Chapter 2
Earliest Fermented Beverages

Fermented beverages may be made from a variety of sugar-containing materials: cider from apples, sake from rice, mead from honey, beer from grains, and of course, wine from grapes [1]. However, if one considers the primary sources of sugar available to early peoples, this quickly becomes limited to wild berries and other fruits, tree sap, honey, and possibly milk from animals. In warmer climates, these sources could have been relatively plentiful, even in pre-farming eras, but in temperate zones, there would have been few abundant sources of sugar other than honey [2]. As a result, the earliest alcoholic beverage is generally thought to have been fermented honey [2, 3].

2.1 Fermentation

Alcoholic fermentation, also referred to as ethanol fermentation, is a biological process in which yeasts obtain energy via the conversion of various sugars (Fig. 2.1) into ethanol and carbon dioxide. Yeasts are eukaryotic microorganisms classified in the kingdom Fungi and are estimated to be approximately one percent of all fungal species. The principal yeast species responsible for fermentation is *Saccharomyces cerevisiae*, which has been used for thousands of years in both baking and the production of alcoholic beverages [4–6]. Evidence for this was found in material collected from Egyptian wine jars dating back to ~3150 BCE. This material, which was presumed to include dead cells and cellular debris from yeast, was extracted and subjected to two independent sets of PCR amplifications with the appropriate negative and positive controls. The resulting analysis then revealed DNA from an organism that can confidently be assigned to *Saccharomyces cerevisiae* [4]. Of course, there exists a wide variety of *S. cerevisiae* strains [6], with differences in kinds of yeast recognized as early as 1550 BCE, as demonstrated by the various yeasts types mentioned in the Ebers Papyrus: wine yeast, beer yeast and mesta-yeast, growing yeast, bottom yeast, yeast juice, and yeast water [7]. In addition, it has been postulated that early craftsmen cultivated successful yeast strains, possibly skimming off the frothy yeast from the surface of

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the fermentation vat in order to use it again for later fermentations [4]. It has even been suggested that yeast was possibly cultivated before grain [1] and may be the oldest domesticated plant [8].

The study of alcoholic fermentation dates back to efforts of Antoine Lavoisier[1] (1743–1794) (Fig. 2.2), who described the phenomenon as "one of the most extraordinary in chemistry" [9]. As a result, Lavoisier published in 1789 the first clear account of the chemical changes that occur in fermentation, reporting that 100 parts by weight of sugar were converted to 60.17 parts of alcohol, 36.81 parts of carbon dioxide and 2.61 parts of acetic acid. After developing improved analytical methods with Louis Thenard (1777–1857), Joseph Louis Gay-Lussac[2] (1778–1850) (Fig. 2.2) later revised Lavoisier's figures in 1810, estimating that fermentation of 100 parts of sugar resulted in 51.34 parts of alcohol and 48.66 parts of carbon dioxide [9]. Perhaps as a result of this work, the overall modern equation for alcoholic fermentation

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$$

is commonly attributed to Gay-Lussac, with most citing his work of 1815. However, as clearly pointed out by Barrett [8], the empirical formula for glucose was not established until 1843 by Dumas, with the molecular formula finally being published in 1870 by Adolf von Baeyer (1835–1917). Thus, as Gay-Lussac died in 1850, the modern equation given above cannot be correctly credited to him.

In reality, the simplistic equation above is somewhat deceptive as it ignores the fact that alcoholic fermentation is catalyzed by a number of enzymes and cofactors

[1] Antoine Laurent Lavoisier (1743–1794) was born in Paris on August 26, 1743 to a family of commoners that was just beginning to attain some status [10, 11]. He was educated at the College Mazarin, where he soon developed a taste for mathematics and physical science [11, 12]. He pursued legal studies as his main interest, however, eventually receiving a Bachelors of Law in 1763 [10, 11]. He eventually became a businessman, astronomer, geologist, tax collector, and a noted chemist. He was a member of the French financial and government establishment and was at one time or another President of the Academy of Sciences, Chief of the Bureau of Accounts, Commissioner to the National Treasury, and member of the National Assembly [10–13]. He is considered by many as the father of modern chemistry and included among his greatest accomplishments were a new, logical system of nomenclature and the organization of a new system of chemistry, with an operational definition of elements, classification of reactions and composition, and the mass balanced equation [11–13]. During the Reign of Terror, he was tried and sentenced as a result of his positions within the old regime, leading to his death by guillotine on May 8th, 1794 [10–13].

[2] Joseph Louis Gay-Lussac (1778–1850) entered the École Polytechnique in 1797. There he attracted the notice of the professor of chemistry, Claude Louis Berthollet (1748–1822), and began working in his private laboratory [14–16]. He received his Master of Arts in 1800 and went on to act as a demonstrator to Antoine François de Fourcroy (1755–1809). In 1809, he became a professor of chemistry in the École Polytechnique, as well as a professor of physics in the Sorbonne [15, 16]. He resigned from the Sorbonne in 1832 and became professor of chemistry at the Jardin des Plantes [15, 16]. Equally proficient both in chemistry and physics, Gay-Lussac made his mark in both sciences and is probably best known for his quantitative studies of the properties of gases [14, 16]. Gay-Lussac died in Paris in 1850.

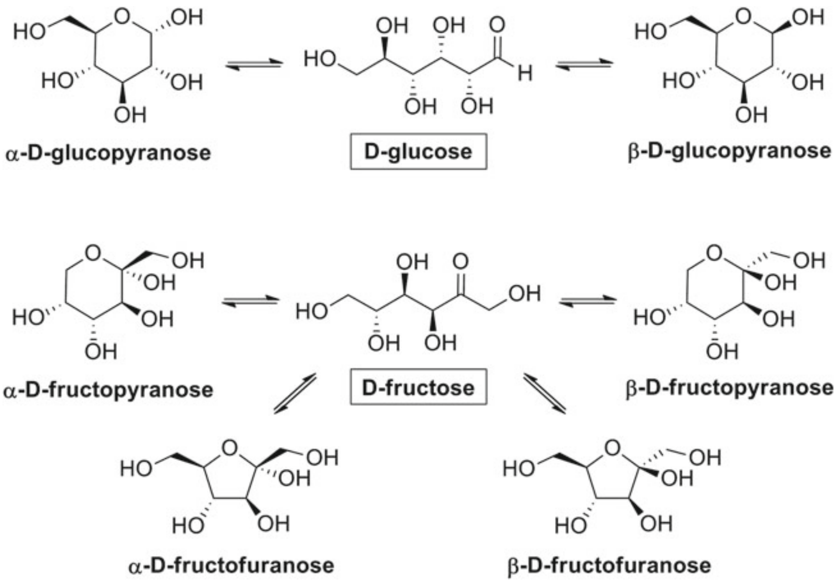

Fig. 2.1 The sugars D-glucose and D-fructose in the linear form, as well as the various cyclic hemiacetal isomers that predominate in solution

Fig. 2.2 Antoine Lavoisier (1743–1794) and Joseph Louis Gay-Lussac (1778–1850). (Edgar Fahs Smith Collection, University of Pennsylvania Libraries)

Fig. 2.3 Eduard Buchner (1860–1917). (Edgar Fahs Smith Collection, University of Pennsylvania Libraries)

that occur naturally in yeast [1, 17]. This mixture was extracted from yeast by Eduard Buchner[3] (1860–1917) (Fig. 2.3) in 1897, which allowed the first alcoholic fermentation outside of the cell. Buchner thought the extract contained an enzyme that catalyzed the fermentation [17, 19–21], stating [22]:

> The active agent in the expressed yeast juice appears rather to be a chemical substance, an enzyme, which I have called "zymase".

Thus, a more complete form of the equation above would give

$$C_6H_{12}O_6 \xrightarrow{zymase} 2\ C_2H_5OH\ +\ 2\ CO_2$$

[3] Eduard Buchner (1860–1917) was born in Munich on May 20, 1860 [18], the son of Ernst Buchner, professor of forensic medicine and physician at the University of Munich [19]. After a short period of study at the Munich Polytechnic, where he attended courses by Emil Erlenmeyer (1835–1909), he worked in a preserve and canning factory for four years to raise money for further studies [19]. He returned to his studies in 1884, including organic chemistry under Adolf von Baeyer [18] and plant physiology under Carl Wilhelm von Nägeli (1817–1891) [18, 19], and taking his doctor's degree at the University of Munich in 1888 [18]. von Baeyer took Buchner on as a paid assistant in 1890, made possible his Habilitation in 1891, and arranged for generous funding from the Munich brewers, which made it possible for Buchner to establish a small laboratory for the chemistry of fermentation [19]. In 1894 Buchner took an interim appointment at the University of Kiel [18, 19] before being granted the title of Professor in 1895. In 1896 he was appointed professor for analytical and pharmaceutical chemistry at the University of Tübingen, before becoming the chair of general chemistry in the Agricultural College in Berlin and director of the Institute for the Fermentation Industry in 1898 [18, 20]. He was awarded the Nobel Prize in 1907 for his biochemical investigations and his discovery of non-cellular fermentation. In 1909 Buchner moved to Breslau to the chair of physiological chemistry and in 1911 to Wurzburg [18, 20]. He died in 1917 as a result of wounds received on the Romanian front during the First World War [18].

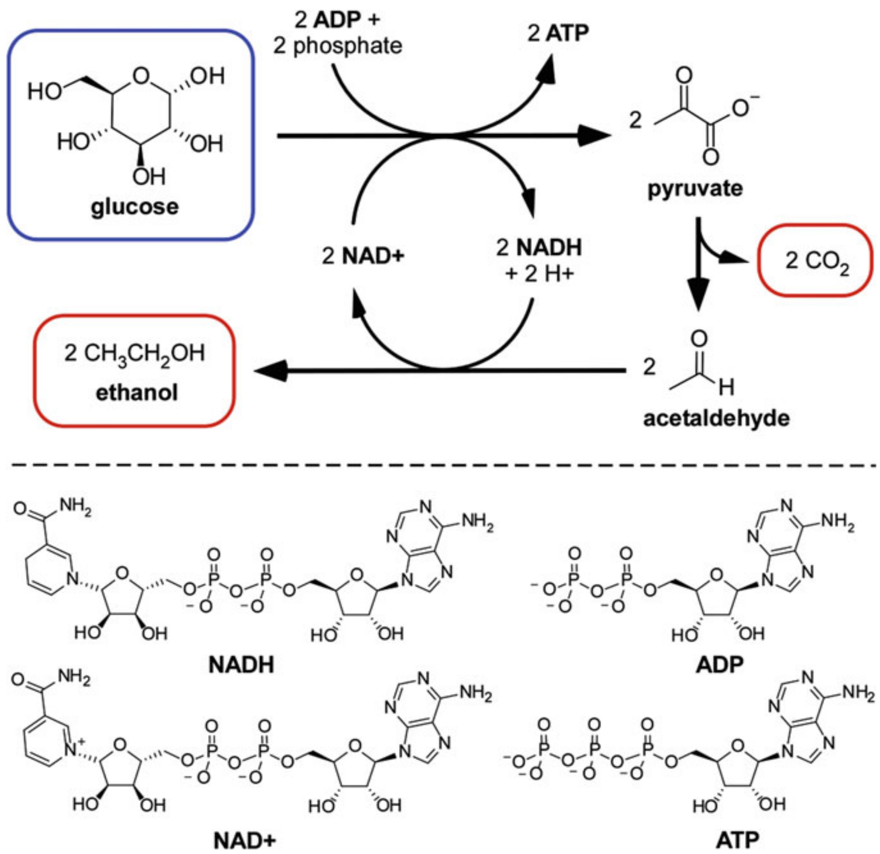

Fig. 2.4 A simplified outline of the alcoholic fermentation process

It was only later that it was determined that *zymase* was a complex mixture of enzymes and not a single species [1]. A simplified scheme of the alcoholic fermentation process is outlined in Fig. 2.4, in which the first overall step shown (i.e. glucose to pyruvate) actually represents ten individual steps requiring ten different enzymes [17, 23]. In addition to the major products of ethanol and carbon dioxide, there are a large number of other minor by-products of yeast metabolism that contribute to the flavor of different fermented products [5]. In fact, the theoretical conversion of 180 g sugar into 92 g ethanol (51.1 % by weight) and 88 g carbon dioxide (48.9 % by weight) could only be expected in the absence of any yeast growth, production of other metabolites, or loss of ethanol as vapor [23]. In a model fermentation process, about 95 % of the sugar is converted into ethanol and carbon dioxide, with 1 % converted into cellular material, and the remaining 4 % into other products such as glycerol [23].

In the production of fermented beverages, ethanol is the primary product with carbon dioxide as a significant by-product. In the case of beer, the dissolved gas gives its carbonation and creates the head or froth on the beer. This additionally assists in preservation as a sealed cask that is retained under the pressure of carbon dioxide keeps air and microbes out of the empty portion of the cask [1].

This same fermentation process is utilized in the production of leavened breads. In this case, carbon dioxide is caught in the glutinous material, causing it to rise and producing bread that is soft, light, and fluffy in texture. Ethanol is still produced in this process, but is lost at the elevated temperatures used during baking [1].

2.2 Mead

The collection of bee honey is an ancient activity and is thought to date back into the Paleolithic period (before 10,000 BCE) [24]. Evidence of this has been found in Mesolithic rock art from Cuevas de la Araña near Valencia, Spain that dates to 6000–8000 BCE. As shown in Fig. 2.5, this rock art illustrates honey collection from a wild nest. A number of such rock art examples have been found in Europe, Africa, Asia, and Australia [24].

As such, honey provided an abundant source of sugar, from which an alcoholic beverage could be produced by the fermentation of aqueous honey solutions. This drink is referred to as mead,[4] hydromel, or honey wine (Table 2.1), and is known from many sources of ancient history throughout Europe, Africa, and Asia [2, 25]. It is thought that such fermented honey drinks were the first intoxicating beverage made by most primitive peoples and were in fact made thousands of years before either wine or beer were produced [2, 25, 27–29]. Archaeological evidence of fermented honey, however, is somewhat ambiguous. The problem lies in that the archeological confirmation of either beeswax or certain types of pollen is indicative of the presence of honey, but not necessarily its fermentation. As honey has been used historically to sweeten various drinks, the detection of honey alone cannot be correlated to the production of mead [2].

One of the earliest items of material evidence of mead is a drinking horn recovered at Skudstrup, in northern Germany. The horn was buried in a peat bog and has been dated to before 100 CE. Analysis of the horn gave evidence of both yeasts and pollen grains, suggesting that it had held mead [27, 29, 30].

More recent archaeological evidence also suggests the use of honey in China for the early production of fermented drinks based upon the chemical analysis of pottery sherds dating to 7000–5500 BCE from Jiahu, an early Neolithic village in the Henan province of China [31]. Material extracted from the sherds were analyzed by Fourier-transform infrared spectroscopy (FTIR), gas chromatography–mass spectrometry (GC–MS), and high-performance liquid chromatography–mass

[4] The English word *mead* derives from the Old English *meodu*, a derivative of the Proto-Indo-European root **médhu* (honey, or an alcoholic drink fermented from honey). While in the east, **médhu* referred to both honey and its fermented drink, its use in the west referred only to the fermented drink and **melit* was used to denote honey [26].

Fig. 2.5 The reproduction of a portion of Mesolithic rock art from Cuevas de la Araña near Valencia, Spain (created by Achillea, 2007)

Table 2.1 Fermented beverages made with honey [27]

Beverage name	Description
Mead (or hydromel)	Fermented mixture of honey and water
Sack mead	Fermented mixture of honey with less water
Metheglin	Fermented mixture of honey, water, and spices
Mulsum	Wine mixed with honey
Pyment (or clarree)	Wine mixed with honey and spices

spectrometry (HPLC–MS), which revealed the presence of long straight-chain hydrocarbons (C_{23}–C_{36}) attributed to the presence of beeswax and IR signals attributed to tartaric acid (a common biomarker for grapes and other select fruits). The presence of tartaric acid was further supported by positive Feigl spot tests [31]. Based upon these analyses and spectral matching of the FTIR and HPLC analyses with various modern samples, the authors suggest that the pottery contained a mixed fermented beverage containing honey, rice, and a fruit, the latter postulated to be Chinese hawthorn.

Further archaeological evidence suggesting the presence of mead was reported as a result of the analysis of various bronze drinking vessels from the tomb of King Midas (ca. 700 BCE) in central Turkey [32]. As with the previous analysis in China, a combination of FTIR, liquid and gas chromatography, and mass spectrometry were used to detect tartaric acid and its salts as biomarkers of wine, calcium oxalate ("beerstone") as a biomarker of beer, and hydrocarbons indicative of beeswax. This combination led the authors to postulate that the vessels contained a mixture of grape wine, beer, and mead [32]. The reliability of calcium oxalate and tartaric acid as biomarkers for beer and wine will be addressed in detail in Chaps. 3 and 4, respectively.

However, as discussed above, all of these analyses suggest the presence of honey, but provide no direct evidence of its fermentation. The correlation of the detection of honey to it being a component of mead is usually based upon the container (i.e. drinking horn, drinking vessels) and the environment in which the material under analysis was found, as well as simple postulation by those carrying out the analyses.

The earliest written evidence of mead is believed to come from the *Rigveda*, an Indian collection of Vedic Sanskrit hymns, dated to around 1700–1100 BCE. This book contains approximately 300 references to *mádhu*,[5] the Sanskrit word for both honey and mead [26–28]. It is unclear, however, if any of these occurrences of *mádhu* actually referred to mead [27, 28]. Another Indian text dated to the 4th–5th century BCE, the *Ramayana*, mentions becoming intoxicated after drinking *mádhu*, likely referring to mead in this case [27]. Mead (as hydromel) [33] was specifically discussed by the first century historian Pliny the Elder[6] in his *Naturalis Historia* (*Natural History*) and differentiates it from wine sweetened with honey (a drink known as mulsum, Table 2.1) [34]. Lucius Junius Moderatus Columella,[7] considered one of the most important writers on agriculture of the Roman empire, also discusses mead in his *De Re Rustica* (written in 42 CE) [27, 35].

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[5] The Sanskrit word *mádhu* has been defined as: honey; the juice or nectar of flowers; anything sweet; mead, sugar, liquorice; sweetness; a spirituous liquor obtained from the blossoms of the *Bassia latifolia*; any sweet intoxicating drink; wine; spirituous liquor [26].

[6] Pliny the Elder or Gaius Plinius Secundus (23–79 CE) was a Roman officer and encyclopedist. Born in late 23 or early 24 at Novum Comum (modern Como), a small city in the region known as Transpadane Gaul (or Gallia Transpadana), he was introduced to Rome at an early age. He studied in Rome before becoming a military tribune at age 21. During his time as an officer, he held three posts, serving primarily in Germany. Pliny is best known as a writer and encyclopedist, writing his first treatise in 50–51, followed by a two-volume biography of the senator Pomponius Secundus, and the twenty-volume History of Rome's German Wars. He is most well-known for his encyclopedia, *Naturalis Historia*, published in 77 CE. This massive work resulted from years of collecting records, both from his own reading and from personal observations, as well as anything else that seemed to him worth knowing. He died in late August of 79 during the evacuation around the erupting volcano Vesuvius. The exact cause of his death is unknown, but it has been said that he was asthmatic and overcome by sulfurous fumes. Reports are that he was still recording his personal observations of the event during the final hours of his life [37].

[7] Lucius Junius Moderatus Columella (4 CE–ca. 70 CE) is considered the most important writer on agriculture of the Roman Empire. He came from provincial Spain, but moved to Italy as a young man, where he took up farming and lived near Rome [38]. He is most well-known for his *De Re Rustica,* which comprised twelve volumes on farming, animal husbandry, and estate management, and this work forms an important source on Roman agriculture.

The ferment for mead is the osmophilic yeasts[8] naturally present in honey [27, 29]. Most of the known osmophilic yeasts are included in the species *Saccharomyces rouxii*, *Saccharomyces bailii* var. *osmophilus*, and *Saccharomyces bisporus* var. *mellis* [36]. As such yeasts are already present in the honey, its fermentation can occur quite easily without effort. For example, unintentional fermentation could occur if rain simply fell into a vessel containing honey combs or honey [27]. The ease of its production is illustrated by the following preparation of mead as described by Pliny the Elder in his *Naturalis Historia* [33]:

> There is a wine also made solely of honey and water. For this purpose it is recommended that rain-water should be kept for a period of five years. Those who show greater skill, content themselves with taking the water just after it has fallen, and boiling it down to one third, to which they then add one third in quantity of old honey, and keep the mixture exposed to the rays of a hot sun for forty days after the rising of the Dog-star; others, however, rack it off in the course of ten days, and tightly cork the vessels in which it is kept. This beverage is known as "hydromeli," and with age acquires the flavour of wine. It is nowhere more highly esteemed than in Phrygia.

An earlier and more detailed preparation of mead is also given by Columella in his *De re rustica* [35]:

> Therefore having set apart this bees-wax-water, and destinated it for preserving of fruits, mead must be made by itself of the very best honey; but it is not made after one manner: for some, many years before, put up rain-water in vessels, and set it in the Sun in the open air; then, having emptied it from one vessel to another, and made it very clear (for, as often as it is poured from one vessel to another, even for a long time, there is found, in the bottom of the vessel, some thick settling like dregs) they mix a sextarius[9] of old water with a pound of honey.
>
> Nevertheless some, when they have a mind to make the mead of a rougher taste, mingle a sextarius of water with three quarters of a pound of honey; and after they have, according to this proportion, filled a stone bottle, and plaistered it, they suffer it to be forty days in the Sun, during the rising of the Dog-star; then they put it up in a lost, which receives smoak. Some, who have not been at the pains to preserve rain-water till it becomes old, take that which is fresh, and boil it into a fourth part: then, after it is grown cold, if either they have a mind to make mead sweeter than ordinary, they mix a sextarius of honey with two sextarii of water; or, if they would have it rougher, they put three quarters of a pound of honey to a sextarius of water; and, having made it according to these proportions, they pour it into a stone bottle; and, after they have kept it forty days in the Sun, as I said above, they put it up in a lost, which receives smoak from below.

Honey wines can be made with alcohol content of up to 10–12 % if fermented long enough, and are often sweet due to significant amounts of unfermented sugars [29, 39, 40]. The osmophilic yeasts present in honey are best for the fermentation of honey solutions with sugar concentrations above 15 %, but generally do not produce alcohol as well as the common yeasts of beer and wine, *Saccharomyces cerevisiae* [29]. *Saccharomyces cerevisiae* species are the best for fermentation of

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[8] The term osmophilic yeast, coined by A. A. von Richter in 1912, has been used to designate yeast strains that are able to thrive in highly concentrated sugar solutions [36].

[9] The theoretical value for the sextarius is about 540.3 ml.

honey, providing the sugar concentration is less than 15 %. However, through the use of various additives, the fermentation of honey by *Saccharomyces cerevisiae* at sugar concentrations of 25 % have been successfully reported, resulting in alcohol concentrations of 12–15 % [29, 39].

Mead can be made from nearly any type of honey and the resulting mead produced retains many of the characteristics of the honey utilized. For example, light honeys yield lighter meads, while dark honeys of stronger flavor are typically favored for the making of honey ales or a more beer-like drink [29, 39]. Mead can also be produced by fermenting an aqueous solution of honey with grain mash, which is then strained after fermentation. Meads can also be flavored with spices (metheglin, Table 2.1), fruit, or hops, the latter of which produces a bitter, beer-like flavor.

As wine was produced in the Mediterranean region and the warm temperate parts of Europe, it obtained a higher social status and displaced honey-based alcoholic drinks. Elsewhere, however, beverages made by fermenting honey often remained important [27]. This was particularly true in the Germanic north [26] and mead was popular in central and northern Europe at least as early as 334 BCE [29].

2.3 Date Wine

Perhaps the most abundant source of sugar in the Fertile Crescent came from the date palm (*Phoenix dactylifera* L., Fig. 2.6), and offers the most likely means by which alcoholic drinks were first produced with any degree of regularity [2, 41]. The date palm was characteristic of the whole of Babylonia from the oldest period, and while it was not indigenous to North Mesopotamia, Syria, or Asia Minor [41], it was still prolific in both Mesopotamia and Egypt [42]. By 4000 BCE, the date palm had been domesticated, most probably in southern Mesopotamia [2, 43, 44] where it was well established by 3000 BCE [45]. The palm is adapted to a xeric habitat and thrives well in desert environments unsuitable for most crops [45]. While it thrives in a hot and dry climate, it does require plenty of water. The date palm, however, can tolerate water of high salinity, much more so than any other cultivated tree [43, 44]. In Palestine, its natural habitat is the Rift Valley, though some small plantations might also be found in the southern coastal plain [43].

The tree furnishes both fruit (dates) and sap. The fruit itself is rich in sugar (dry dates contain 70–80 % sugar [2, 43–45]) and provided a source of honey (i.e. a date-sugar syrup) [41]. As the fruit itself contains the necessary yeast, fermentation of the fruit or honey is fairly rapid in these warm climates [42], thus facilitating the production of both wine and vinegar [41]. Economically, the date palm is a very worthwhile plant with significantly high productivity [43] and the ancient Egyptians considered it the most important of the fruit trees cultivated [46]. Trees can bear fruit for 60–100 years and the average palm tree can produce as much as 40 kg of fruit per year [44], while very productive trees can produce as much as 100 kg or more each year [45]. In addition, it has been reported that in modern

Fig. 2.6 *Phoenix dactylifera* L. (Botanical print (dated 1884); photo by Symac 2004)

Israeli plantations, the annual harvest of a typical tree is 100–200 kg of sugar. As such, up to 10 tons of sugar can be achieved with a relatively small investment of labor [43].

As with other fermented beverages, it is unknown exactly when the production of date wine (or date beer, as it is sometimes referred) began [43]. The oldest solid evidence of date wine comes from the period of 3000–2000 BCE [42, 44]. However, it is believed to have been prepared by the people in Mesopotamia and Egypt long before that and it is thought that date wine probably preceded the production of barley beer [42, 43]. It is believed by some that the date palm and barley provide the first direct evidence that both the Mesopotamians and the Egyptians were making fermented drinks [42]. In Egypt, however, the consumption of date wine (*bená*) was limited to the lower classes [7]. In a similar manner, it was largely secondary to barley beer in Mesopotamia until the beginning of the Iron Age, after which it then became the principal alcoholic beverage of choice [43]. Pliny the Elder described date wine as one of the varieties of artificial wines (i.e. non-grape wines) and stated that it was prepared by the Parthians[10] and the Indians, as well as throughout all the countries of the East [47].

[10] Parthia was a region of north-eastern Persia.

The production of date wine was not a very complex process and was much simpler than that required for cereal beers [42, 43]. Fundamentally one only required a container in which to put the date mash during fermentation and some device with which to strain it when complete [42]. However, in order to produce the mash, the fruit first required pressing [43, 44]. It is theorized that the dates were initially pitted, as crushed pits in the mash might be a nuisance. In addition, the date pits are known to have nutritional value, similar to barley. In modern times, shredded or ground date pits are served as animal fodder and in times of desperation can be added to wheat or barley flour [43].

Pressing the fruit could be accomplished by simple foot-treading, but it is much more efficient to press it with heavy stone rollers. Four such rollers have been found so far, with one large roller thought to weigh 900 kg discovered at Ein Feshkha, on the northwestern shore of the Dead Sea [43]. It is proposed that such rollers must have been operated by two or three people. Rolling such a heavy cylindrical stone, however, was thought to have been not that difficult as task, as the crushed dates could theoretically serve as a lubricant [43].

A nearly equal amount of water was then added to the mash [42]. In his *Naturalis Historia*, Pliny the Elder described this as follows [47]:

> A modius[11] of the kind of ripe date called "chydææ" is added to three congii[12] of water, and after being steeped for some time, they are subjected to pressure.

As described by Pliny, this ratio would be approximately 0.83 equivalents of dates to each equivalent of water. In Egypt, the date wine was made in January when the water used from the Nile was the clearest [7]. This mixture was then allowed to undergo fermentation and strained. The same dates could be used a number of times, as the yeast stops functioning when the alcohol content becomes too high, thus ending the fermentation. After straining, fresh water could be added to the remaining date mash and the fermentation processes could be repeated again [43]. Date wines were also sometimes flavored with herbs or other additives. Numerous varieties of date wines have been described in surviving records and it has been proposed that the additions made to these drinks and the exact methods of manufacture were jealously guarded secrets [42].

2.4 Palm Wine

Palm wine is also produced from the date palm, but differs in that it is the sap that is collected and fermented, rather than the fruit [2, 7, 44]. The sap is said to consist of about 10 % sugar and significant amounts of sap can be extracted from the palm

[11] The modius was equal to 16 sextarii or a little more than the peck, a unit of dry volume equivalent to 2 gallons.

[12] The congius was a liquid measure equivalent to approximately 3.48 L or 0.92 U.S. gallons.

tree. Quantities quoted per tree have been given as high as 8 L a day and up to 400–500 L a year. However, a tree used for its sap is significantly weakened [44], causing it to stop bearing fruit [43, 46, 48]. It has been reported that it then requires at least 4–5 years to recover enough to do so again [40], although others have noted that the tree often dies as a consequence [46, 48]. As such, sap is generally harvested only from male or fruitless old trees [43, 44], or in regions in which they grow in great abundance [46].

Palm wine was produced by first gathering the sap, which was accomplished by making an incision in the heart of the date tree below the base of the upper branches [46, 48]. A jar was then attached to this part of the tree in order to catch the juice which flowed from the incision [46]. The liquid extracted from date trees can be drunk in large quantity, but after fermentation it became a powerfully intoxicating beverage [46, 48]. Fermentation occurs rapidly and sap collected in the morning can contain 4–5 % alcohol by the same evening.

In Egypt, palm wine (*áama*) was drunk by the lower classes in the same way as date wine [7]. In addition to its production in Egypt, it is highly probable that such wine was also produced in ancient Palestine, although there is not explicit evidence of such. However, 'palm water' is mentioned in the Mishnah[13] as a thirst quencher, and it is thought that such 'palm water' would have been fermented for wine [43].

Palm wine is still being produced today, particularly in Egypt (where it is now called *lowbgeh*) and Libya (where it is called *lakbi*) [7, 43, 46, 48]. It is also much used in West Africa and Madagascar, as well as most of the East Indian islands, where it is known as Indian toddy [7].

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[13] The Mishnah is a Jewish text which represents the first major written record of the Jewish oral traditions.

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