important cash crop and was taxed heavily on the level of trade as well as on the level of consumption. As state revenue from wine started to fall, beer taxation and regulation of the brewing process increased.

Second, an increase in the population caused what has been termed the ‘sixteenth-century price revolution’. Population growth, currency debasement and growth of the money supply, combined with climatic effects, resulted in an accelerated inflation, particularly of grain prices [81, 82]. This had an impact on nutrition in general. From the sixteenth century meat consumption started to drop from about 100 kg/head in the fourteenth and fifteenth centuries to a minimum of 14 kg/head in the eighteenth and nineteenth centuries. Therefore, bread became the most important staple food and the daily amount considered as the minimum to survive almost doubled [83]. As 1l of good beer provided only 400–800 calories

in the fifteenth century, while 1 kg of bread yielded 2500 calories [3], brewing was restricted by legislation with respect to the types of grains used and malting/brewing periods (beginning only well after harvest until spring). Also during that time, the important fodder grain oats was increasingly substituted for barley. Urban and state purity laws prescribing barley as the sole brewing cereal perhaps also meant that the summer grain barley might be sown only after yields in winter varieties (wheat) appeared sufficient for bread supply.

The competition between bread and brewing in turn accelerated the rise in grain prices even more; the latter increased faster than beer prices in most regions [84]. This required restructuring and process optimization from brewers. The numerous ordinances interdicting malting and brewing during the summertime might have been motivated by concerns over the quality of malt and beer as well as the price situation before harvest time [3]. It might also, but by no means exclusively, be an indicator of bottom fermentation.

By the sixteenth century the infrastructure in Central Europe had improved so far that traveling and transport became possible at speeds not encountered since the times of the Roman legions [85]. Thus, overland transport became feasible even for commodities like beer, although at low volumes and high costs. A chart carrying 6 barrels of 1.75 hl (1 Rostock Ton) moved at a speed of 20–30 km/day, hampered by the numerous toll stations and bad roads. In contrast, a Hansa Kogge carried 600 such barrels much faster to distant customers. Accordingly, land transport added about 50–70% to the price of beer for every 100 km transported overland [84], and only very famous and stable beers were transported over longer distances. Strong hopped beers suitable for overland transport were developed, for instance in Einbeck, Hannover (Broyhan) and Braunschweig (Mumme), their increasing reputation being successfully marketed.

After an unprecedented increase in beer consumption during the fifteenth and sixteenth centuries the situation changed during the seventeenth and eighteenth century. The Thirty Years War had ravaged Central Europe, destroying capital and knowledge. In particular, the cities, centers of commercial brewing, were hit. The political structures had changed too, abating the significance of the cities. The territorial states emerged, and taxed and regulated professional brewing. Nobility as well as the monasteries and the rural populace increasingly ignored the privileges of the cities, particularly the precinct. As beer sales within the monopolized zone could make up to 80% of overall sales [3], these tendencies had a severe impact. After a war the Bohemian cities, for instance, lost their precincts in the treaty of St Wenzeslau in 1517 and the nobility began to erect breweries on their domains. Being producers of brewing raw materials themselves, the domain breweries could produce cheap beer of high quality. As in Bavaria, however, where the nobility had held the brewing privilege since the Middle Ages, the greater competition secured in the long run the supply of wholesome beer. More pressing, however, was increased taxation. No less than 18 different state and local taxes applied to beer production and beer selling in the renowned brewing city of Freiberg in Saxony [86]. The most decisive development, however, was the pricing of beer and its raw materials. As the raw materials made up about 60% of the costs

[84] (fuel and labor together made up 20%, and taxes 20%), the ratio of raw material cost to beer price was the most important parameter in brewing and the only one a brewer could govern to a degree. In the North, costs of raw materials increased at a faster rate than beer prices, inducing the brewers to compromise on quality. Beer consumption in these regions was therefore replaced by coffee, tea and particularly boozes. On the other hand, in the southern regions of Central Europe like Bohemia, Württemberg and Bavaria, lower raw material costs ensured profitability of brewing and consequently a constant beer quality. Therefore, these regions saw a constant rise in beer consumption over the seventeenth and eighteenth centuries [84].

1.4.3

Rise of Dutch Brewing

In the sixteenth and seventeenth the Dutch commanded the largest fleet on the seven seas and established a trading empire stretching from New York to Jakarta. The rise of The Netherlands to this height was accompanied by the formation of a brewing industry unmatched in its time.

The Low Countries had been a stronghold of *Gruit* beer until the fifteenth century. However, in the fourteenth century the Hansa had exported its hopped beer along the shores of the North Sea and Holland became the preferred market. While the textile industry was the major economic factor in Holland and Flanders, the displacement of the Hansa town of Lübeck from the lucrative herring and salt trade with Scandinavia was a starting point for the Dutch seaborne trade in the late fourteenth century. Concomitantly, an impressive brewing industry emerged in the Dutch cities, producing a stable hopped beer. This product first replaced the Hansa beers from the domestic markets, and consequently supplanted them in the markets of Scandinavia and Northern France [87]. Apart from beer, the export of textiles and herring and the import of grain and timber fuelled the Dutch economy. From 1400 to 1700, Dutch per capita income growth was the fastest in Europe.

The Dutch brewing industry resembled that of the Hansa towns in many ways: it was based on an urban economy and shaped by the peculiarities of the respective city. Although the Low Countries established the most advanced and efficient agriculture of its time, grains had to be imported to a considerable degree from Prussia and Pomerania. Barley, wheat, oats and in some cases rye were used for brewing depending on local and temporary trends [72]. Altogether, Dutch brewing did not differ significantly technologically from the European standards, but did differ in the fuels used. While wood was the standard heating fuel for brewing in Germany until the middle of the nineteenth century, Dutch brewers used peat and coal. Wood, which was rare and expensive, had to be imported from Scandinavia and Russia; however, peat was a domestic product. Beginning in the fifteenth century, Scottish coal was used for brewing. Fourteen tonnes of peat were required for a brew, requiring handling huge volumes. That volume was reduced by 75% if coal was used [87].

During the seventeenth and eighteenth centuries brewing in the Netherlands declined. For once, beer export had lost its significance. Moreover, from 1600 to the 1800s Dutch incomes were the highest in Europe, permitting the consumption of tea, coffee and French wine. Thus, the domestic market shrunk, too. The most serious threat, however, came from distilled spirits like brandy, gin and genever [87].

The Dutch brewers had contributed significant improvements to fuel efficiency in brewing, and they had spread their brewing technology to other continents, erecting the first breweries in New York, the Cape Province Indonesia.

1.5

'For a Quart of Ale is a Dish for a King' [88]: John Bull and the Industrialization of Brewing

Fermented malt liquors had been native to the British Isles since primeval times. In Roman times the shopping lists of the garrison document that beer was an important constituent of the legion's diet. In the eighth and ninth centuries different types of malt liquors were already in common use: clear ale, mild ale and Welsh (*wylisc*) ale [2, 51], the latter probably being an originally Celtic drink made from ale and honey [89]. At the same time, the *Historia Brittonum* speaks of '*vinum et siceram*', using the Carolingian expression '*sicera*' (see above) for alcoholic drinks. On the other hand, a lease dated 901 AD mentions 'beer' (*beor*) besides 'sweet Welsh ale' and 'clear ale', indicating that 'beer' was already common [51]. The term beer vanishes thereafter for 500 years to be used later for a hopped malt liquor. Moreover, 'bragot' (braggot), a drink mentioned again in the fourteenth century in Geoffrey Chaucer's *The Canterbury Tales* was probably a honey-containing malt liquor of Celtic origin.

As early as the ninth century the numerous alehouses could be identified by a long pole (and a bush of evergreens if they also sold wine). Later, the bush also indicated the serving of ale [90]. The pronounced affinity of his subjects towards ale compelled King Edgar, the reformer, on the advice of St Dunstan, to issue several laws against abuse and decreed that the large drinking vessels passed round at meals should be marked with pins at intervals to show the amount to be drunk. The distinct fondness of the English people for ale intrigued other governments too. The Magna Charta included a provision for the standardization of measures, mentioning explicitly ale in this context. However, it was the prospect of sharing profits with the government that soon fired the imagination of various administrations. The first tax on all movables, the 'Saladin tithe', was imposed on ale in 1188 and Henry III levied the 'Assize of Bread and Ale' on these basic victuals in 1267.

At the end of the fourteenth century their trading partners from the Low Countries confronted the Englishmen with hopped beer. Up to then, ale was the characteristic British drink of the time. It was probably not fermented throughout and the omission of hops gave it a heavy, sweet taste [91]. It was, as all British beers

were until the advent of lager from the continent in the nineteenth century, a top-fermented beverage. The new drink, soon called beer (*bière*), was adopted at a few places at the southern coast, but was at first vehemently opposed in the rest of the country. Although the brewers of beer were officially recognized as a guild in 1493, their product was viewed with utmost suspicion until well into the sixteenth century. ‘Hops, Reformation, Bays, and Beer Came into England all in one year’ goes a rhyme from the early sixteenth century based on Henry Buttes’ *Dyets Dry Dinner* and Andrew Boorde states in his *Brewiary of Helthe* that ale is the natural drink for an Englishman. In contrast, beer ‘is a natural drink for a Dutchman. And now of late days it is much used in England to the detriment of many Englishmen; for the drink is a cold drink; yet it doth make a man fat and doth inflate the belly, as it doth appear by the Dutchmen’s faces and bellies’ [92]. Nevertheless, hop growing was legalized by an Act of Parliament in 1554 and hopped beer slowly established itself alongside ale in England during the first half of the sixteenth century.

At this time producing ale and beer and selling it had become separate activities in Britain, much like on the continent. Thus, in 1522 the licensing of alehouses was made mandatory by law. The census of 1577 lists 14 202 alehouses, 1631 inns and 329 taverns (which sold wine in addition to ale)—one license per 183 people [51]. These licenses were an important revenue for the state and a century later the desperate need for money by successive governments resulted in the first excise ever on ale, beer, cider and perry in Britain early in 1643.

However, apart from tax revenues there was yet another reason for the various governments to be interested in the production of high-quality ales and beers. The Tudors laid the foundations for British sea power and beer soon proved to be a prerequisite for British maritime expansion, as indispensable as had it been for the Vikings, the Hansa and the Dutch. Thus, ale was a standard article of the sea ration as early as the fourteenth century. Henry VII established a naval brewery at Portsmouth in 1492 to supply his ships with beer [93] and Henry VIII granted his sailors 10 pints (5.7l) of beer daily. Later other naval brewhouses followed at East Smithfield (1683), London and Portsmouth [91]. At the latest after a series of stunning military misfortunes due to lack of beer and near catastrophes like the one caused by tainted beer during the battle with the Armada, the significance of beer in building an empire became evident to everybody. Beer was not only a rather stable beverage during sea voyages, but was also indispensable for the sailors health. Accordingly, Shakespeare’s son-in-law, Dr John Hall, cured scurvy by brewing a beer or ale of ‘ascorbic herbs, viz.: scurvy grass, watercresses and brook lime’ [94]. As Samuel Pepys, Secretary to the Admiralty, observed: ‘Englishmen, and more especially seamen, love their bellies above anything else, and therefore it must always be remembered in the management of the victualling of the Navy that to make any abatement from them in the quantity or agreeableness of the victuals is to discourage and provoke them in the tenderest point and will sooner render them disgusted with the King’s service than any one other hardship that can be put upon them’. It was Pepys who laid down that every sailor was entitled to 1 gallon of beer daily—a standard upheld until after Nelson’s time.

The provision of the fleet with victuals drew heavily on national resources. Between September 1651 and December 1652, for instance, the victualling contracts for the fleet came to 332 000 pounds sterling [95]. The building of the British maritime empire had two important ramifications for brewing: (i) the necessity to cater the ships for wholesome beer at all stations abroad resulted in the spread of British brewing techniques all over the world and (ii) the need to supply beer in large quantities at home contributed to the industrialization of beer production.

Attempts to discourage small-scale brewing had been made by local administrations since the fifteenth century. This trend was accelerated during the seventeenth century, when commercial constraints and an increased capital requirement for brewing technology added to the disadvantage of small-scale brewing. Large commercial ('Common') brewers were noted first in London in the sixteenth century and emerged soon in other large cities all over the kingdom.

Thus, at the dawn of the eighteenth century a number of powerful commercial breweries had already been concentrated in the London area. At the end of the century commercial large-scale brewing had been firmly established over the entire country with its center still being London. Nothing indicates better than these numbers the tremendous changes that took place in brewing during the eighteenth century.

This change was associated with one name: 'porter'. There are numerous legends around the invention of this black, bitter and thick beer. One has it that it was brewed for the first time at the Bellin brewhouse at Shoreditch in 1722, although an earlier version called 'Entire' might have consisted of a ready-made blend of three different styles previously available: 'ale', 'beer' and 'twopenny'. A sharp rise in beer taxes in 1692 would have encouraged brewers to blend the differently taxed beers. Most likely, however, 'porter's beer' was a popular synonym for 'brown butt-beer', a long established London drink [96]. Porter soon became known as a distinct beer style and dominated the British Empire for about 100 years. It defied the gin fever in the 1730s, and the competition of tea and coffee as well. John Bull with a glass of porter and a barley ear on his hat as sketched by Hogarth came to symbolize the Englishman and British way of life.

Three factors triggered the emergence of industrial brewing [96]. The first was the British exchequer, which depended heavily on the excise duties from beer. The authorities granted the large London brewers higher rates of tax relief than their smaller competitors, officially on the grounds that large-scale operations suffered more wastage [91]. The second factor was the London market. At times when beer was very susceptible to contamination, and transport was difficult and expensive, a booming home market in the world's most industrialized city was a distinctive incentive for scale-up. The third factor was porter itself. Made from dark brown malts, a specialty of the Hertfordshire maltsters, and large quantity of hops, it required extended maturation over several months to attain its characteristic flavor. Storage of large quantities made it easy to blend different batches of beer, smoothing out the inevitable variations to create a standard, reliable product [96]. Porter seems to have been the first beer technically suited to mass production at contemporary standards of control [91].

Porter brewing triggered a series of groundbreaking technical, organizational and commercial innovations to facilitate industrial-scale brewing. The porter brewers were affluent men, ready to command any innovation they thought potentially useful. The new breweries combined aesthetics with practicability. They comprised several floors to facilitate transport of intermediates and reduce unwanted contamination through compartmentalization. Industrial (i.e. mechanized) brewing reverted to cast iron equipment like malt mills, pumps and tubing. The scale-up of pans (kettles), fermentation vessels and storage vats proved challenging. The first sizable vats installed in 1736 were capable of holding 1500 barrels each; a vat mounted in 1790 held 10000 barrels [2]. When such a vat collapsed in 1814, 7600 barrels of porter flooded the brewery and its neighborhood, destroying several houses and killing eight people. At that time, walled storage facilities holding up to 20000 barrels were in use at Whitbread's brewery. Other important inventions concerned the advancement of the brewing process itself like the cooling of large quantities of wort or introduction of isinglass (collagen) for fining and stabilization.

In 1784, Henry Goodwin and Samuel Whitbread were the first brewers ever to establish a steam engine at a brewery. Needless to say that by then coal was the fuel in breweries. Coal had been used in manufacturing in England as far back as 1307 AD [97] and by the end of the seventeenth century some 1 million tons of coal were consumed in Britain in manufacturing [2]. The soaring price of wood had soon enticed many brewers to use coal for heating and it took only a little more time for the adoption of coal in malting. Thus, indirect kilning was devised and around 1800 the first experiments with malting drums were conducted. The use of the thermometer—described by Michael Combrune in 1762 [98]—permitted a fairly exact adjustment of malt colors. Although many more obstacles had to be overcome, the resulting 'English' malting process of indirect kilning proved to be far superior to anything known up to then.

Equally important, the acquisition, storage and transport of huge quantities of raw materials and providing appropriate financing had to be organized. Raw materials made up to more than half of the costs; duties constituting the biggest fraction of the rest [91]. This resulted in sophisticated malt and hops trading networks as well as in the spread of commercial malting, either at one's own risk or commissioned by the brewers who provided the barley. Finally, marketing strategies also changed. The industrialization of brewing started in the urban centers, where a mass market existed, and there new patterns in the distribution of beer emerged first too. The brewing victualler yielded to the retailer and the independent inns became tied public houses. The percentage of publicans tied by London breweries around 1850 exceeded 60% of all served and the loans made to them valued up to 1.5–2.7 pounds per barrel [91]. Thus, most of the fundamentals of manufacturing and selling beer in our times had been put in place in London by 1850.

The technology of industrialized brewing did not remain confined to England for long, but spread first to Scotland and Ireland, and consequently to other regions of the British Empire. In particular, in Ireland, the development of a brewing industry linked to the name of Guinness is noteworthy. The London

porter brewers had established a prospering market for their product in Ireland and sold considerable quantities of their beer there. However, high import duties rendered English beer rather expensive and tilted the market in favor of ardent spirits. The war with Napoleonic France increased the price of exports drastically and the determination of the government to curb hard liquor consumption at the same time opened a unique opportunity for Irish brewers [91]. Arthur Guinness of Dublin was most successful in adapting London brewing technology to Irish conditions. By 1840, over half of Guinness's annual production of 80 000 barrels was sold to England [91].

In the mid nineteenth century porter lost public favor and had to yield to new ale types. This change was initiated by modifications in porter manufacture itself. During the 1780s research had established that pale malts contained more fermentable sugars than the dark malts used to make traditional porter [99]. Porter breweries therefore substituted dark malts by pale ones and shortened maturation times. The traditional dark color was now obtained by the addition of charred 'color malt'. Only by increasingly sophisticated temperature management techniques could the stability of the product be maintained, but its flavor changed, resembling that of dark-colored ale [91]. In the meantime the brewers of paler ales and beers in the northern provinces had adopted the London technologies and adjusted them to their product. With the advent of fast and cheap freight, provincial ale brewers gained access to urban markets and began to scale-up their production. While London porter slowly sunk into oblivion, the different ale styles dominated the British market until the 1960s.

1.6

'We Live in a Country Where Beer Constitutes Quasi the Fifth Element' [100]: Advent of Lager and the Internationalization of Brewing

1.6.1

Bavaria and the Rise of Lager Beer

Bavaria is a medium-sized state stretching between the rim of the Alps and the Danube. After the Napoleonic wars it absorbed the Franconian countries up to the central German mountains and with them a long brewing tradition, a fine barley region and the then most important hop market in Germany. Until the twentieth century Bavaria was an agrarian state, with only few urban centers. Wine had constituted the preferred beverage of its inhabitants until the first half of the sixteenth century, and there was widespread consensus in the fifteenth and early sixteenth centuries that the qualitatively best beers originated from the Hansa towns followed by beers from Saxony, Thuringia and Bohemia. In the south, the brews from the northern parts (Franconia, Upper Palatinate) were considered superior to those from Bavaria. The reasons for this are manifold: the competition of cheap wine, smaller production volumes as well as the use of wooden vessels and instruments which facilitated infections.

In the sixteenth century the situation changed dramatically and subsequently Bavaria became synonymous with beer. Several factors, among them climate change and state intervention, precipitated this development. Nothing exemplifies the role of the state in shaping the drinking habits of its subjects and in regulating brewing better than the famous Bavarian Purity Law ('*Reinheitsgebot*'; literally 'purity order') of 23 April 1516 [69]. The purity law was certainly not the most pressing of the topics negotiated at the diet of Ingolstadt in this spring of 1516 and hardly any of the participants would have thought that the small paragraph dealing with brewing in the new governance passed then would be of any particular importance. However, the decree limiting brewing ingredients to hops, barley, malt and water turned out to be one of the few legislative measures lasting half a millennium and granted the name of the sovereign Wilhelm (the fourth) some status of immortality.

Purity laws had already been part of urban legislation for more than four centuries. However, these were issued by cities and never attained more than local significance. In contrast, the Bavarian Purity Law and aligned later ordinances regulated brewing in an entire state. It laid down fundamental standards for beer production at a time when rapid changes in brewing technology and beer varieties alienated authorities and consumers alike. The Bavarian Purity Law in the first place defined unambiguously the term 'beer', it stated the price of this indispensable staple food, and it established administrative measures to ensure a sufficient supply and a satisfactory quality. Its best known provisions are the instructions concerning quality: the exclusive use of barley malt, water and hops, the omission of other herbs and inorganic ingredients (with the exception of low quantities of salt, juniper berries and caraway, as specified later in 1553 and 1616), and the bottom fermentation, interdicting brewing activities during summertime.

Bottom fermentation had probably been known in Bavaria since the beginning of the fifteenth century as brewing ordinances from Landshut (1409) and Regensburg (1454) indicate [69]. In Munich, bottom fermentation was presumably first practiced by a 'Bohemian' brewer from Eger (Cheb, at the Bohemian–Franconian border) [101]. While in Bohemia proper top fermentation was universally in use until the nineteenth century [1], the brewing ordinances of Nuremberg of 1303–1325 indicate that a dark, hopped, bottom-fermented beer was brewed in Franconia at the beginning of the fourteenth century [102, 103]. In Nuremberg, a special guild, the 'Hefner' (Yeasters), was responsible for maintaining a stock of (dried) yeast over the summer (when brewing was not permitted) and providing sufficient yeast when brewing was resumed in September. From Franconia, bottom fermentation might have spread to Bavaria where it was firmly established by 1600.

While the Bavarian Purity Law set a binding norm for what beer is and how it is manufactured, it left sufficient room for competition between the three emancipated brewing classes: the burghers, the nobility and the church. Unlike other German regions, where such competition was curtailed by precincts and privileges, contributing to a decline in beer quality, an acceptable excellence of beer was maintained in Bavaria. The great public concern in all brewing matters and the strict governmental scrutiny of producing and serving beer encouraged the

widespread idolization of beer. There were three styles of beer available. The first was the white (top-fermented) wheat beer, which only the sovereign was permitted to manufacture [104], resembling an earlier Bohemian type. The second, available only in some regions, was a 'white', top-fermented barley beer. The ubiquitous, typical Bavarian beer, however, was the bottom-fermented brew of dark brown color.

After the Napoleonic Wars, Bavaria was the first German State to enact a constitution, liberalize trade regulations, and harmonize weights and measures, thus paving the way for the industrialization of brewing. However, as elsewhere it was the taxation (the 'Bierregulativ') that favored larger production units by setting a maximum price [105]. Although slowly, industrial-scale brewing emerged, always following British examples. 'So much is certain that the English are the very masters of brewing. They had been the first ones who wrested brewing from empirical handicraft and practiced it with reliability and precision by applying chemistry, mathematics and physics' wrote a compendium in 1811 [106].

However, it was not possible just to copy British technology and processes as Bavarian lager brewing significantly differed in some respects from porter and ale brewing (Table 1.2).

The outstanding property of Bavarian lager was its stability as it was intended to last over the summer. Therefore, enough nutrients had to be left after the main fermentation to allow residual yeast cells to remain viable and continue fermentation at the low temperatures in the storage cellars. A low degree of attenuation was therefore desired, and this was accomplished by special bottom-fermenting yeasts and low temperatures. This type of fermentation of course results in a distinct flavor pattern [111], which differed significantly from the other beers of the time. Differences existed also in the malting process, where British technology was unsurpassed at the time.

1.6.2

Spread of Lager Brewing

Until about 1860 there were two different developments proceeding in Munich and Franconia, respectively. In Munich, which attracted increasing numbers of inhabitants, rapidly expanding breweries served the home market. As Munich brewers commanded respectable financial resources, they were able to implement the newest technology. The first 'English-type' malting kiln with indirect heating was installed in 1818, the first steam engine in 1840 and wooden equipment replaced by metal appliances as far as possible. After the completion of the important railways connecting Bavaria with the rest of Germany the most severe limitation of Munich breweries—cooling and supply of coal—could be overcome. Wood remained the principle fuel for brewing and malting in Bavaria until the middle of the nineteenth century. Even more pressing was the development of technical means for cooling wort, fermentation vats and maturing vessels—an essential prerequisite to overcome the legal restriction of (bottom-fermenting) brewing during summertime. The construction of underground cellars in the vicinity of

Table 1.2 The three primary beer styles (about 1875–1914 [107–109]).

Process	Brown Bavarian lager	Pale American lager	British pale ale
Malt	summer barley, germination 4–10 days, air-drying and subsequent direct and indirect kilning, close at 85–87°C	six-row barley malt, drying/kilning for 26–30 h, close at 85–87°C	germination 10–15 days, indirect kiln, air drying for 3–4 days, close 5 h at 75°C; pale, excellent solution
Mashing process	decoction, two- or three-mashing process	malt, corn, rice, syrups; ‘double’ mashing technology: unmalted materials, mashed at 40–70°C, boiled; malt doughed at 38°C, boiled adjuncts added, subsequently infusion mashing at 67°C	infusion process, high starting temperature (64–69°C)
Main fermentation	bottom fermentation, 6–12 days, 6–10°C, limited attenuation	bottom fermentation, closed tubs, CO ₂ collected, one tub, 2–5 days, 8–12°C	top fermentation, two tubs, 49 h, 17–22°C, high degree of attenuation
Microorganism	slow-fermenting yeasts (<i>S. uvarum</i>) with uniform genomes [110].	bottom-fermenting yeasts, slight flocculation	fast-fermenting yeasts (<i>S. cerevisiae</i>), heterogeneous genomes, several species
Second fermentation, storage	after saccharification for 6–8 days, storage up to 6 months	2–12 weeks at ≤3°C; fining (chip tanks), carbonating	>3 months
Beer (W: wort; A: alcohol)	W: 11.0–13.5%; A: 2.7–4.0%	W: 12–13%; A: 3.8%	W: 13.5–14.0%; A: 4.1–5.0%

Munich and the availability of natural ice were decisive in the abolition of the time-honored proscription of summer brewing in 1850. Soon the enormous quantities of natural ice required by the brewers and other food industries could only be provided by an extensive international trading network [112]. Only the advent of the Linde ammonia refrigeration in 1875 finally permitted large-scale lager brewing anywhere at any season. From 1806 to 1871, beer production in Bavaria rose from 3 700 000 to 8 600 000 hl; 97% of it being the characteristic bottom-fermented brown beer. By 1897, it had almost doubled again to 17 000 000 hl; 2 600 000 hl of which were exported. More than half, 1 500 000 hl, of the exports were produced in Munich [105].

This success of Bavarian lager beer can be attributed to a large extent to the Franconian breweries that had previously popularized this beer type in Saxony and

Table 1.3 Beer export of selected Bavarian cities (1000 hl).

	1843	1869	1879	1889	1896
Kitzingen	10.8	13.1	7.9	1.7	0.6
Erlangen	0.1	42.9	100.4	112.3	99.3
Kulmbach	3.8	60.6	143.7	379.8	626.1
Nürnberg	8.6	78.5	186.9	236.7	151.7
Munich	0.01	28.3	254.5	ca. 1200.0	1450.1

the Prussian countries. Much smaller and technically less advanced than their Munich counterparts, Franconian breweries nevertheless succeeded in developing a beer type that matched the taste of the northern German public. This beer, dark and bottom fermented like the products from Munich, contained about 1% more alcohol [107, 113] and exhibited an excellent stability. In the adjacent northern countries, top-fermented beers still prevailed until the last quarter of the nineteenth century, which were inferior to the Franconian products with respect of price and quality.

As indicated in Table 1.3, three distinct phases in the spread of Bavarian beer can be roughly distinguished. In a first phase until about 1850, beer exports were driven by the abolition of trading barriers as a consequence of the German customs accord of 1834 and the expanding railway network. A second phase spanning roughly between 1850 and 1890 was characterized by great technical improvements, the final liberalization of trade in 1869 and the German unification of 1871. The latter resulted in a dramatic acceleration in the pace of industrialization with a corresponding increase in beer consumption. During this period, however, the well-established market for Bavarian beer was threatened by the large newly built lager breweries in other German states.

During the industrialization of Germany, lager beer played the role that porter had played in eighteenth-century London. Accordingly, lager breweries came into being all over Germany. Particularly dramatic was the development in the centers of industrialization. In Berlin, lager beer production rose from 150 000 hl in 1860 to 1 940 000 hl in 1890, while the output of the traditional top-fermented beer increased over the same time from 370 000 to only 1 060 000 hl [114]. In Dortmund, where a strong, stable lager beer called ‘Export’ was brewed, production soared from 120 000 hl in 1866 to 1 400 000 hl in 1900 [115].

As the scale of production necessary to compete in the larger markets required considerable working capital, only companies able to raise equity carried the day. During this time Munich breweries rushed into the markets developed previously by Franconian brewers (Table 1.3). The final phase, from the last decade of the nineteenth century until World War I, is characterized by a saturated market where tied houses, extensive advertising and marketing as well as new sales channels like bottled beer become widespread.

Moreover, new beer styles came into vogue. In particular, Pilsner, a pale, heavily hopped beer styled by a head brewer at the civic brewhouse at Plzen (Pilsen), Josef Groll in 1842, quickly attained attention throughout Europe. Between 1880 and 1897, Pilsner exports to Germany multiplied 6-fold and in the Austrian empire the Civic Brewery in Plzen came only second to Anton Dreher's brewery in Schwechat [113]. Soon other breweries tried to copy the Pilsner brew. As the soft water of Plzen was a decisive factor in Pilsner brewing, at first only a few breweries that had exceptional soft water at their disposal succeeded in producing Pilsner style beers. One of them was the brewery in Freiberg (Saxony) in 1863. Successively, however, the Pilsner style was reproduced in many places. However, at first only places where a particular soft water was available and in 1899, when breweries generally had recognized the marketing value of a 'place of origin' labeling, a court decided that 'Pilsner' did not designate a regional provenance, but a distinct beer style.

As indicated in Table 1.3, only Kulmbach, a small city of about 8000 inhabitants at the time, and Munich, numbering about 400 000 inhabitants, were major centers of Bavarian beer export in 1900. The disproportionate ranking of Kulmbach can be explained by three factors: its distinct dark beer, its brand name relying on the high recognition of Kulmbach as a brewing and malting center, and, most important, the affiliation to the Dresden–Berlin brewery holding. The latter was structured by the brothers Max and Georg Arnhold who concentrated their Dresdner private bank business early in brewing. During the 1880s they acquired malt factories, breweries in the industrial centers (Berlin, Dresden and Frankfurt) as well as famous brands (Radeberg, Kulmbach, Kiel), and set up a special bank (Braubank) to manage their holdings. By cost cutting and optimizing marketing and sales channels, they became an all-round provider that could offer different products and services through a standardized distribution network [116].

The British brewing industry had experienced exceptional growth too, using newly raised equity for expansion, technology and—a specialty of the British market—the acquisition of tied houses. This increasingly costly engagement in estates provoked a concentration process in the brewing industry and dangerously exposed it to the hazards of the property markets [117]. However, as in Germany, dividends of incorporated breweries and malt factories at that time never fell short of 5%.

After 1900, the economic boom of the 1880s and 1890s came to an end all over Europe, resulting in unprecedented restructuring and concentration of processes in Germany and Britain alike. By 1914, in Britain, the big breweries, in particular Guinness, had weathered the storm and experienced prosperity again [117]. In Germany, the Arnholds were in a comfortable position to adapt to the new realities. The structures that they had created around 1900 were to last until the 1990s when globalization reshaped German brewing.

1.6.3

From Alchemy to Biochemistry: The Science of Brewing

The quantum leap in brewing during the eighteenth and nineteenth century was for the most part the result of the implementation of scientific principles that facilitated the development of appropriate equipment and technologies.

The first step towards scientific brewing was the adaptation of measuring devices to the specific needs of the brewers and maltsters, and the development of new instruments. Here, British brewers led the way. In 1762, Michael Combrune published his *Essay on Brewing* stressing the importance of using a thermometer in brewing and malting. The book was almost immediately translated into German and French, and a subsequent edition found its place on the bookshelf of Thomas Jefferson. A little later, in 1769, James Baverstock used a hydrometer to measure hop extract. However, it was John Richardson's treatise on *Statistical Estimates of the Materials of Brewing* that precipitated the search for means to measure the 'attenuation' (i.e. the decrease of wort density and concomitant formation of ethanol with increasing precision). After considerable progress linked to the names of T. Thomson, S. Hermbstädt, J. Long, C. Steinheil and J. Fuchs, it was Carl Josef Napoleon Balling from Prague who finally established a reliable method to measure and control the conversion of wort sugars into ethanol by fermentation in the brewery in 1843 [118].

Even though it was possible from the 1830s on to quantify satisfactorily the wort sugar content and its conversion to alcohol (the Spaten brewery in Munich had used a Long saccharometer since 1834), the process of fermentation itself still remained a mystery. In 1803, the Institut de France had offered a medal worth 1 kg of gold for an answer to the question: 'What are the characteristics which distinguish vegetable and animal substances acting as ferments [substrates] from those that undergo fermentation [enzymes]?' [119] The Frenchmen A. Lavoisier (1789) and J. Gay-Lussac (1815) had established the chemical formula of the oxidation of glucose to CO₂ and ethanol. The Swede J. Berzelius had formulated the principles of catalysis (1835) and the German J. Liebig had applied these to sugar fermentation (1839), giving a fairly accurate description of the overall process. The snag with the chemical theories was that they were of little use for brewing practice.

Meanwhile, the first enzymological studies were published: amylase (diastase) was discovered in barley by the Frenchmen A. Payen and J. Perzoz in 1833, invertase in yeast by P. Berthelot in 1860, and the acid protease pepsin by the German T. Schwann in 1836 in the mucosa. On the other hand, progress in optics permitted Giovanni Battista Amici from Italy to build a microscope in 1837 that had a numerical aperture and a resolution not much inferior to modern microscopes [119, 120] These improvements opened up the possibility of detecting and characterizing microbes for the first time, and laid the foundations of a new science—microbiology. Soon, in 1837, three scientists, C. Cagniard-Latour of Paris, F. Kützing from Halle and T. Schwann of Berlin, discovered independently that yeasts are living organisms. The fascinating aspect of the theories of the 'microscopists' was that the catalyst, yeast, was not only well known to brewers, but could now be observed directly under the microscope. The Spaten brewery in Munich bought a microscope for 7 Gulden in 1855.

It was another Frenchman, L. Pasteur, who subsequently laid the fundamentals of scientific microbiology and established unequivocally between 1855 and 1875 the role of yeast in alcoholic fermentation, the physiological nature of fermentation, and the differences between aerobic and anaerobic metabolism. The immense

interest awakened in microbes sensitized the scientists to the differences of microbial genera and resulted in the characterization of different yeasts [121]. In 1876, in *Études sur la Bière*, Pasteur had already recommended ensuring that brewing yeast was free of ‘disease-causing ferments’ by purifying it from bacteria. However, it was C. E. Hansen who in 1883 separated three different species from the yeast used the Carlsberg brewery. The original strain had been obtained from the Spaten brewery in Munich in 1845 and used ever since. It turned out that only one clone resembled the original strain, while the two others were ‘wild yeasts’ from the Carlsberg orchards just outside the brewery [122]. Although some time passed until it was generally accepted, the theory of pure yeasts prevailed at the end of the century.

The newly flourishing science of chemistry had its impact on brewing too. In 1820, the German-born London-based Professor Frederic Accum published *A Treatise on the Adulteration of Food and Culinary Poisons*. In his manuscript, Accum not only revealed a long list of unwholesome additives in beer, but also named those brought to the courts for beer adulteration. His book caused an outcry among food manufacturers in London and after much harassment Accum fled to Germany.

Ten years later, Arthur Hill Hassall, John Postgate and Thomas Wakley resumed the fight against food adulteration. Their analyses revealed that industrialization had by no means improved beer quality. Among other poisonous substances, the presence of picric acid, *Cocculus indicus* (fishberry), Levant nut (containing the alkaloid picrotoxin) and strychnine were detected in beer. Moreover, beer purchased directly from the brewers was shown to contain 4.53–7.15% alcohol, while the same beer bought from a publican varied in its ethanol content from 3.23 to 4.87%. Thus, at the sales level beers were adulterated too and spiked with poisonous bittering substances to delude the consumer. In Germany, the situation was by no means better; work by G. Hopf (1846), H. Klencke (1858) and M. Bauer (1877) detected strychnine, picric acid and opium among many detrimental substances in beer. In spite of these findings, powerful brewing lobbies delayed legislation for many years. Only in 1860 was an ‘Adulteration of Foods Act’ adopted and in 1885 a bill regulating the content of beer passed in Britain. In Germany, a law regulating food safety was enacted in 1879 and the Bavarian Purity Law became federal German law in 1919.

The most lasting consequence of the developments outlined above, however, was the emergence of brewing as a scientific discipline. Certainly, by the middle of the nineteenth century a vast literature on brewing existed, accumulated ever since movable letters had been used to print books. However, these were pure descriptions of individual knowledge on how to fabricate beer. Their use for others was rather limited, as the publications lacked the most important prerequisites: standardized equipment and objective measurements. Only after thermometers and saccharometry had been established in brewing, weights and measures had been aligned, and brewing equipment became comparable, could scientific theories be conceptualized. Brewing science commences with small groups of apprentices being taught the basics of physics and chemistry, and their application in

brewing. In Munich, Professor Cajetan Kaiser started teaching in his parlor in 1836. Of the scholars, only about a third were from Bavaria—the majority came from other German states or abroad. In 1865, a brewing curriculum was established at the Technical University at Weihenstephan near Munich and in 1888, brewing classes started at the University of Berlin [122]. The Institute of Brewing was formally established in London in 1890. In the United States, John E. Siebel opened the Zymotechnic Institute in 1872 [123] and Anton Schwarz founded the Brewers' Academy of the United States in 1880 in New York. The establishment of an academic brewing science was accompanied by the publication of scientific journals and a multitude of books on brewing technology. By 1900, brewing had become an accepted branch of the natural sciences.

1.6.4

Europe, the United States and the Internationalization of Beer Brewing

At the turn of the twentieth century beer production and consumption had spread all over the world (Table 1.4; the numbers are estimates due to large fluctuations in beer output at the time and inaccuracy of records).

While at that time 79% of the world's beer still was of European origin, today the corresponding figure is rated at 34%, as the Americas and Asia have developed their own production and beer markets. Moreover, grouping of beer output according to countries was reasonable in 1900, when national habits formed beer styles and markets. However, such a classification is of less significance today, when companies rather than states have the main impact on brewing. Currently, the world's leading brewing conglomerate produces more beer than all the breweries in Germany and Britain—in 1900 the leading brewing nations—combined. The basis for this development was laid down at the end of the nineteenth century with the concentration of breweries within Europe and the emergence of a powerful brewing industry in the United States.

American brewing mirrors the cultural diversity of its immigrants and the variety of brewing materials available as much as the ingenuity of its inhabitants. Legend has it that the Pilgrim Fathers debarked in Massachusetts because their beer supply was exhausted. Following the advice of established settlers it was recommended to newcomers in 1620 to bring a sufficient supply of malt for brewing with them in order 'to avoid the sudden transit to water drinking which can cause great transformations of their body' [126]. The first authentic record of the existence of a public brewery dates back to 1637, as far as Massachusetts Bay, and to 1638, as far as Rhode Island is concerned [127]. Later, William Penn built a brewhouse at Pennsbury in 1683 and the brewery Leonhard Baretz established in 1744 at Baltimore was the largest in the states at its time. However, it was at 'New Amsterdam' (Manhattan) where brewing flourished first. New Netherlands established public breweries in 1632, an excise tax on private brewers in 1644, and laws regulating brewing and the quality of beer in 1664. However, home brewing prevailed in the sparsely populated country and resorted to suitable materials and methods. As only the rich brewers in the cities could afford to buy malt from

Table 1.4 World beer production around 1900 and 2003 [113, 124, 125].

Country	Output (1000 hl)	
	1897–1901	2004
Germany	69,000	106,190
British Empire	64,000	
United Kingdom	60,500	58,911
Ireland		8,142
British Colonies	3,500	
Australia		1600
Canada		1100
India		245
Cape Province/South Africa		100
United States	46,400	233,300
Austria–Hungary	21,500	
Austria		4,800
Bohemia/Czech Republic		9,400
Moravia/Slovakia		2,000
Galicia/Poland		1,200
Hungary		1,400
Rest Austro-Hungarian Empire		2,700
Italy		13,125
Belgium	14,100	17,409
France	9,600	16,801
Russia (Commonwealth of Independent States)	5,200	85,200
Sweden	3,300	3,788
Denmark	3,000	8,550
Switzerland	2,500	3,561
Netherlands	2,200	23,828
Middle and South America	1,500	233,626
Mexico		300
Chile		400
Argentina		290
Brazil		220
Peru		15
Norway	500	
Japan	270	65,490
Smaller states of Europe	230	73,000
Serbia		70
Romania		65
China		291,000
Spain		30,677

Britain, poorer people used molasses, corn or bran for brewing, or even resorted to a kind of beer-bread [128]. John Winthrop was awarded a prize for succeeding in preparing an acceptable beer from corn. The following years saw a decrease in beer consumption, as Robert Proud in his history of Pennsylvania notes, because ‘the consumption of tea, coffee and chocolate spread more and more and supplanted beer’ [123]. The beverages made from domestic grain or other native raw materials were considered of inferior quality even before the War of Independence discontinued the malt supply from Britain and caused further deterioration in malt liquor quality. As a measure for business development as well as to curb hard liquor consumption, Massachusetts passed an act encouraging the manufacture and consumption of ale and beer in 1789. Around 1810, Americans still consumed 18 quarts of distilled drinks and 5 quarts of beer per head; 218 000 hl of beer were produced by 140 breweries – Pennsylvania and New York being the leading brewing centers.

In 1840, a German born brewer, John Wagner, produced the first lager beer in the United States in a tiny hut next to his house, using yeast he had brought from Bavaria [123, 124]. Increased immigration and a resulting change in the ethnic composition as well as the industrialization in the big cities had a dramatic impact on beer consumption and production. Brewing spread along the waterways and, later on, along the railways. Due to the deep-rooted ale tradition, it would take almost 40 years for lager to outsell ale. In 1881, John Ewald Siebel published an article in the *Western Brewer* concerning the use of unmalted cereals in brewing. This was a milestone in the development of beers specifically adapted to the United States taste for lighter colors, flavors and texture, and marked the beginning of a distinct American brewing technique [129]. Thus, the ensuing famous pale American lager differed significantly from European beers (Table 1.2). First, it was made not only from malt but contained corn (grits, flakes and flour), rice and corn syrups as well, since the native six-rowed barley did not yield malts of the desired properties. Enzymes were applied in brewing from 1910 on to improve raw material utilization and enhance beer stability. Mashing, fermenting and storage were perfected to yield a clear, pale beer of about 3.8% alcohol by weight. The typical European decoction technique was replaced by most brewers by the American infusion mashing method to yield more ‘fruity’ beers. Finally, the new lager styles dominated the market; ale and porter accounting for less than 5% of beer production between 1910 and 1915 [130]. Thus, American breweries at the dawn of the twentieth century developed the technologies to make a distinct beer from any starch-containing material, that is, even at places where the traditional brewing grains cannot be grown.

Secondly, America was a relatively sparsely populated country. To reach consumers outside of the big cities made long-range transport necessary, and required very stable beers, adequate packing and sophisticated logistic networks. Thus, refrigeration technology was not only optimized for production, but also for (rail) transport. Moreover, bottled beer played an important role, accounting for approximately 30% of the total output during the period from 1910 to 1915. Standardized bottles and barrels were the norm, and the crown cork was introduced by W.

Painter in 1892. To enhance stability, elaborate filter systems, pasteurization and CO₂ management (artificial carbonization) became routine. Thus, beer production and distribution became standardized and independent of seasonal and climatic variations.

Nothing changed the American brewing scene as much as prohibition, which became general law (Volstead Act) in 1920. Although prohibition laws had been enacted in some states before and Canada had prohibited alcohol consumption since 1917, now the whole of America was affected. While 1243 breweries existed there in 1916, only 31 were left in 1933 and 756 in 1934. At first brewers tried to make a living from 'near beer' or find alternative uses for their factories, but only a few managed to diversify and bring innovative products on the market to a degree to ensure their survival. The Anheuser-Bush brewery, for instance, spent US\$11.3 million on equipment for alcohol removal, diversification in yeast production, and the manufacture and marketing of alternative beverages like ginger ale [130]. However, the restraints of prohibition also resulted in innovations (e.g. in accelerating fermentation or home brewing equipment) and it had forged a powerful, consolidated brewing industry.

In summary, industrialization created the prerequisites for beer production all over the world, wherever a market had developed. Accordingly, it was not the availability of malt or suitable grains or favorable climatic conditions that were preconditions for brewing anymore, but demand and capital. Lead by the British colonies, brewing industries developed in many countries. In Japan, brewing started in 1853. By 1900, Japanese breweries manufactured bottled draft beer and Japanese beer received a Grand Prix at the Paris World Exhibition. In Rio de Janeiro, the first brewery operated in 1836 and over 900 000 hl of beer were produced in Brazil by 1913 [131]. Kulmbacher and Pilsner style beers were made at almost 4000 m above sea level in the Bolivian Andes in 1900, while Colonial ales were brewed at the same time in Tasmania [124]. This development is still going on and opens a wide scope for innovations, as native raw materials and regional preferences have increasingly to be considered.

We have encountered now almost 10 000 years history of fermented malt liquors. Based on the fundamentals established in antiquity, the cities generated the technology and organization for professional brewing. The necessity to provide a wholesome and stable beverage for sea voyages resulted in the creation of hopped beer and a flourishing beer trade along the shores of Northern Europe. The British Isles led the way from manufacture to industry, and the industrialized production of lager beer in Central Europe and North America set the stage for a global brewing industry.

As soon as man managed to pass on his most important experiences to further generations in writing, he immediately used this ability to describe brewing and the enjoyment of drinking beer. After so many years and regardless of numerous attempts to spoil this pleasure, the esteem of this sociable and wholesome beverage is the same as 10 000 years ago. Therefore, although beer has had a very eventful history so far, it will continue to be an indispensable attendant of humanity and there will always be the necessity to rewrite its history in the centuries to come.

References

- 1 Arnold, J.P. (1911) *Origin and History of Beer and Brewing*, Alumni Association of the Wahl-Henius Institute of Fermentology, Chicago, IL.
- 2 Hornsey, J.S. (2003) *A History of Beer and Brewing*, The Royal Society of Chemistry, Cambridge.
- 3 Unger, R. (2004) *Beer in the Middle Ages and The Renaissance*, University of Pennsylvania Press, Philadelphia, PA.
- 4 Nelson, M. (2005) *The Barbarian's Beverage*, Routledge Taylor & Francis, London.
- 5 Michel, R.H., McGovern, P.E. and Badler, V.R. (1993) The first wine and beer. *Analytical Chemistry*, **65**, A408–413.
- 6 Thunaeus, H. (1965) Sprachliches vom Bier, in *Jahrbuch der Gesellschaft für Geschichte und Bibliographie des Brauwesens 1965*, Institut für Gärungsgewerbe, Berlin, pp. 169–97, p. 174.
- 7 Egyptian inscription 2200 BC.
- 8 Maurizio, A. (1933) *Geschichte der gegorenen Getränke*, Verlagsbuchhandlung Paul Parey, Berlin.
- 9 Heun, M., Schäfer-Pregl, R., Klawan, D., Castagna, R., Accerbi, M., Borghi, B. and Salamini, F. (1997) Site of einkorn wheat domestication identified by DNA fingerprinting. *Science*, **278**, 1312–14.
- 10 Feldman, M. (2001) Origin of cultivated wheat, in *The World Wheat Book, A History of Wheat Breeding* (eds A.P. Bonjean and W.J. Angus), Lavoisier Publishing, Paris, pp. 1–56.
- 11 Simons, K., Fellers, J., Trick, H., Zhang, Z., Tai, Y., Gill, B. and Faris, J. (2006) Molecular characterization of the major wheat domestication gene *Q*. *Genetics*, **172**, 547–55.
- 12 Badr, A., Müller, K., Schäfer-Pregl, R., El Rabey, H., Effgen, S., Ibrahim, H.H., Pozzi, C., Rohde, W. and Salamini, F. (2000) On the origin and domestication history of barley (*Hordeum vulgare*). *Molecular Biology and Evolution*, **17**, 499–510.
- 13 McGovern, P. *et al.* (2004) Fermented beverages of pre- and proto-historic China. *Proceedings of the National Academy of Sciences of the United States of America*, **101**, 17593–8.
- 14 Michel, R. and McGovern, P. (1992) Chemical evidence for ancient beer. *Nature*, **360**, 24.
- 15 A seal from Tepe Gawra in Northern Iraq, now in the University of Pennsylvania Museum of Archaeology and Anthropology, shows two people drinking from a jar. They use bent straws characteristically for the consumption of grain-based fermented beverages.
- 16 Katz, S. and Voigt, M. (1986) Bread and beer. *Expedition*, **28**, 23–34.
- 17 Benitez, T. and Codon, A. (2003) Ethanol-tolerance and production by yeast, in *Handbook of Fungal Biotechnology*, 2nd edn (ed. D.K. Aurora), Marcel Dekker, New York, pp. 249–65.
- 18 Rabie, C. *et al.* (1997) Enumeration of fungi in barley. *International Journal of Food Microbiology*, **35**, 117–27.
- 19 Ishida, H. (2005) Two different brewing processes revealed from two ancient Egyptian mural paintings. *MBAA Technique Quarterly*, **42**, 273–82.
- 20 McGovern, P.E. *et al.* (1999) A funerary feast fit for King Midas. *Nature*, **402**, 863–4.
- 21 De Keersmaecker, J. (1996) The mystery of Lambic beer. *Scientific American*, **275** (2), 74–80.
- 22 'Oinos krithios' or 'oinos krithown' (types of barley wine) are mentioned by Herodotus, Aeschylus and Xenophon.
- 23 Van Oevelen, D., Spaepen, M., Timmermans, P., Geens, L. and Verachtert, H. (1977) Microbial aspects of spontaneous wort fermentation in the production of lambic and geuze. *Journal of the Institute of Brewing*, **83**, 356–60.
- 24 Civil, M. (1963) *A Hymn to the Beer Goddess and a Drinking Song: Studies Presented to A. Leo Oppenheim June 7, 1964*, Oriental Institute Press, Chicago, IL, pp. 67–89.
- 25 Hartman, L. and Oppenheim, A. (1950) On beer and brewing techniques in

- ancient Mesopotamia. *Supplement to the Journal of the American Oriental Society*, **70** (4), 10.
- 26** Damerow, P. (2001) Sumerian beer: the origins of brewing technology in ancient Mesopotamia, *Proceedings of the 16th ICAF Conference 1, Andechs*.
- 27** Huber, E. (1926) Bier und Bierbereitung bei den Babyloniern, in *Bier und Bierbereitung bei den Völkern der Urzeit, Veröffentlichungen der Gesellschaft für die Geschichte und Bibliographie des Brauwesens*, Institut für Gärungsgewerbe, Berlin pp. 9–28.
- 28** Röllig, W. (1971) Das Bier im Alten Mesopotamien, in *Jahrbuch der Gesellschaft für Geschichte und Bibliographie des Brauwesens 1971*, Institut für Gärungsgewerbe, Berlin, pp. 9–104.
- 29** Lutz, H. (1922) *Viticulture and Brewing in The Ancient Orient*, J.C. Hinrich'sche Buchhandlung, Leipzig.
- 30** Zarnkow, M., Spieleder, E., Back, W., Sacher, B., Otto, A. and Einwag, B. (2006) Interdisziplinäre Untersuchungen zum altorientalischen Bierbrauen in der Siedlung von Tall Bazi/Nordsyrien vor rund 3200 Jahren. *Technikgeschichte*, **73**, 3–25.
- 31** *Anabasis*, **IV**, 26–27.
- 32** Maeir, A. and Garfinkel, Y. (1992) Bone and metal straw tip beer-strainers from the ancient near east. *Levant*, **XXIV**, 218–23.
- 33** Homan, M. (2002) Beer production by throwing bread into water: a new interpretation of QOH. XI, 1–2. *Vetus Testamentum* **52**, 275–8.
- 34** Huber, E. (1927) Die Völker unter babylonischem Kultureinfluss. Auftreten des gehopften Bieres, in *Bier und Bierbereitung bei den Völkern der Urzeit (II)*, Gesellschaft für die Geschichte und Bibliographie des Brauwesens, Berlin.
- 35** Death, J. (1887) *The Beer of the Bible*, Trübner, London.
- 36** Helck, W. (1972) Das Bier im Alten Ägypten, in *Jahrbuch der Gesellschaft für Geschichte und Bibliographie des Brauwesens 1972*, Institut für Gärungsgewerbe, Berlin, pp. 9–120.
- 37** Mechow, M. (1977) Wer war Gambrinus? in *Jahrbuch der Gesellschaft für Geschichte und Bibliographie des Brauwesens 1977*, Institut für Gärungsgewerbe, Berlin, pp. 120–9.
- 38** Maksoud, S. et al. (1994) Beer from the early dynasties (3500–3400 ca. BC) of upper Egypt, detected by archeochemical methods. *Vegetation History and Archeobotany*, **3**, 219–24.
- 39** Geller, J. (1992) From prehistory to history: beer in Egypt, in *The Followers of Horus (Egyptian Studies Association Publication 2)* (eds R. Friedman and B. Adams), Oxbow Books, Oxford, pp. 19–26.
- 40** Samuel, D. (2000) Brewing and baking, in *Ancient Egyptian Materials and Technology* (eds P. Nicholson and I. Shaw), Cambridge University Press, Cambridge, pp. 537–76.
- 41** Faltings, D. (1998) *Die Keramik der Lebensmittelproduktion im Alten Reich*, Heidelberger Orientverlag, Heidelberg.
- 42** Samuel, D. (1996) Investigation of ancient Egyptian baking and brewing methods by correlative microscopy. *Science*, **273**, 488–90.
- 43** Ishida, H. (2002) Insight into ancient Egyptian beer brewing using current folkloristic methods. *Master Brewers Association of the Americas Technical Quarterly*, **39**, 81–8.
- 44** Bowman, A. (1974) Roman military records from Vindolanda. *Britannia*, **5**, 360–73.
- 45** Audouze, F. and Büchschütz, O. (1992) *Villages and Countryside of Celtic Europe*, Indiana University Press, Bloomington, IN.
- 46** Stika, H. (1996) Traces of a possible Celtic brewery in Eberdingen-Hochdorf, Kreis Ludwigsburg, southwest Germany. *Vegetation History and Archeobotany*, **5**, 81–8.
- 47** Grüss, J. (1932) Zwei altgermanische Trinkhörner mit Bier- und Metresten. *Forschung und Fortschritte*, **8** (23/24), 289–91.
- 48** Grüss, J. (1931) Zwei altgermanische Trinkhörner mit Bier- und Metresten. *Praehistorische Zeitschrift*, **XII**, 180–7.

- 49 From 'St Brigid's alefeast', Irish poem from the 11th century [2].
- 50 Jonas: Vita Columbani I 16a, according to Poll, I. (1928) Beiträge zur Geschichte des Klosterbrauwesens, in *Gesellschaft für die Geschichte und Bibliographie des Brauwesens*, Institut für Gärungsgewerbe, Berlin, pp. 9–33.
- 51 Monckton, H.A. (1966) *A History of English Ale & Beer*, The Bodley Head, London.
- 52 Riedesel zu Eisenbach, M. (1992) 'Fortis ab invicta cruce celia sit benedicta'. Das Klosterbrauwesen in St. Gallen, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1991.1992*, Institut für Gärungsgewerbe, Berlin, pp. 101–21.
- 53 Huber, E. (1927) Bier und Bierbereitung bei den indogermanischen Völkern in Persien und am Kaukasus, in *Bier und Bierbereitung bei Völkern der Urzeit II, Veröffentlichungen der Gesellschaft für die Geschichte und Bibliographie des Brauwesens*, Institut für Braugerwerke, Berlin.
- 54 Wilson, D. (1975) Plant remains from the Graveney boat and the early history of *Humulus Lupulus* in W. Europe, *New Phytology*, 75, 627–48.
- 55 Behre, K. (1999) The history of beer additives in Europe—a review. *Vegetation History and Archaeobotany*, 8, 35–48.
- 56 Behre, K., (1983) Ernährung und Umwelt der wikingerzeitlichen Siedlung Haithabu: die Ergebnisse der Untersuchungen der Pflanzenreste. *Ausgr. Haithabu* 8, Neumünster.
- 57 Eifler, O. (1940) Das Schrifttum über die physiologischen Wirkungen des Hopfens, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1940*, Institut für Gärungsgewerbe, Berlin.
- 58 Lutterbeck, W. (1940) Das Bier am Niederrhein, in *Veröffentlichungen der Gesellschaft für die Geschichte und Bibliographie des Brauwesens*, Institut für Gärungsgewerbe, Berlin.
- 59 Bartscherer, A. (1967) Vom Magdeburger Bärm-Amt und dem Kampf um dessen Ende, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1967*, Institut für Gärungsgewerbe, Berlin, pp. 67–79.
- 60 Plinius, *Historia Naturalis*, XVIII, 26, quoted according to Arnold [1], p. 125.
- 61 Boyle, R. (1661) *Tentamina quaedam Physiologica, Cum Historia Fluiditatis et Firmitatis. Accessit de novo Tractatus de Absoluta Quiete in Corporibus*, 9th edn, Samuel de Tournes, Geneva.
- 62 Bartscherer, A. (1952) Beiträge zur Lösung der Gruitbier-Rätsel, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1952*, Institut für Gärungsgewerbe, Berlin, pp. 109–32.
- 63 Anonymous (1936) Die anlässlich des 50-jährigen Jubiläums des schwedischen Brauerbundes im Nordischen Museum zu Stockholm veranstaltete Ausstellung, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1936*, Institut für Gärungsgewerbe, Berlin, pp. 166–73.
- 64 Poll, I. (1936) Das Brauwesen des Klosters Prüfening, in *Veröffentlichungen der Gesellschaft für die Geschichte und Bibliographie des Brauwesens: Beiträge zur Geschichte des Klosterbrauwesens 1*, Institut für Gärungsgewerbe, Berlin.
- 65 Anonymus (1992) Lodewijk van Gruuthuse und sein Bier, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1991/1992*, Institut für Gärungsgewerbe, Berlin, pp. 227–8.
- 66 Huber, E. (1934) Bier und Brauerei im Bereich der Hanse, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1934*, Institut für Gärungsgewerbe, Berlin, pp. 50–66.
- 67 Herzog, B. (1928) *Die Konkurrenzverhältnisse im Deutschen Braugerwerke*, Verlag Hans Carl, Nürnberg.
- 68 Meister, H. (1970) Ein Beitrag zur Geschichte des Hamburger Bieres, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1970*, Institut für Gärungsgewerbe, Berlin, pp. 92–9.
- 69 Hackel-Stehr, K. (1987) Das Brauwesen in Bayern vom 14. bis 16. Jahrhundert, in

- Gesellschaft für Öffentlichkeitsarbeit der Deutschen Brauwirtschaft e.V.*, Deutschen Brauwirtschaft, Bonn.
- 70 Behre, K. (1986) Die Ernährung im Mittelalter, in *Mensch und Umwelt im Mittelalter* (ed. B. Herrmann), Deutsche Verlags-Anstalt, Stuttgart, pp. 74–87.
- 71 Rösch, M., Jacomet, S. and Karg, S. (1992) The history of cereals in the region of the former dutchy of Swabia (Herzogtum Schwaben) from the Roman to the post-medieval period. *Vegetation History and Archaeobotany*, **1**, 193–231.
- 72 Unger, R. (2001) *A History of Brewing in Holland*, Brill, Leiden.
- 73 Trum, M. (2002) Historische Darstellungen, Zunftzeichen und Symbole des Brauer- und Mälzerhandwerks, Diplomarbeit, Lehrstuhl für Technologie der Brauerei I, Technischen Universität München-Weihenstephan.
- 74 Dutch proverb: 'Where there are people there are customers'.
- 75 von Blanckenburg, C. (2001) *Die Hanse und ihr Bier*, Böhlau Verlag, Köln.
- 76 Pilgrim, K. (1969) Der Durst auf den Weltmeeren, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1969*, Institut für Gärungsgewerbe, Berlin, pp. 70–123.
- 77 Gaessner, H. (1938) Bier, Malz und Hopfen im deutschen und besonders hansischen Überseeverkehr von 1562 bis 1657, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1938*, Institut für Gärungsgewerbe, Berlin, pp. 80–100.
- 78 Moberg, A., Sonechkin, D., Holmgren, K., Datsenko, N., Karlen, W. and Lauritzen and S. (2005) Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data. *Nature*, **433**, 613–17.
- 79 Osborn, T. and Briffa, K. (2006) The spatial extent of 20th-century warmth in the context of the past 1200 years. *Science*, **311**, 841–4.
- 80 Landsteiner, E. (1999) The crisis of wine production in late sixteenth-century central Europe: climatic causes and economical consequences. *Climatic Change*, **43**, 323–34.
- 81 Braudel, F. and Spooner, F. (1967) Prices in Europe from 1450–1750, in *The Cambridge Economic History of Europe*, Vol. IV (eds E.H. Rich and C.H. Wilson), Cambridge University Press, Cambridge, pp. 374–486.
- 82 Bauernfeind, W. and Woitek, U. (1999) The influence of climatic change on price fluctuations in Germany during the 16th century price revolution. *Climatic Change*, **43**, 303–21.
- 83 Montarini, M. (1999) *Der Hunger und der Überfluss*, Verlag C.H. Beck, Munich, pp. 126–30.
- 84 Huntemann, H. (1970) Bierproduktion und Bierverbrauch in Deutschland vom 15. bis zum Beginn des 19. Jahrhunderts, Dissertation, Wirtschafts- und Sozialwissenschaftlichen Fakultät, Georg-August-Universität zu Göttingen.
- 85 Behringer, W. (1990) *Thurn und Taxis: die Geschichte ihrer Post und ihrer Unternehmen*, Piper-Verlag, München.
- 86 Thiel, U. (1998) Das Brauwesen im 16. und 17. Jahrhundert, *Mitteilungen des Freiburger Altertumsvereins*, Freiburg/SN, **81**, 4–96.
- 87 Unger, R. (1995) The scale of Dutch brewing, 1350–1600. *Research in Economic History*, **15**, 261–92.
- 88 Shakespeare, W. (1611) A Winters Tale, Act 4, Scene III.
- 89 Breeze, A. (2004) What was 'Whelsh Ale' in Anglo-Saxon England? *Neophilologus*, **88**, 299–301.
- 90 Anonymus (1880) A bush is a sign of an ale-house. *Notes and Queries*, s6-II, 467.
- 91 Mathias, P. (1959) *The Brewing Industry in England 1700–1830*, Cambridge University Press, Cambridge.
- 92 Scarlett, E. (1938) A Tudor worthy: Master Andrew Boorde of Physycke Doctour. *The Canadian Medical Association Journal*, June 1938, 588–95.
- 93 Stubbs, B. (2003) Captain cook's beer: the antiscorbutic use of malt and beer in late 18th century sea voyages. *Asia Pacific Journal of Clinical Nutrition*, **12**, 129–37.
- 94 Waife, S. (1953) 1753 lind, lemons and limeys. *The American Journal of Clinical Nutrition*, **1**, 471–3.

- 95 Oppenheim, M. (1896) The navy of the commonwealth, 1649–1660. *English Historical Review*, XI, 20–81.
- 96 Sumner, J. (2005) Powering the porter brewery. *Endeavour*, 29, 72–7.
- 97 Nef, J. (1932) *The Rise of the British Coal Industry*, George Routledge & Sons, London.
- 98 Combrune, M. (1762) *The Theory and Practice of Brewing*, J. Haberkorn, London.
- 99 Sumner, J. (2001) John Richardson, saccharometry and the pounds per-barrel extract. *British Journal for the History of Science*, 34, 255–74.
- 100 Freiherr, W. (1756) Rechtsregeln und Sprüche/ Herausgezogen aus des Wiguläus Xaver Alois Freiherrn von Kreittmayr Anmerkungen zu den bayerischen Gesetzbüchern, Durch den Magistrat München gedruckt bei J. G. Weiss 1848, chapter 9, paragraph 1752, p. 164.
- 101 Sedlmayr, F. (1941) Die Irrungen der Münchner Brauer und Bäcker wegen der Hefe, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1941*, Institut für Gärungsgewerbe, Berlin, pp. 7–36.
- 102 Schultheiss, W. (1978) *Brauwesen und Braurechte in Nürnberg bis zum Beginn des 19. Jahrhunderts*, Nürnberger Werkstücke zur Stadt- und Landesgeschichte, Nürnberg.
- 103 Sprotte, J. (2005) Von 1303/1305 bis zum Jahre 2005. 700 Jahre Nürnberger Bier, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 2005*, Institut für Gärungsgewerbe, Berlin, pp. 87–131.
- 104 Letzing, H. (1995) *Die Geschichte des Bierbrauwesens der Wittelsbacher*, Verlag Dr. Bernd Wissner, Augsburg.
- 105 Struve, E. (1893) *Die Entwicklung des Bayerischen Braugewerbes*, Duncker & Humblot, Leipzig.
- 106 Anonymus (1811) Geschichte der Künste und Wissenschaften seit der Wiederherstellung derselben bis an das Ende des achtzehnten Jahrhunderts. Von einer Gesellschaft gelehrter Männer ausgearbeitet. 3rd volume, Göttingen (quoted according to [105]).
- 107 Heiss, Ph. (1875) *Die Bierbrauerei*, 6. Auflage, edited by V. Griessmayer, Lampart & Co., Augsburg.
- 108 Schönfeld, F. (1938) *Obergärige Biere und ihre Herstellung*, Verlag Paul Parey, Berlin.
- 109 Hartung, J. (1932) Die Brautechnik in den Vereinigten Staaten vor und nach der Einführung der Prohibition, in *Die Brauindustrie in den Vereinigten Staaten in ihrer technischen und wirtschaftlichen Entwicklung, Gesellschaft für die Geschichte und Bibliographie des Brauwesens*, Institut für Gärungsgewerbe, Berlin, pp. 101–90.
- 110 Hutter, K. (2001) Flußzytometrische Prozesskontrolle obergäriger Betriebshefen. *Monatszeitschrift für Brauwissenschaft*, 3/4, 48–54.
- 111 Fix, G. and Fix, L. (1997) *An Analysis of Brewing Techniques*, Brewers Publications, Boulder, CO.
- 112 Teich, M. (2000) *Bier, Wissenschaft und Wirtschaft in Deutschland 1800–1914*, Böhlau Verlag, Wien.
- 113 Michel, C. (1899) *Geschichte des Bieres von der ältesten Zeit bis zum Jahre 1899*, Verlagsbuchhandlung Gebrüder Reichel, Augsburg.
- 114 Stresemann, G. (1900) Die Entwicklung des Berliner Flaschenbiergeschaefts, in *Inauguraldissertation der Philosophischen Fakultät der Universität Leipzig*, R.F. Funke, Berlin.
- 115 Tappe, H. (2005) Dortmunder Bierproduktion und –ausfuhr im 19. und 20. Jahrhundert, *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 2005*, Institut für Gärungsgewerbe, Berlin, pp. 49–84.
- 116 Starke, H. (2005) *Vom Brauerhandwerk zur Brauindustrie*, Böhlau Verlag, Wien.
- 117 Vaizey, J. (1960) *The Brewing Industry 1886–1951*, Sir Isaac Pitman & Sons, London.
- 118 Balling, C. (1843) *Die sacharometrische Bierprobe*, Borrosch & André, Prag.
- 119 Barnett, J. (2003) Beginnings of microbiology and biochemistry. *Microbiology*, 149, 557–67.
- 120 van Cittert, P.H. and van Cittert-Eymers, J.G. (1951) Some remarks on the development of the compound microscopes in the 19th century.

- Proceedings of the Koninklijke Nederlandse Akademie Van Wetenschappen*, 54, 73–80.
- 121 Barnett, J. (2000) A history of research on yeasts 2: Louis Pasteur and his contemporaries, 1850 ± 1880. *Yeast*, 16, 755–71.
- 122 Luers, H. and Weinfurter, F. (1931) Die Einführung der Hefereinzucht im Brauereibetrieb, in Die Hefereinzucht in der Entwicklungsgeschichte der Brauerei, in *Gesellschaft für die Geschichte und Bibliographie des Brauwesens*, Institut für Gärungsgewerbe, Berlin, pp. 23–105.
- 123 Baron, S. (1962) *Brewed in America, The History of Beer and Ale in the United States*, Little, Brown and Company, Boston, MA.
- 124 Western Brewer (1903) *One Hundred Years of Brewing*, H. S. Rich, Chicago, IL.
- 125 Johann Barth & Son (2005) The Barth Report 2004/2005.
- 126 Schmölders, G. (1932) Die Brauindustrie in den Vereinigten Staaten von der Kolonialzeit bis zur Gegenwart, in *Die Brauindustrie in den Vereinigten Staaten in ihrer technischen und wirtschaftlichen Entwicklung*, Gesellschaft für die Geschichte und Bibliographie des Brauwesens, Institut für Gärungsgewerbe, Berlin, pp. 3–100.
- 127 Thomann, G. (1909) *American Beer: Glimpses of its History and Description of Its Manufacture*, United States Brewers Association.
- 128 Acrelius, I. (1759) *History of New Sweden: Or the Settlements on the River Delaware*, Translated from the Swedish original by William M. Reynolds, Historical Society of Pennsylvania, Philadelphia, PA, 1874.
- 129 Ryder, S. (2000) Editorial—The World Brewing Congress, *ASBC Newsletter*, 60, (2).
- 130 Hartung, J. (1932) Die Brautechnik in den Vereinigten Staaten vor und nach der Einführung der Prohibition, in Die Brauindustrie in den Vereinigten Staaten in ihrer technischen und wirtschaftlichen Entwicklung, in *Gesellschaft für die Geschichte und Bibliographie des Brauwesens*, Institut für Gärungsgewerbe, Berlin, pp. 101–90.
- 131 Köb, E. (1999) Wie das Bier brasilianisch wurde, in *Jahrbuch der Gesellschaft für die Geschichte und Bibliographie des Brauwesens 1998*, Institut für Gärungsgewerbe, Berlin, pp. 85–118.