CONSUMPTION OF ALCOHOLIC BEVERAGES

1. Exposure Data

1.1 Types and ethanol contents of alcoholic beverages

1.1.1 *Types of alcoholic beverage*

Most cultures throughout the world have traditionally consumed some form of alcoholic beverages for thousands of years, and local specialty alcoholic beverages still account for the majority of all those that exist. Only a small number have evolved into commodities that are produced commercially on a large scale. In world trade, beer from barley, wine from grapes and certain distilled beverages are sold as commodities. Other alcoholic beverages are not sold on the international market. In many developing countries, however, various types of home-made or locally produced alcoholic beverages such as sorghum beer, palm wine or sugarcane spirits continue to be the main available beverage types (WHO, 2004).

It is difficult to measure the global production or consumption of locally available beverages, and few data exist on their specific chemical composition (see Section 1.6). A discussion of unrecorded alcohol production, which includes these traditional or home-made beverages, is given in Section 1.3. Although these types of alcoholic beverage can be important in several countries at the national level, their impact is fairly small on a global scale.

This monograph focuses on the main beverage categories of beer, wine and spirits unless there is a specific reason to examine some subcategory, e.g. alcopops or flavoured alcoholic beverages. These categories are, however, not as clear-cut as they may seem. There are several beverages that are a combination of two types (e.g. fortified wines, in which spirits are added to wine). The categorization above is based on production methods and raw materials, and not on the ethanol content of the beverages (see Section 1.2).

Another classification of beverages is the Standard International Trade Classification (SITC) that has four categories: wine from fresh grapes, cider and other fermented

beverages, beer and distilled alcoholic beverages (for further details, see SITC Rev 3 at United Nations Statistics Division (2007; http://unstats.un.org/unsd/cr)).

1.1.2 *Alcohol content of different beverages*

In this monograph, percentage by volume (% vol) is used to indicate the ethanol content of beverages; this is also called the French or Gay-Lussac system. The American proof system is double the percentage by volume; a vodka which is 40% by volume is thus 80 proof in the USA (IARC, 1988).

The standard approach to measuring the amount of ethanol contained in a specific drink is as follows. The amount of alcoholic beverage typically consumed for each type of beverage (e.g. a 330-mL bottle of beer or a 200-mL glass of wine) is multiplied by the ethanol conversion factor, i.e. the proportion of the total volume of the beverage that is alcohol. Ethanol conversion factors differ by country, but are generally about 4–5% vol for beer, about 12% vol for wine and about 40% vol for distilled spirits. Thus, the ethanol content of a bottle of beer is calculated as (330 mL) × (0.04) = 13.2 mL ethanol. In many countries, ethanol conversion factors are used to convert the volume of beverage directly into grams of ethanol. In other countries, volumes of alcohol may be recorded in 'ounces'. Relevant alcohol conversion factors for these different measures are (WHO, 2000): 1 mL ethanol = 0.79 g; 1 United Kingdom fluid oz = 2.84 cL = 28.4 mL = 22.3 g; 1 US fluid oz = 2.96 cL = 29.6 mL = 23.2 g.

The ethanol content in beer usually varies from 2.3% to over 10% vol, and is mostly 5–5.5% vol. In some countries, low-alcohol beer, i.e. below 2.3% vol, has obtained a considerable share of the market. In general, beer refers to barley beer, although sorghum beer is consumed in large quantities in Africa.

The ethanol content of wine usually varies from 8 to 15% vol, but light wines and even non-alcoholic wines also exist.

The ethanol content of spirits is approximately 40% vol, but may be considerably higher in some national specialty spirits. Also within the spirits category are aperitifs, which contain around 20% vol of alcohol. Alcopops, flavoured alcoholic beverages or ready-to-drink beverages usually contain 4–7% vol of alcohol, and are often pre-mixed beverages that contain vodka or rum.

1.2 Production and trade of alcoholic beverages

1.2.1 *Production*

(a) Production methods

Most yeasts cannot grow when the concentration of alcohol is higher than 18%. This is therefore the practical limit for the strength of fermented beverages, such as wine, beer and sake (rice wine). In distillation, neutral alcohol can be produced at strengths in excess of 96% vol of alcohol.

(i) *Beer production*

The process of producing beer has remained unchanged for hundreds of years. The basic ingredients for most beers are malted barley, water, hops and yeast. Barley starch supplies most of the sugars from which the alcohol is derived in the majority of beers throughout the world. Other grains used are wheat and sorghum. The starch in barley is enclosed in a cell wall, and these wrappings are stripped away in the first step of the brewing process, which is called malting. Removal of the wall softens the grain and makes it more readily milled. The malted grain is milled to produce relatively fine particles and these are then mixed with hot water in a process that is called mashing. The water must process the right mix of salts. Typically, mashes contain approximately three parts of water to one part of malt and are maintained at a temperature of ~65 °C. Some brewers add starch from other sources such as maize (corn) or rice to supplement the malt. After ~1 h of mashing, the liquid portion is recovered by either straining or filtering. The liquid (the wort) is then boiled for ~1 h. Boiling serves various functions, including sterilization and the removal of unpleasant grainy contents that cause cloudiness. Many brewers add sugar or at least hops at this stage. The hopped wort is then cooled and pitched with yeast. There are many strains of brewing yeast and brewers tend their strains carefully because of their importance to the identity of the brand. Fundamentally, yeasts can be divided into lager and ale strains. Both types need a little oxygen to trigger off their metabolism. Ale fermentations are usually complete within a few days at temperatures as high as 20 °C, whereas lager fermentations, at temperatures which are as low as 6 °C, can take several weeks. Fermentation is complete when the desired alcohol content has been reached and when an unpleasant butterscotch flavour, which develops during all fermentation, has been removed by the yeast. The yeast is then harvested for use in the next fermentation. Nowadays, the majority of beers receive a relatively short conditioning period after fermentation and before filtration. This is performed at –1 °C or lower (but not so low as to freeze the beer) for a minimum of 3 days. This eliminates more proteins and ensures that the beer is less likely to cloud in the packaging or glass. The filtered beer is adjusted to the required degree of carbonation before being packed into cans, kegs, or glass or plastic bottles (Bamforth, 2004).

(ii) *Wine production*

A great majority of wine is produced from grapes, but it can also be produced from other fruits and berries. The main steps in the process of wine making are picking the grapes, crushing them and possibly adding sulfur dioxide to produce a wine must. After addition of *Saccharomyces*, a primary/secondary fermentation then takes place. This newly fermented wine is then stabilized and left to mature, after which the stabilized wine is bottled (and possibly left to mature further in the bottle).

Red grapes are fermented with the skin, and yield ~20% more alcohol than white grapes. Ripe fruit should be picked immediately before it is to be crushed. Harvesting is becoming increasingly mechanical although it causes more physical damage to the

grapes, and sulfur dioxide may be added during the mechanical harvesting. The grapes are then stemmed and crushed. The stems are not usually left in contact with crushed grapes to avoid off-flavours. An initial crushing separates grapes from stems with the aim of achieving an even breakage of grapes. It is not necessary to separate the juice from the skins immediately for red wine, but it is for white, rosé or blushwines. The juice is settled at a low temperature (< 12 °C), after which it is drained and pressed. To accelerate juice settling and obtain a clearer product, pectic enzyme is frequently added at the crushing stage. Once the juice is separated from the skins, it is held overnight in a closed container. Thereafter, it is centrifuged before the addition of yeast. In locations where the grapes do not ripen well because of a short growing season, it may be necessary to add sugar (sucrose). Dried yeast is usually used in wine making (contrary to beer brewing). Oxygen is introduced to satisfy the demand of the yeast. White wines are fermented at 10–15 °C, whereas red wines are fermented at 20–30 °C. Fermentation is complete within 20–30 days. Wine is usually racked off the yeast when the fermentation is complete, although some winemakers leave the yeast for several months to improve the flavour. After fermentation, the wine is clarified with different compounds depending on the type of wine (bentonite, gelatine, silica gels). Maintaining them in an anaerobic state then stabilizes the wines and prevents spoilage by most bacteria and yeast. Wines tend to benefit from ageing, which is performed in either a tank, barrel or bottle. The extent of ageing is usually less for white than for red wines. During ageing, the colour, aroma, taste and level of sulfur dioxide are monitored. If wine is aged in oak barrels, some characteristics are derived from the barrel.

Residual oxygen is removed during packaging and some winemakers add sorbic acid as a preservative to sweet table wines. To avoid the use of additives, attention must be paid to cold filling and sterility, and to avoid taints, corks should be kept at a very low moisture content. The shelf life of wine is enhanced by low-temperature storage (Bamforth, 2005).

(iii) *Production of spirits*

The neutral alcohol base used for several different spirits is frequently produced from cereals (e.g. corn, wheat), beet or molasses, grapes or other fruit, cane sugar or potatoes. These basic substances are first fermented and then purified and distilled. Distillation entails heating the base liquid so that all volatile substances evaporate, collecting these vapours and cooling them. This liquid may be distilled several times to increase purity. The process leads to a colourless, neutral spirit, which may then be flavoured in a multitude of ways. For some spirits, such as cognac and whisky, the original flavouring of the base liquid is retained throughout the distilling process, to give the distinct flavour. After distillation, water is added to give the desired strength of the beverage.

Vodka is a pure unaged spirit distilled from agricultural products and is usually filtered through charcoal. Neutral alcohol is the base for vodka, although many flavourings can be found in modern vodkas, such as fruit and spices. Other beverages based

on neutral distilled alcohol are gin, genever, aquavit, anis and ouzo. For example, the distinct flavour of gin comes from distillation in the presence of plants such as juniper, coriander and angelica, and the peel of oranges and lemons.

Rum is produced from molasses or cane sugar; whisky is produced from a mash of cereals and is matured for a minimum of 3 years. Brandy comes from distilled wine and needs to mature in oak. Fruit spirits may be produced by fermentation and distillation of a large number of fruit and berries, such as cherries, plums, peaches, apples, pears, apricots, figs, citrus fruit, grapes, raspberries or blackberries (Bamforth, 2005).

(b) Production and trade volumes

According to the SITC (SITC Rev. 3.1, code 155; United Nations Statistic Division 2007), the activity of manufacture of alcoholic beverages is divided into three categories:

1551 **- Distilling, rectifying and blending of spirits; ethyl alcohol production from fermented materials**. This class includes: the manufacture of distilled, potable, alcoholic beverages: whisky, brandy, gin, liqueurs and 'mixed drinks'; the blending of distilled spirits; the production of ethyl alcohol from fermented materials; and the production of neutral spirits.

1552 – **Manufacture of wine**. This class includes: the manufacture of wine from grapes not grown by the same unit; the manufacture of sparkling wine; the manufacture of wine from concentrated grape must; the manufacture of fermented but not distilled alcoholic beverages: sake, cider, perry, mead, other fruit wines and mixed beverages containing alcohol; the manufacture of vermouth and similar fortified wines; the blending of wine; and the manufacture of low-alcohol or non-alcoholic wine.

1553 – **Manufacture of malt liquors and malt**. This class includes: the manufacture of malt liquors, such as beer, ale, porter and stout; the manufacture of malt; and the manufacture of low-alcohol or non-alcoholic beer.

According to the alcoholic beverage industry, the global market for alcoholic drinks reached a volume of 160.2 billion litres of alcohol in 2006. The market is forecasted to grow further in the coming years. The compound annual average growth rate in volume has been around 2% per year from 2000 to 2006. A similar growth rate is expected in the coming 5 years. The value of the global drinks market in 2006 was 812.4 billion US $ (Market is valued according to retail selling price including any applicable taxes). Both volume and value grow at a steady rate of around 1–2% per year.

The sales of beer, cider and flavoured alcoholic beverages dominate the market with a 48.7% share of the global value. Wine is the second highest in value at 28.3% and is followed by spirits at 22.9%.

Europe continues to be the largest alcoholic drinks market and accounts for 59% of the global market value. Europe is followed by the USA (23.7%) and the Asia-Pacific region (17.2%).

On-trade (on-premises) sales distribute alcoholic products worth 38.7% of the total market revenue, followed by supermarkets/hypermarkets (20.8%) and specialist

Table 1.1 Top 10 beer producers

Rank	Country	Production in 1000 hectolitres (2002 estimate)
1	USA	231 500
2	China	231 200
3	Germany	109 000
4	Brazil	85 000
5	Japan	70 500
6	Russia	70 000
7	Mexico	65 000
8	United Kingdom	56 800
9	Spain	28 000
10	Netherlands	25 300

From Modern Brewery Age (2002)

retailers (12.1%) (Datamonitor, 2006, Datamonitor does not cover all countries as it is more focused on developed countries; for e.g. Africa, the data are almost non-existent).

The market for alcoholic beverages shows considerable variation in growth. In most developed economies, the market is mature, i.e. stable but not growing. In these countries, most people have reached an economic status where they can buy alcoholic beverages if they wish to do so. However, Brazil, the Russian Federation, China, India and some transitional economies in Europe have a market that is greatly increasing in value. In general, low- and middle-income countries tend to move from locally produced alcoholic beverages to commercial brands as their economic status improves. Simultaneously, they also show a shift from other beverages to beer. In developed markets, sales volumes for beer are static or declining, with intensified competition from wine and spirits (ICAP, 2006). Regarding beverage-specific production, Table 1.1 presents the 10 largest beer-producing countries in 2002. Of these, Germany, Mexico and the Netherlands are especially prominent exporters of beer (see Section 1.2.2). In Brazil, China, Japan and the Russian Federation, most of the beer produced is consumed in the domestic market.

The largest wine producers (Table 1.2) are the traditional European wine-producing countries such as France, Spain and Italy, but also include those from the New World such as South Africa. It is clear that the major wine-producing countries are also the greatest wine-exporting countries.

With regard to the production of spirits, China and India are the largest producers (Table 1.3). All of the developing countries listed (plus Japan and the Russian Federation) are large producers of spirits but are not prominent exporters of their products; they are all predominantly spirit-drinking countries.

Table 1.2 Top 10 wine (including all fermented) producers

Rank	Country	Production in 1000 hectolitres (2001)
1	France	53 389
2	Italy	50 093
3	Spain	30 500
4	USA	19 200
5	Argentina	15 835
6	China	10 800
7	Australia	10 163
8	Germany	8 891
9	Portugal	7 789
10	South Africa	6 471

From WHO Global Alcohol Database (undated)

An overall observation is that developing countries, such as Brazil, China and India are prominent among the largest producers of beer and/or spirits.

1.2.2 *Trade in alcoholic beverages*

(a) Trends in trade

Overall, trade in alcoholic beverages has increased almost 10-fold over the past 30 years. The increase is, however, proportional to the overall increase in world trade of all goods. Alcoholic beverages hold a stable 0.5% of the total value of global trade. This

Table 1.3 Top 10 spirits producers

Rank	Country	Production in 1000 hectolitres (2003)
1	China	577 490
2	India	154 860
3	Russian Federation	138 500
4	Japan	102 360
5	USA	98 000
6	United Kingdom	82 195
7	Thailand	71 340
8	Brazil	70 000
9	Germany	39 100
10	France	36 345

From WHO Global Alcohol Database (undated)

Table 1.4 Principal importers and exporters of beer in 2005[a]

Country	Share of world total (%)
Imports	
USA	42.5
United Kingdom	8.4
Italy	6.7
France	5.9
Canada	4.6
Germany	3.8
Ireland	2.7
Netherlands	2.6
Spain	2.5
Belgium	1.4
Exports	
Netherlands	19.4
Mexico	18.8
Germany	13.1
Belgium	8.4
United Kingdom	7.5
Ireland	4.1
Denmark	4.0
Canada	3.0
USA	2.5
France	2.4

From United Nations Statistics Division (2007) [a] Based on value of trade

would mean that for every 200 US $ in global trade, 1 US $ involves alcoholic beverages. The trends in trade do not correlate to trends in consumption.

(b) Countries with highest imports or exports

Over the past 30 years, France, Italy, the United Kingdom and the USA have been the largest importers of beer. The major change is that the USA have increased their share of the world trade from 29% in 1992 to 42% in 2005. For beer exports, Mexico features prominently, and has had an increase in trade share from 5.8% in 1992 to 18.8% in 2005 (see Table 1.4).

Regarding wine imports, two new countries have emerged as principal traders—Japan and the Russian Federation. Global export is still dominated by the traditional large wine-producing countries, such as France, although the share of French wines has decreased from nearly 50% in 1992 to 33% in 2005. Two more recent wine-producing

Table 1.5 Principal importers and exporters of wine in 2005[a]

Country	Share of world total (%)
Imports	
United Kingdom	20.0
USA	18.5
Germany	11.3
Belgium	5.0
Canada	4.9
Japan	4.9
Netherlands	4.0
Switzerland	3.6
Russian Federation	3.1
France	3.0
Exports	
France	33.3
Italy	18.9
Australia	10.0
Spain	9.4
Chile	4.2
Germany	3.4
Portugal	3.1
USA	3.0
South Africa	2.8
New Zealand	1.6

From United Nations Statistics Division (2007) [a] Based on value of trade

countries—South Africa and New Zealand— have entered the list of large wine traders (see Table 1.5).

The Russian Federation is now a major importer of spirits. For the principal exporting countries, there has been more fluctuation over the past 30 years than for other beverages. For example, Mexico and Spain have been on and off the list of major exporters, and Germany and Sweden became major exporters in 2005 (see Table 1.6).

Overall, the ranking of countries for both imports and exports of all beverages has been fairly stable over the years. Almost no low-income countries are among the top 10. Only a small minority of countries worldwide are involved in any significant trade at the global level and mostly the same countries are implicated for all beverages.

Table 1.6 Principal importers and exporters of distilled alcoholic beverages in 2005[a]

Country	Share of world total (%)
Imports	
USA	27.8
Spain	7.9
Germany	6.6
France	5.1
United Kingdom	5.0
Russian Federation	4.1
Japan	3.8
Canada	2.8
Singapore	2.7
Italy	2.2
Exports	
United Kingdom	32.6
France	17.8
USA	4.9
Germany	4.8
Ireland	4.5
Mexico	4.3
Sweden	3.8
Italy	3.4
Singapore	2.9
Spain	2.5

From United Nations Statistics Division (2007) [a] Based on value of trade

1.3 Trends in consumption

1.3.1 *Indicators of alcoholic beverage consumption*

Three methods exist to measure consumption of alcoholic beverages in a population: surveys of a representative sample of a country or a large region of a country; determination of consumption from available statistics, such as production and sales/taxation records; and determination of consumption based on indirect indicators such as availability of raw materials to produce alcohol (e.g. sugar, fruit).

Overall, surveys have been shown in general to underestimate consumption compared with estimates from production and sales records (Gmel & Rehm, 2004), at least in developed countries. One reason for this underestimation is that surveys do not usually include people who live outside a household and who drink heavily, such as institutionalized people or the homeless. The degree of underestimation varies, and can range from 70% in some cases up to almost full coverage in others. For this reason,

international comparisons of total consumption between developed countries mostly use production and sales-based statistics (Rehm *et al.*, 2003). Whenever possible, recorded consumption should be supplemented by estimates of unrecorded consumption. This is especially important in developing countries, where unrecorded consumption is on average more common and, in some regions of the world, constitutes more than 50% of the overall consumption.

1.3.2 *Assessment of total consumption per head (per-capita consumption)*

(a) Measurement of adult per-capita consumption of recorded alcoholic beverages

Data on per-capita alcoholic beverage consumption provide the consumption in litres of pure alcohol per inhabitant in a given year. They are available for the majority of countries, often given over time, and avoid the underestimation of total volume of consumption that is commonly inherent in survey data (e.g. Midanik, 1982; Rehm, 1998; Gmel & Rehm, 2004). Adult per-capita consumption, i.e. consumption by all persons aged 15 years and above, is preferable to per-capita consumption *per se* since alcoholic beverages are largely consumed in adulthood. The age pyramid varies in different countries; therefore, per-capita consumption figures based on the total population tend to underestimate consumption in countries where a large proportion of the population is under the age of 15 years, as is the case in many developing countries. For more information and guidance on estimating per-capita consumption, see WHO (2000).

Three principal sources for per-capita estimates are national government data, information from the Food and Agriculture Organization of the United Nations (FAO) and data from the alcoholic beverage industry (Rehm *et al.*, 2003). Where available, the best and most reliable information stems from national governments, usually based on sales figures, tax revenue and/or production data. Generally, sales figures are considered to be the most accurate, provided that sales of alcoholic beverages are separated from those of any other possible items sold at a given location, and that they are beverage-specific. One of the drawbacks of production figures is that they are always dependent on accurate export and import data; if these are not available, the production figures will yield an under- or an overestimation.

The most complete and comprehensive international data set on per-capita consumption was published by FAO (until 2003). FAOSTAT, the database of the FAO, publishes production and trade information for different types of alcoholic beverage for almost 200 countries. The estimates are based on official reports of production by national governments, mainly by the Ministries of Agriculture in response to an annual FAO questionnaire. The statistics on imports and exports derive mainly from Customs Departments. If these sources are not available, other government data such as statistical yearbooks are consulted. The accuracy of the FAO data relies on reporting by member nations. The information from member nations probably underestimates informal,

home and illegal production, but these sources are still covered more accurately by the FAO than by estimates based solely on production or sales figures.

The third main source of information is the alcoholic beverage industry. In this category the most widely used is World Drinks Trends (WDT), published by the Commission for Distilled Spirits (World Advertising Research Centre Ltd, 2005). The WDT estimates are based on total sales in litres divided by the total mid-year population and use conversion rates that are not published. WDT also tries to calculate the consumption of both incoming and outgoing tourists. Currently, at least partial data are available for 58 countries. Other sources from the alcoholic beverage industry, as well as market research companies, are less systematic, entail fewer countries and are more limited in providing information over time.

The WHO Global Alcohol Database (undated) systematically collects and compares per-capita data from different sources on a regular basis (for procedures and further information, see Rehm *et al.*, 2003; WHO, 2004) using data from the United Nations for population estimates. The information in this section derives from this database, which has explicit rules for selecting and processing data to ensure their comparability.

The main limitations of adult per-capita estimates are twofold: they do not incorporate most unrecorded consumption (see below); and they are only aggregate statistics that cannot easily be disaggregated into sex and age groups. Thus, surveys have to play a crucial role in any analysis of the effect of consumption of alcoholic beverages on the burden of disease (see below).

(b) Assessment of adult per-capita consumption of unrecorded alcoholic beverages

Most countries have at least a low level of so-called unrecorded alcoholic beverage consumption. Unrecorded alcoholic beverages simply means that the alcoholic beverages produced and/or consumed are not recorded in official statistics of sales, production or trade. In some countries, unrecorded alcoholic beverages are the major source of such commodities (see Table 1.7). Unrecorded consumption stems from a variety of sources (Giesbrecht *et al.*, 2000): home production, illegal production and sales, illegal (smuggling) and legal imports (cross-border shopping) and other production and use of alcoholic beverages that are not taxed and/or are not included in official production and sales statistics.

A portion of the unrecorded alcoholic beverages derives from different local or traditional beverages that are produced and consumed in villages or homes. The production may be legal or illegal, depending on the strength of the beverage. Worldwide, information on these alcoholic beverages and their production or consumption volumes is scarce. Local production consists mostly of the fermentation of seeds, grains, fruit, vegetables or parts of palm trees, and is a fairly simple process. The alcohol content is quite low and the shelf life is usually short—1 or 2 days before the beverage is spoilt.

Table 1.7 Characteristics of alcoholic beverage consumption by country 2002 (average of available data 2001–03)[a]

WHO Region Country	Adult population[b]	Alcohol consumption[c]	Unrecorded consumption[d]	Abstainers[e]		Recorded beverages consumed		
				Men (%)	Women (%)	Beer (%)	Wine (%), inc. other fermented beverages	Spirits (%)
Africa D								
Algeria	21 300	0.5	0.3	80	98	70.1	51.4	0.0
Angola	7 777	5.1	1.6	NA	NA	63.5	21.1	15.4
Benin	4 214	1.7	0.5	NA	NA	91.0	7.2	1.8
Burkina Faso[f]	6 255	7.9	3.3	63	64	93.2	0.7	6.1
Cameroon	8 926	6.4	2.6	59	74	63.8	35.6	0.6
Cape Verde	277	6.1	1.9	NA	NA	55.9	37.1	7.0
Chad	4 665	6.6	6.3	72	82	84.0	2.4	13.7
Comoros	424	0.2	0.0	97	100	22.5	25.8	51.7
Equatorial Guinea	263	2.5	0.8	NA	NA	100.0	0.0	0.0
Gabon	776	12.2	3.7	NA	NA	64.1	15.9	19.9
Gambia	827	3.2	1.0	NA	NA	99.6	0.0	0.4
Ghana	12 390	5.2	3.6	47	62	83.5	5.2	11.4
Guinea N. A. Bissau	767	3.6	1.1	NA	NA	51.4	26.7	21.9
Guinea	4 939	0.2	0.1	NA	NA	73.5	24.2	2.4
Liberia	1 703	5.2	1.6	NA	NA	5.8	0.1	94.1
Madagascar	9 509	2.0	0.6	NA	NA	11.7	10.7	77.6
Mali[f]	6 381	0.5	0.0	95	97	85.5	10.4	4.1
Mauritania[f]	1 596	0.0	0.0	97	98	20.6	16.9	62.5
Mauritius[f]	904	3.9	1.0	26	56	75.8	7.9	16.4
Niger	6 433	0.1	0.0	NA	NA	68.0	31.9	0.1
Nigeria	67 835	14.1	3.5	46	55	12.1	87.9	0.0
Sao Tome and Principe	87	9.5	2.9	NA	NA	18.9	71.1	10.0

Table 1.7 (continued)

WHO Region Country	Adult population[b]	Alcohol consumption[c]	Unrecorded consumption[d]	Abstainers[e]		Recorded beverages consumed		
				Men (%)	Women (%)	Beer (%)	Wine (%), inc. other fermented beverages	Spirits (%)
Senegal[f]	6 094	1.3	0.8	91	98	51.6	39.6	8.8
Seychelles[f]	NA	8.5	5.2	14	46	66.2	20.6	13.2
Sierra Leone	2 800	9.0	2.4	57	65	4.7	95.0	0.3
Togo	3 174	1.5	0.5	NA	NA	85.8	10.0	4.2
Africa E								
Botswana	1 090	7.9	3.0	37	70	45.2	26.9	27.9
Burundi	3 619	14.0	4.7	NA	NA	24.8	75.1	0.0
Central Africa Republic	2 208	3.3	1.7	NA	NA	58.8	39.7	1.5
Congo (Democratic Republic of the)	27 875	3.2	1.3	NA	NA	63.0	36.3	0.6
Congo (Republic of) [f]	1 946	4.5	2.2	48	61	62.4	12.2	25.4
Cote d'Ivoire[f]	9 940	2.4	0.5	57	76	79.8	19.0	1.1
Eritrea	2 134	1.4	0.6	NA	NA	97.9	0.0	2.1
Ethiopia[f]	39 460	5.5	4.6	57	64	88.6	1.0	10.4
Kenya	18 137	5.6	4.0	NA	NA	59.9	1.8	38.4
Lesotho	1 084	5.6	3.7	47	81	86.1	0.0	13.9
Malawi	6 416	1.9	0.5	58	91	80.3	1.1	18.6
Mozambique	10 430	2.1	0.8	NA	NA	25.0	10.5	64.5
Namibia[f]	1 118	7.5	3.8	39	53	68.0	9.5	22.5
Rwanda	4 678	11.3	4.3	NA	NA	14.6	85.2	0.2
South Africa	31 159	9.1	2.2	57	82	58.5	21.1	18.9
Swaziland	592	11.0	4.1	79	92	93.3	0.7	6.0
Tanzania (United Republic of)	20 452	7.5	2.0	NA	NA	92.5	5.6	2.0
Uganda	12 884	18.6	0.0	48	60	31.6	67.3	1.1

Table 1.7 (continued)

WHO Region Country	Adult population[b]	Alcohol consumption[c]	Unrecorded consumption[d]	Abstainers[e]		Recorded beverages consumed		
				Men (%)	Women (%)	Beer (%)	Wine (%), inc. other fermented beverages	Spirits (%)
Zambia	5 966	5.8	3.2	57	81	84.6	0.4	15.0
Zimbabwe	7 473	13.5	9.0	52	90	30.0	1.2	68.8
America A								
Canada	25 516	9.8	2.0	18	26	55.1	18.6	26.9
Cuba	8 915	4.5	2.0	29	70	17.1	9.4	71.4
USA	228 220	9.6	1.0	34	54	61.2	14.4	28.7
America B								
Antigua and Barbuda	NA	6.3	0.8	NA	NA	14.7	21.6	63.7
Argentina	27 331	10.5	2.0	9	26	26.7	62.8	4.7
Bahamas	220	11.1	1.3	NA	NA	8.9	9.7	81.4
Barbados	214	7.0	–0.5	29	70	28.5	8.3	63.3
Belize	156	8.6	2.0	24	44	51.9	1.3	46.8
Brazil	127 411	8.8	3.0	13	31	58.5	5.0	35.7
Chile	11 569	8.8	2.0	22	29	26.5	35.2	34.7
Colombia	29 554	7.7	2.0	5	21	54.9	1.1	43.6
Costa Rica	2 852	7.7	2.0	33	66	15.2	3.9	80.9
Dominica	NA	9.2	1.1	NA	NA	9.7	13.7	76.6
Dominican Republic	5 617	7.5	1.0	12	35	43.8	1.7	54.6
El Salvador	4 243	5.6	2.0	NA	NA	30.6	1.4	68.0
Grenada	NA	7.2	0.9	NA	NA	24.0	10.9	65.1
Guyana	523	5.9	2.0	20	40	34.5	0.0	62.1
Honduras	3 992	4.7	2.0	72	84	46.3	1.5	52.2
Jamaica	1 767	3.9	2.0	38	61	88.2	4.7	7.0
Mexico	69 336	7.6	3.0	36	65	76.8	0.7	22.6

Table 1.7 (continued)

WHO Region Country	Adult population[b]	Alcohol consumption[c]	Unrecorded consumption[d]	Abstainers[e]		Recorded beverages consumed		
				Men (%)	Women (%)	Beer (%)	Wine (%), inc. other fermented beverages	Spirits (%)
Panama	2 106	6.6	0.8	NA	NA	60.2	2.7	37.1
Paraguay[f]	3 512	5.2	1.5	9	33	92.4	6.7	0.0
St Kitts and Nevis	NA	7.6	0.9	NA	NA	45.9	9.3	44.9
St Lucia	109	9.7	–1.0	24	52	19.7	4.5	75.8
St Vincent and the Grenadines	81	7.9	1.0	NA	NA	14.1	3.2	82.7
Suriname	302	6.2	0.0	30	55	47.2	0.8	52.1
Trinidad and Tobago	991	4.3	0.0	29	70	56.3	2.1	41.6
Uruguay[f]	2 557	9.8	2.0	25	43	15.3	61.2	17.6
Venezuela	17 072	9.0	2.0	19	39	84.6	0.0	14.6
America D								
Bolivia	5 276	6.3	3.0	24	45	59.2	2.0	38.8
Ecuador	8 407	7.2	5.4	41	67	76.9	3.2	19.9
Guatemala[f]	6 582	3.8	2.0	49	84	40.5	1.7	57.8
Haiti	4 967	7.5	0.0	58	62	0.4	0.4	99.2
Nicaragua	3 057	3.6	1.0	12	50	32.4	1.6	65.9
Peru	17 761	9.9	5.9	20	29	NA	NA	NA
Eastern Mediterranean B								
Bahrain	503	6.8	0.0	NA	NA	32.5	5.2	62.3
Iran	45 725	1.0	1.0	90	95	0.0	1.8	98.2
Jordan	3 236	0.5	0.3	NA	NA	71.8	2.0	26.1
Kuwait	1 823	0.1	0.0	NA	NA	63.2	0.0	36.8
Lebanon	2 431	4.0	0.5	67	87	10.3	18.4	71.4
Libyan Arab Jamahiriya	3 789	0.0	0.0	NA	NA	76.4	10.3	13.3
Oman	1 606	0.6	0.3	NA	NA	100.0	0.0	0.0

Table 1.7 (continued)

WHO Region Country	Adult population[b]	Alcohol consumption[c]	Unrecorded consumption[d]	Abstainers[e]		Recorded beverages consumed		
				Men (%)	Women (%)	Beer (%)	Wine (%), inc. other fermented beverages	Spirits (%)
Qatar	521	4.3	0.5	NA	NA	7.0	0.0	93.0
Saudi Arabia	13 917	0.6	0.6	NA	NA	100.0	0.0	0.0
Syrian Arab Republic	10 838	0.9	0.4	NA	NA	10.4	73.3	16.3
Tunisia[f]	7 001	1.6	0.5	77	100	62.5	38.5	0.0
United Arab Emirates[f]	2 879	1.0	1.0	86	94	0.0	100.0	0.0
Eastern Mediterranean D								
Afghanistan	13 802	0.0	0.0	NA	NA	36.9	6.4	56.8
Djibouti	432	2.1	0.5	NA	NA	30.2	4.4	65.4
Egypt	45 581	0.6	0.5	99	100	70.2	10.9	18.9
Iraq	15 378	0.2	0.0	NA	NA	79.0	0.0	20.9
Morocco[f]	20 375	1.5	1.0	77	99	60.0	51.3	0.0
Pakistan	89 157	0.3	0.3	90	99	34.4	65.6	0.0
Somalia	4 172	0.5	0.5	NA	NA	100.0	0.0	0.0
Sudan	20 536	1.3	1.0	NA	NA	0.0	0.0	100.0
Yemen	10 024	0.3	0.2	NA	NA	88.1	0.0	11.9
Europe A								
Austria	6 813	11.6	0.7	6	16	59.0	35.6	15.2
Belgium	8 577	10.7	0.2	12	26	54.5	30.0	14.1
Croatia	3 768	17.0	4.5	12	29	38.7	52.0	9.3
Cyprus	633	12.2	1.0	10	15	30.2	20.4	47.3
Czech Republic	8 642	13.9	1.0	9	20	71.8	16.8	34.3
Denmark	4 370	13.7	2.0	2	4	50.9	37.1	11.6
Finland	4 278	11.2	1.9	7	8	47.9	24.8	27.4
France	48 750	13.3	1.0	4	9	16.9	59.8	23.3

Table 1.7 (continued)

WHO Region Country	Adult population[b]	Alcohol consumption[c]	Unrecorded consumption[d]	Abstainers[e]		Recorded beverages consumed		
				Men (%)	Women (%)	Beer (%)	Wine (%), inc. other fermented beverages	Spirits (%)
Germany	70 042	13.2	1.0	7	9	58.4	25.6	19.2
Greece	9 415	10.9	1.8	NA	NA	25.0	47.8	23.1
Iceland	221	7.6	1.0	11	12	50.7	24.2	24.2
Ireland	3 112	14.7	1.0	17	26	68.1	14.5	23.1
Israel	4 565	3.3	1.0	26	45	41.8	10.6	47.6
Italy	49 689	9.9	1.5	19	49	19.1	75.8	5.4
Luxembourg	362	14.2	–1.0	NA	NA	45.5	54.6	13.4
Malta	321	6.4	0.3	NA	NA	41.1	46.0	16.3
Netherlands	13 106	10.3	0.5	9	22	49.5	26.1	20.8
Norway	3 644	7.5	2.0	6	6	59.8	27.5	18.2
Portugal	8 678	12.9	1.0	NA	NA	30.2	48.8	14.4
Slovenia	1 674	9.9	3.0	6	26	55.9	33.8	10.3
Spain[f]	35 646	12.5	1.0	25	50	38.2	33.9	25.0
Sweden	7 315	9.0	3.0	10	16	57.0	35.9	20.4
Switzerland	5 969	11.4	0.5	14	30	30.8	51.1	17.8
United Kingdom	48 042	13.3	2.0	9	14	52.4	22.5	17.7
Europe B								
Albania	2 188	5.2	3.0	NA	NA	41.8	17.4	40.9
Armenia	2 323	3.3	1.9	16	56	8.7	18.0	73.4
Azerbaijan	5 860	7.0	1.9	39	62	22.8	2.3	74.9
Bosnia and Herzegovina	3 218	13.5	3.0	45	87	18.4	2.4	79.1
Bulgaria	6 717	9.4	3.0	26	57	13.4	43.4	39.3
Georgia[f]	3 666	4.1	2.5	11	51	23.1	71.4	5.5
Kyrgyzstan	3 383	4.9	2.0	34	61	9.0	7.6	83.4

Table 1.7 (continued)

WHO Region Country	Adult population[b]	Alcohol consumption[c]	Unrecorded consumption[d]	Abstainers[e]		Recorded beverages consumed		
				Men (%)	Women (%)	Beer (%)	Wine (%), inc. other fermented beverages	Spirits (%)
Macedonia (Former Yugoslav Republic of)	1 596	7.0	2.9	NA	NA	46.8	33.9	19.3
Poland	31 693	10.9	3.0	16	34	53.6	18.7	25.8
Romania	18 192	14.7	4.0	23	53	34.7	32.7	29.4
Slovakia[f]	4 412	14.6	4.0	5	9	52.4	17.4	39.8
Tajikistan	3 705	4.6	4.0	NA	NA	3.4	38.5	58.1
Turkey	49 177	4.1	2.7	66	92	55.0	8.8	40.0
Turkmenistan	3 035	2.1	1.0	NA	NA	8.4	90.3	1.3
Uzbekistan	16 380	3.4	1.9	NA	NA	17.7	16.6	65.7
Europe C								
Belarus	8 215	11.0	4.9	11	29	16.7	12.4	70.9
Estonia	1 122	11.0	1.0	10	32	57.3	4.8	22.6
Hungary[f]	8 498	17.4	4.0	4	8	31.9	35.7	30.6
Kazakhstan[f]	11 043	8.1	4.9	26	44	27.1	8.2	64.6
Latvia	1 955	11.6	2.3	15	32	23.4	5.7	74.0
Lithuania	2 820	14.2	4.9	10	28	48.0	11.2	40.9
Moldova (Republic of)	3 353	25.0	12.0	13	30	5.7	7.9	86.4
Russian Federation[f]	120 831	15.2	4.9	12	26	18.1	10.2	72.1
Ukraine[f]	40 054	15.6	10.5	15	28	20.0	11.0	80.0
South East Asia B								
Indonesia	151 683	0.6	0.5	90	99	46.5	0.8	52.8
Sri Lanka	15 117	2.4	2.1	67	98	49.9	1.6	48.4
Thailand	47 053	7.7	2.0	44	90	23.3	0.3	79.5
South East Asia D								

Table 1.7 (continued)

WHO Region Country	Adult population[b]	Alcohol consumption[c]	Unrecorded consumption[d]	Abstainers[e]		Recorded beverages consumed		
				Men (%)	Women (%)	Beer (%)	Wine (%), inc. other fermented beverages	Spirits (%)
Bangladesh	84 829	0.2	0.2	87	100	36.4	3.8	59.7
Bhutan	1 215	0.7	0.3	NA	NA	100.0	0.0	0.0
India	703 046	2.2	1.9	80	98	17.5	0.0	100.0
Korea (Democratic People's Republic of)	16 377	3.5	0.5	NA	NA	6.6	0.0	93.4
Maldives	175	2.3	0.5	NA	NA	20.6	23.5	55.9
Myanmar	33 574	0.7	0.4	52	91	10.4	0.2	89.4
Nepal	15 234	2.4	2.2	51	73	36.3	1.5	62.2
Western Pacific A								
Australia	15 488	9.2	0.0	14	21	63.3	31.0	16.2
Brunei Darussalem	242	0.5	0.3	NA	NA	70.6	5.9	23.5
Japan	109 266	9.6	2.0	11	29	25.1	4.7	50.8
New Zealand	3 029	9.8	0.5	12	17	49.5	26.1	20.8
Singapore	3 283	3.1	1.0	67	82	62.2	6.7	27.8
Western Pacific B								
Cambodia	8 099	2.1	0.5	NA	NA	18.2	0.6	81.2
China	988 456	5.9	0.8	25	61	23.5	0.6	76.9
Cook Islands	NA	2.0	0.4	NA	NA	0.0	39.8	60.2
Fiji	557	2.9	1.0	79	98	79.3	7.9	12.7
Kiribati	NA	2.8	2.0	51	93	90.8	0.6	8.6
Korea (Republic of)	37 833	14.8	7.0	12	39	29.6	38.0	32.4
Lao People's Democratic Republic	3 205	7.9	1.0	30	67	12.3	0.4	87.3
Malaysia	16 002	2.1	1.0	83	97	85.7	0.0	14.3

Table 1.7 (continued)

WHO Region Country	Adult population[b]	Alcohol consumption[c]	Unrecorded consumption[d]	Abstainers[e]		Recorded beverages consumed		
				Men (%)	Women (%)	Beer (%)	Wine (%), inc. other fermented beverages	Spirits (%)
Micronesia (Federated States of)	65	2.2	1.1	45	91	100.0	0.0	0.0
Mongolia	1 705	4.8	2.0	NA	NA	15.8	3.7	80.5
Nauru	NA	2.3	0.4	NA	NA	86.9	13.1	0.0
Niue	NA	10.8	2.1	NA	NA	24.9	21.9	53.2
Papua New Guinea	3 255	2.4	0.5	NA	NA	34.2	0.6	65.2
Philippines[f]	49 880	6.6	3.0	28	73	21.6	1.4	77.0
Solomon Islands	258	0.9	0.2	NA	NA	26.0	2.6	71.3
Tonga	64	1.0	0.2	NA	NA	28.3	12.6	59.2
Tuvalu	NA	1.5	0.3	NA	NA	54.3	23.4	22.3
Vanuatu	117	1.0	0.2	NA	NA	6.2	26.4	67.4
Vietnam[f]	55 099	2.9	2.1	39	95	94.2	0.0	1.7

NA, not available [a] Calculated by the Working Group from WHO Global Alcohol Database (undated) [b] Numbers in thousands ≥15 years of age [c] Per-capita (age ≥15 years) average consumption per year in litres of absolute alcohol from 2001 to 2003, including unrecorded consumption [d] Unrecorded consumption was mainly derived from surveys by local experts based on fragmented data. [e] Abstainer figures relate to 'last year' and were derived from surveys, which contain measurement errors. Moreover, in some countries, only lifetime abstention rates were available, but no information on abstention during the last year. [f] Estimates of 'last year' abstention based on lifetime abstention

In terms of pricing, locally produced traditional alcoholic beverages tend to be considerably cheaper than their western-style, commercially produced counterparts.

In many regions of the world, illegal alcoholic beverages are approximately 2–6 times cheaper (McKee *et al.*, 2005; Lang *et al.*, 2006) than commercial alcoholic beverages and are thus most likely to be consumed by those who are on the margins of society, are very heavy drinkers or are dependent on alcohol, all of whom are commonly underrepresented in surveys. In spite of the higher price, industrially produced alcoholic beverages are gaining popularity in many of these countries.

1.3.3 *Global consumption in 2002*

Although the global average consumption is 6.2 L of pure alcohol *per capita* per year, there is wide variation around the world (Table 1.8). The countries with the highest overall consumption are those in eastern Europe that surround the Russian Federation; however, other areas of Europe also have high overall consumption. The Americas have the next highest overall consumption. Except for some individual countries, alcoholic beverage consumption is lower in other parts of the world. Globally, 55.2% of adult men and 34.4% of adult women consume alcoholic beverages; in 2002, this constituted more than 1.9 billion adults. The fraction of unrecorded consumption is higher in less developed parts of the world, and is thus highest in the poorest regions of Africa, Asia and South America. In addition, unrecorded consumption is estimated to be proportionally high in the Eastern Mediterranean Region where many of the countries are Islamic, although the level of consumption is very low. Table 1.8 gives further details on consumption.

Table 1.9 shows the rates of drinking more than 40 g pure alcohol per day in different parts of the world. As expected from the per-capita figures, there is huge variation between sexes and by region, with highest prevalence in eastern Europe (Russian Federation and surrounding countries) and lowest prevalence in the WHO Eastern Mediterranean Region where countries are mostly Islamic.

1.3.4 *Trends in recorded per-capita consumption*

Figs. 1.1–1.4 give an overview of trends in alcoholic beverage consumption over the past 40 years. Trends of unrecorded consumption are not available because of the lack of data. However, in regions that have relatively high recorded consumption, these figures also reflect the trend of overall consumption.

Changes in the trend of overall alcoholic beverage consumption have varied between different countries and regions. In Europe, consumption declined in the 1980s and has been stable since 1990. The European trend obscures various developments in different countries, such as an increase in countries with formerly lower consumption such as the Nordic countries, and a decline in consumption in traditional wine-producing countries such as France, Italy, Portugal and Spain. Other regions have remained

Table 1.8 Characteristics of alcoholic beverage consumption throughout the world in 2002[a]

WHO Region[b]	Adult population[c]	Percentage of abstainers[d]		Total alcohol consumption[e]	Unrecorded consumption	Recorded beverage most commonly consumed
		Men	Women			
Africa D	180 316	59.3	69.3	7.2	2.2	Other fermented beverages
Africa E	208 662	55.4	73.3	6.9	2.7	Other fermented beverages and beer
America A	262 651	32.0	52.0	9.4	1.1	Beer
America B	311 514	18.0	39.1	8.4	2.6	Beer
America D	46 049	32.1	51.0	7.4	4.0	Spirits and beer
Eastern Mediterranean B	94 901	86.9	95.0	1.0	0.7	Spirits
Eastern Mediterranean D	219 457	90.8	98.9	0.6	0.4	Beer
Europe A	347 001	11.4	23.0	12.1	1.3	Beer and wine
Europe B	155 544	38.6	62.4	7.5	2.8	Spirits and beer
Europe C	197 891	13.0	26.9	14.9	6.1	Spirits
South East Asia B	215 853	77.6	96.9	2.3	0.9	Spirits

Table 1.8 (continued)

WHO Region[b]	Adult population[c]	Percentage of abstainers[d]		Total alcohol consumption[e]	Unrecorded consumption	Recorded beverage most commonly consumed
		Men	Women			
South East Asia D	854 450	79.0	98.0	1.9	1.6	Spirits
Western Pacific A	131 308	13.0	29.0	9.4	1.7	Spirits
Western Pacific B	1 164 701	26.3	62.5	6.0	1.1	Spirits
World	4 388 297	44.8	65.6	6.2	1.7	Spirits (53%)

[a] Calculated by the Working Group from WHO Global Alcohol Database (undated) [b] Listing of WHO Regions: **Africa D**: Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Togo; **Africa E**: Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe; **Americas A**: Canada, Cuba, USA; **Americas B**: Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, St Kitts and Nevis, St Lucia, St Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela; **Americas D**: Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru; **Eastern Mediterranean B**: Bahrain, Iran (Islamic Republic of), Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates; **Eastern Mediterranean D**: Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen; **Europe A**: Andorra, Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom; **Europe B**: Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Slovakia, The Former Yugoslav Republic of Macedonia, Tajikistan, Turkey, Turkmenistan, Uzbekistan; **Europe C**: Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine; **South East Asia B**: Indonesia, Sri Lanka, Thailand; **South East Asia D**: Bangladesh, Bhutan, Democratic People's Republic of Korea, India, Maldives, Myanmar, Nepal; **Western Pacific A**: Australia, Brunei Darussalam, Japan, New Zealand, Singapore; **Western Pacific B**: Cambodia, China, Cook Islands, Fiji, Kiribati, Lao People's Democratic Republic, Malaysia, Marshall Islands, Micronesia (Federated States of), Mongolia, Nauru, Niue, Palau, Papua New Guinea, Philippines, Republic of Korea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Viet Nam [c] Numbers in thousands [d] Abstainer figures relate to 'last year' and were derived from surveys, which contain measurement errors. Moreover, in some countries, only lifetime abstention rates were available, but no information on abstention during the last year. [e] Per-capita (age ≥ 15 years) average consumption in litres of absolute alcohol from 2001 to 2003, including unrecorded consumption [f] Estimates of 'last year' abstention based on lifetime abstention

Table 1.9 Consumption of more than 40 g pure alcohol per day by sex and WHO region, 2002[a]

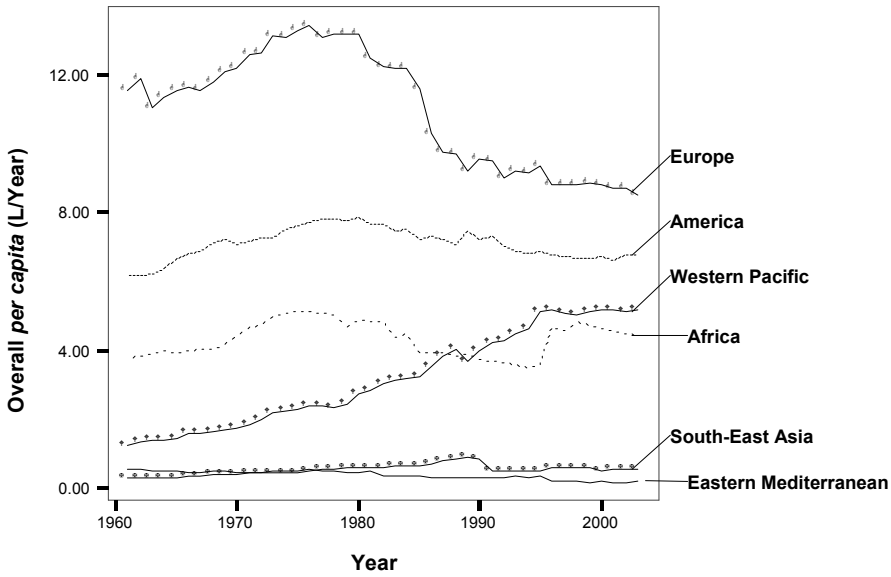
Region[b]	Men	Women
Africa D	27.6%	8.2%
Africa E	30.1%	6.1%
America A	33.9%	5.1%
America B	21.4%	6.5%
America D	20.7%	2.6%
Eastern Mediterranean B	2.1%	0.0%
Eastern Mediterranean D	1.0%	0.0%
Europe A	44.2%	7.6%
Europe B	34.4%	4.7%
Europe C	63.7%	11.1%
South East Asia B	12.0%	0.1%
South East Asia D	8.4%	0.1%

Table 1.9 (continued)

Region[b]	Men	Women
Western Pacific A	29.6%	2.3%
Western Pacific B	20.5%	0.8%
World	22.2%	3.1%

[a] From WHO Global Alcohol Database (undated) [b] Listing of WHO Regions: **Africa D**: Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Togo; **Africa E**: Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe; **Americas A**: Canada, Cuba, USA; **Americas B**: Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, St Kitts and Nevis, St Lucia, St Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela; **Americas D**: Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru; **Eastern Mediterranean B**: Bahrain, Iran (Islamic Republic of), Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates; **Eastern Mediterranean D**: Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen; **Europe A**: Andorra, Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom; **Europe B**: Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Slovakia, The Former Yugoslav Republic of Macedonia, Tajikistan, Turkey, Turkmenistan, Uzbekistan; **Europe C**: Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine; **South East Asia B**: Indonesia, Sri Lanka, Thailand; **South East Asia D**: Bangladesh, Bhutan, Democratic People's Republic of Korea, India, Maldives, Myanmar, Nepal; **Western Pacific A**: Australia, Brunei Darussalam, Japan, New Zealand, Singapore; **Western Pacific B**: Cambodia, China, Cook Islands, Fiji, Kiribati, Lao People's Democratic Republic, Malaysia, Marshall Islands, Micronesia (Federated States of), Mongolia, Nauru, Niue, Palau, Papua New Guinea, Philippines, Republic of Korea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Viet Nam

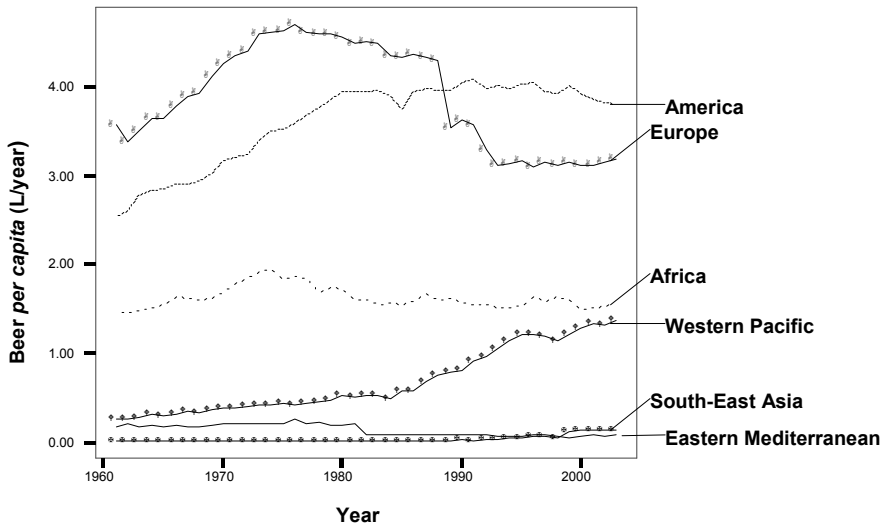
Figure 1.1. Recorded overall adult per-capita consumption of alcoholic beverages in six WHO Regions: Africa, Americas, Eastern Mediterranean, Europe, South-East Asia and Western Pacific, 1961–2003[a]



From FAO Statistical Database [FAOSTAT]

[a] Calculated by the Working Group [population weighted]

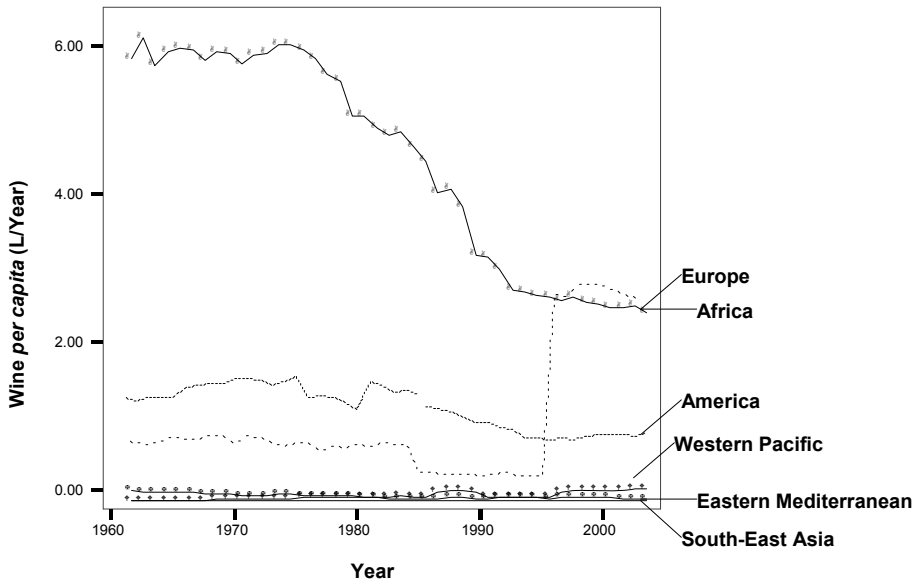
Figure 1.2. Recorded adult per-capita beer consumption in six WHO Regions: Africa, Americas, Eastern Mediterranean, Europe, South-East Asia and Western Pacific, 1961–2003[a]



From FAO Statistical Database [FAOSTAT]
[a] Calculated by the Working Group [population weighted]

Note: In 1989, the Russian Federation, a typically non-beer-drinking nation, was included in calculations of European per-capita consumption. Previously, no estimates were available for the former Soviet Union.
Figures for the Americas were estimated and imputed for the years 1976–80.

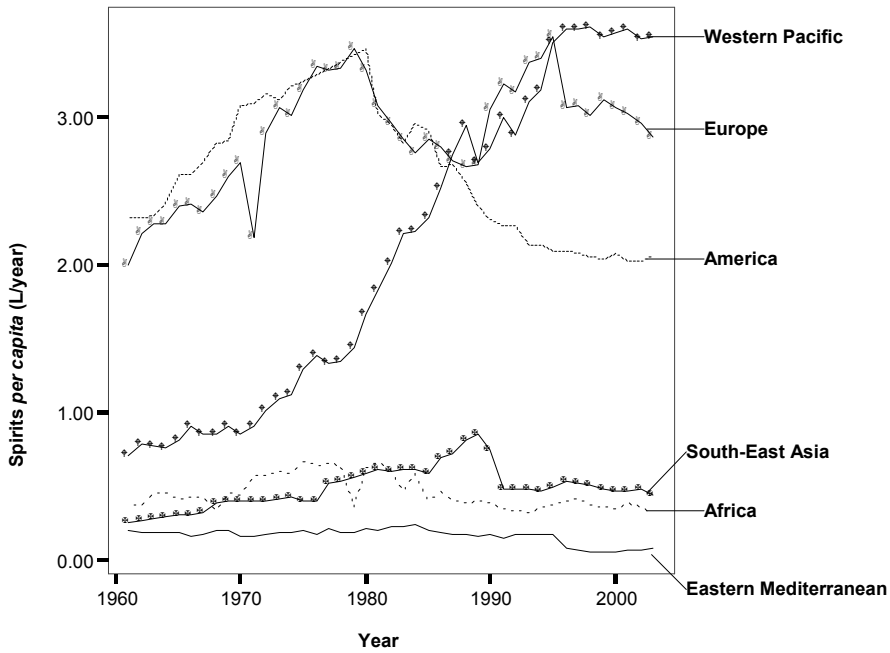
Figure 1.3. Recorded adult per-capita wine consumption in six WHO Regions: Africa, Americas, Eastern Mediterranean, Europe, South-East Asia and Western Pacific, 1961–2003[a]



From FAO Statistical Database [FAOSTAT]
[a] Calculated by the Working Group [population weighted]

Note: The increase in African consumption resulted from the inclusion of fermented beverages into the wine category by FAO.

Figure 1.4. Adult per-capita consumption of spirits in six WHO Regions: Africa, Americas, Eastern Mediterranean, Europe, South-East Asia and Western Pacific, 1961–2003[a]



From FAO Statistical Database [FAOSTAT]

[a] Calculated by the Working Group [population weighted]

Note: Figures for the Americas were estimated and imputed for the years 1976–80.

relatively stable, but consumption in the Western Pacific Region, mostly influenced by China because of the large population there, has almost steadily increased.

The trends in beer consumption follow the same pattern. In addition, beer consumption has been increasing in the Americas; this region now has the biggest beer consumption *per capita* in the world.

Europe and, to a much lesser degree, America are the only regions with notable consumption of wine. The seemingly high consumption in Africa is due to the fact that FAO has been recording fermented beverages under this category since the mid 1990s.

Finally, spirits are the most commonly consumed beverage type around the world. They have also contributed to the large increase in consumption in the Western Pacific Region. In a global perspective, the Western Pacific Region, and especially China, is now the region with the highest consumption of spirits in the world. It should also be noted that the consumption of spirits has decreased in the Americas, where this type of beverage has been replaced by beer.

1.4 Sociodemographic determinants of alcoholic beverage consumption

1.4.1 *Introduction*

As noted in Section 1.3, per-capita consumption figures offer overall a comparable picture of alcoholic beverage consumption across countries and avoid the problems of underestimation as well as other sources of bias present in survey methods (e.g. recall bias). However, per-capita consumption does not provide any information on patterns of consumption within a country; that is, the frequency and quantity of consumption as well as occasions on which a large amount of alcoholic beverages may be consumed at one time. Also, with per-capita consumption, it is not known which subgroups engage in particular patterns of drinking. Survey data, although imperfect in certain respects, still provide the only method to obtain knowledge on the patterns of consumption within a population.

Key measures of patterns of consumption include the assessment, within a given period, of the proportion of the population that drinks at all and, conversely, the proportion that abstains from drinking. Among those who drink, central measures include the frequency of drinking over a pre-defined period and the total amount or volume of ethanol consumed over that period. It is also informative to gather this information for the three major classes of beverage: beer, wine and spirits. In addition, it is helpful to calculate the average amount of alcoholic beverages consumed per day as well as the number of drinking days. The former measure is often used to communicate safe drinking limits to the public (e.g. British Medical Association, 1995). A final important indicator of patterns of consumption is a measure of so-called ‘heavy episodic drinking’. This is defined as an intake of ethanol sufficient to lead to intoxication in a single session of drinking, and is usually 60 g ethanol or more (WHO, 2000).

Knowledge of the patterns and habits of alcoholic beverage consumption in various countries and among cultures has increased markedly over the past decade. This has been due to efforts of various cross-cultural social-epidemiological studies as well as initiatives of various regional and global institutions such as the European Commission and the WHO to conduct general population surveys. Despite these advances, gaps in knowledge still exist; however, it is now possible to obtain a general picture of drinking habits in various regions of the world, which was not the case previously. Such information can help to indicate which geographic and demographic groups may be at greater risk from certain exposures to alcoholic beverage consumption than others.

1.4.2 *Gender*

It has been often observed that men are more frequently drinkers of alcoholic beverages, drink larger amounts and drink more often than women (Wilsnack *et al.*, 2000, 2005). This appears to be a universal gender difference in human social behaviour. However, the magnitude of these gender differences varies by age group, socioeconomic group and by region and/or culture.

With respect to the European Region, gender differences in the rates of current drinkers are small, with gender ratios (i.e. the value of a variable for men divided by that for women) that range between 1.0 and 1.2 (calculated from Mäkelä *et al.*, 2006). In the adult drinking population (20–64 years), gender ratios for overall drinking frequency are between 1.8 and 2.5. Larger variation exists for beverage-specific drinking frequency: men and women are most similar in their wine-drinking habits and the least similar in their beer-drinking habits. This basic pattern holds true for beverage-specific volume. Although in some countries women may drink wine more frequently than men, men almost always consume more of each beverage than women. Gender ratios for mean quantities of specific beverages consumed per drinking day have a narrow range for wine (1.0–1.8) and a wider range for spirits (1.1–2.0) and beer (1.3–2.2). For total mean volume and frequency of heavy episodic drinking, gender ratios are larger than those for drinking status or drinking frequency and most range between 1.8 and 5.8 across the European Region. Gender differences are smaller in the northern European countries for current drinking, frequency of drinking and frequency of heavy episodic drinking, but gender ratios for mean consumption reveal no clear regional pattern (Mäkelä *et al.*, 2006).

In the 14 WHO regions, more women than men are abstainers, yet the rates of current drinking for both men and women are similar across the regions, showing that, where the level of current drinking for men is high, that for women is also high. The gender ratios are extremely variable: western Europe and the Western Pacific (e.g. Australia and Japan) have low ratios of 1.1 while the Eastern Mediterranean (e.g. Afghanistan and Pakistan) has a ratio of 17 and South-East Asia (e.g. Bangladesh and India) has a ratio of 6.5 (Wilsnack *et al.*, 2005). Furthermore, the percentage of alcoholic beverages consumed by women also varies greatly across regions. In Europe, the

share of alcoholic beverages consumed by women generally varies between 20% and 30% (Mäkelä *et al.*, 2006). In developing countries, the percentage share can be much lower: based on recently conducted surveys, it is, for example, 8% in China, 10% in India and 15% in Ecuador (WHO, 2004).

Data – as yet unpublished – obtained from a recent general population survey in many countries (Argentina, Australia, Austria, Brazil, Costa Rica, Czech Republic, Denmark, Finland, France, Germany, Hungary, Iceland, India, Israel, Italy, Japan, Mexico, the Netherlands, Nigeria, Norway, Spain, Sri Lanka, Sweden, Uganda, United Kingdom, USA, Uruguay) in various regions of the world through the GENACIS project (Rahav *et al.*, 2006) confirm the previously mentioned variations in drinking by gender: men are more likely to be drinkers than women, women are more likely to be lifetime abstainers, men are more likely to drink heavily and more frequently and women drinkers are more likely to be light drinkers. These gender differences are more marked for countries outside North America and northern Europe.

1.4.3 *Age*

The relationship of age to drinking habits is very much affected by gender and culture. In general terms, however, among adult populations in the developed world, abstention rates increase with older age and, among those who drink, frequency of drinking increases. Heavy episodic drinking is most frequent among the younger age groups; however, in some countries (e.g. central Europe), such rates do not always decline.

As stated, these general tendencies are very much affected by both age and region. For example, in Europe, a decrease in current drinking rates with age (age categories of 20–34, 35–49, 50–64 years) has been seen for some (e.g. northern and eastern Europe) but not all European countries (Mäkelä *et al.*, 2006). Men and women tend to have similar current drinking rates at a given age. In many European countries, drinking frequency increases with increasing age, which can be attributed mostly to an increase in the frequency of drinking wine. This holds for both sexes. Typical amounts of alcoholic beverage consumed also generally decrease with age across many European countries and across the genders, although a slight increase in wine consumption with increasing age can be observed in France (Mäkelä *et al.*, 2006). In most northern European countries, heavy episodic drinking clearly declines with increasing age, but such reductions are not as observed in more central European countries.

Age also interacts variously with gender across the GENACIS study countries. For example, drinking status and frequency of drinking do not decline with age everywhere. For most European countries, the gender ratio for current drinking status remains rather stable across age groups and, in low- and middle-income countries, there is no clear pattern of the gender gap being larger at younger or older ages. The proportion of heavy drinkers (e.g. 23.2 g ethanol per day or more) tends to decline with increasing age (age categories of 18–34, 35–49, 50–65 years) among the North

American and European countries (central and southern European countries tend to be exceptions). The non-European, non-North American countries have varying patterns: in several low- and middle-income countries (e.g. Brazil, India, Nigeria) as well as Japan, heavy drinking is positively correlated with increasing age, especially among men. Heavy episodic drinking has much clearer patterns. In almost all of the GENACIS study countries, the prevalence of heavy episodic drinking decreases with increasing age. However, this reduction is not always proportional across the sexes, leading to higher gender ratios in the older age categories (Rahav *et al.*, 2006).

1.4.4 *Socioeconomic status*

In developed economies, people with higher socioeconomic status are more likely to be current drinkers than those with lower socioeconomic status. Among those who drink, drinking frequency is higher among those with higher status. Heavy drinking and heavy episodic drinking are, in general, found to be more common among women of higher socioeconomic status; for men, the trend for both indicators is converse (e.g. Bloomfield *et al.*, 2006). Further, in the USA, it is known that household income, education and employment status are positively associated with current drinking status and more frequent drinking, but are negatively correlated with measures of heavier drinking such as weekly heavy drinking (Midanik & Clark, 1994; Greenfield *et al.*, 2000).

In the Netherlands, van Oers *et al.* (1999) found that lower educational status was positively related to abstinence from alcohol for both men and women; however, among men, very excessive drinking was more prevalent in the lowest educational group. Among women, higher educational level was associated with fewer reports of psychological dependence and symptomatic drinking, while among men higher educational level was associated with fewer reports of social problems.

Bloomfield *et al.* (2000) investigated socioeconomic status and drinking behaviour in a sample of the German general population and found, in comparison with men of high socioeconomic status, that men of middle status had increased odds for heavy episodic drinking, while men of lower status had higher odds for symptoms of alcohol dependence. Women of middle socioeconomic status had significantly lower odds for reporting alcohol-related problems and symptoms of alcohol abuse in comparison with women of higher status.

Marmot (1997) examined data from the Whitehall II Study in the United Kingdom and found variations in prevalence of alcoholic beverage consumption by grade of employment. Higher rates of abstention were evident for both sexes among those in the lower employment grades. More moderate drinking was found among men in the higher employment grades, but the proportion of heavier drinkers was rather constant from the highest to lowest grades. However, among women, there was not only a higher proportion of women in the higher grades who drank moderately, but also a much higher rate of heavier drinking.

In a comparative study of socioeconomic position and health, Kunst *et al.* (1996) found differing associations between heavy drinking and level of education among men and women in eight European countries. Excessive (four glasses or more per day) alcoholic beverage consumption was more common among men with a lower level of education. Among women, no substantial differences were found.

A less consistent pattern has emerged in some low- and middle-income countries such as Brazil, where the higher classes tend to have higher rates of heavier drinking among both genders (Almeida-Filho *et al.*, 2005; Bloomfield *et al.*, 2006). Similarly, among Argentinean men, more of those with a low level of education (less than 8 years of schooling) are abstainers, while more of those who drink weekly or engage in heavy episodic drinking are more highly educated; for Argentinean women, however, more of those who usually drink three or more drinks or engage in heavy episodic drinking are less educated (Munné, 2005). In a regional sample of China, Wei *et al.* (2001) reported that men and women with a lower level of education (0–6 years of schooling) were more frequently abstainers, but also more men with a lower level of education drank daily or more frequently than those with a higher level.

1.4.5 *Socioeconomic status and beverage preferences*

Those who prefer wine compared with beer, spirits or a more mixed consumption come from higher sociodemographic backgrounds (higher socioeconomic status, higher education) and are more frequently light or moderate drinkers. Men and younger individuals more frequently tend to be beer drinkers and women and older people are more frequently wine drinkers (see e.g. the literature reviews in Wannamethee & Shaper, 1999; Graves & Kaskutas, 2002; Klatsky *et al.*, 2003; Nielsen *et al.*, 2004). With regard to age, Gmel *et al.* (1999) have shown, in a longitudinal study in Switzerland with clearly different drinking cultures between the German- and Latin-speaking regions, that young people across all regions more often preferred beer, but were more likely when growing older to change to the typical regional pattern. The preference for beer at younger ages was probably related to the fact that beer is the cheapest alcoholic beverage.

Most of the studies on background characteristics of individuals who have different beverage preferences were conducted in only very few countries such as the North American countries, the United Kingdom or Denmark, which are commonly 'beer countries', and thus wine consumption might be more closely associated with the habits of the more prosperous sectors of the population. Some similarities have also been found for southern European 'wine' countries, such as a higher proportion of heavy drinkers among those who do not drink exclusively wine in Greece (San José *et al.*, 2001), consumption of more beer and spirits compared with wine among younger individuals in Spain (Del Rio *et al.*, 1995) and the proportion of beer in total alcoholic beverage consumption increasing with total ethanol intake in France (Ruidavets *et al.*, 2002). There is nevertheless sufficient evidence that harm from chronic heavy drinking

of wine is found in southern European countries where wine is the culturally preferred and therefore often also the cheapest alcoholic beverage.

The price of alcoholic beverages seems to be a main determinant of which type of beverage is usually preferred, and thus wine as the 'drink of moderation' in many established market economies may reflect the better economical status of wine drinkers, which in turn is related to better education and other healthier lifestyles. Decades ago, excessive drinkers or even alcoholics in the USA were called 'winos' because they drank the cheapest wines from which they could obtain the most alcohol for their money (Klatsky, 2002). It has been argued that there has been a worldwide shift away from cheap wines to quality wines marketed to middle-class consumers, which may have helped to make table wine the more frequent choice of alcoholic beverage among the better-educated segments of society in Denmark, the USA and some other countries.

Outside the established market economies, the gender and sociocultural backgrounds of beverage preferences are much less consistent. It appears that beverage preference is mostly determined by economic conditions, and the poorest people drink the cheapest and most readily available beverages, which can be wine, beer or locally produced beverages. In contrast, people who have a higher standard of living drink the more expensive beverages, which can be industrial, lager type beers or foreign spirits such as whiskies (WHO, 2005).

According to Benegal (2005), 95% of the total alcoholic beverages consumed in India by both male and female drinkers is in the form of licit and illicitly distilled spirits; the remainder is mainly beer. The market for wine is small and wine is mainly drunk by people in high socioeconomic classes and predominantly by women. In contrast, consumption of illicit 'moonshine' by women was more frequently found among rural and working classes. Men who drink beer consume less alcohol than those who drink spirits in India. On the basis of equal quantities of alcohol, beer is more expensive than spirits, and thus beer is drunk by the middle and upper socioeconomic classes (Saxena, 1999). Beer is also more expensive in Brazil than locally produced spirits such as cachaça and thus the latter is more often consumed by heavy drinkers and is preferred by the poorest and least educated (Carlini-Cotrim, 1999). In Mexico (Romero-Mendoza *et al.*, 2005), most women drink beer and spirits, but not table wine. Table wine is consumed by the highest socioeconomic classes, whereas the poorest people drink pulque and aquardiente which are often produced illicitly (Medina-Mora, 1999). Among men, more than half of the pulque drinkers were heavy drinkers. In Nigeria (Ibanga *et al.*, 2005), although wine is the only alcoholic beverage consumed by more women than men, a higher percentage of women (but fewer men) drink beer and local beverages such as burukutu, palmwine and ogogoro (distilled from palmwine) compared with wine. Among men, lower socioeconomic classes prefer traditional African beers and other local beverages whereas commercial western-style beers are preferred by higher socioeconomic classes (Gureje, 1999). In Zimbabwe, the traditional opaque beer is most frequently consumed. Among people with higher incomes, this is

replaced by clear (lager-style) beer, fortified wines and imported spirits that are more expensive than the cheapest opaque beer (Jernigan, 1999). Beer and cheap local brews are also more popular than wine among women who drink in Sri Lanka (Hettige & Paranagama, 2005) where women in higher socioeconomic classes also drink wine and whisky, and those in the lower classes also drink hard liquor such as arrak and illicit liquor. In Papua New Guinea (Marshall, 1999), beer is again by far the most popular beverage, followed by rum and Scotch whiskies. White wines are consumed regularly by only a small number of modern, well educated urban women.

The poorest populations and those on the fringe of society, very heavy drinkers and those who are dependent on alcohol are also the people who show the highest prevalence of consumption of surrogate and illegally produced alcoholic beverages (see Sections 1.3 and 1.5). The reasons for using illicit and surrogate alcoholic beverages are mainly twofold. Illegal alcoholic beverages are much cheaper, e.g. around 2–6 times less expensive in Estonia and the Russian Federation (McKee *et al.*, 2005; Lang *et al.*, 2006) than commercial alcoholic beverages. Another reason can be the restricted availability of alcoholic beverages during particular periods (e.g. war or economic crises), or in particular regions such as the native American reservations in the USA (see Section 1.4). Particularly in developing countries, illegally produced alcoholic beverages are often the main source of alcohol intake in the lower socioeconomic groups (Marshall, 1999; WHO, 2001).

Few representative population surveys on the use of illicit and surrogate alcoholic beverages have been carried out to date. Nevertheless, there is evidence from small-scale studies that their use can be substantial. Lang *et al.* (2006) reported that 8% of alcoholic beverage consumers in Estonia drink illegal and surrogate alcohols. Mc Kee *et al.* (2005) estimated that among 25–54-year-olds in Izhevsk, the Russian Federation, 7.3% have drunk surrogate alcoholic beverages in the past year and 4.7% drink them weekly. Consumption of illegally produced alcoholic beverages is very high and can represent up to more than 50% of total alcoholic beverage consumption (see Section 1.5) in developing countries (WHO, 2001).

1.5 Non-beverage alcohol consumption

Particularly in central and eastern Europe, but also in developing countries, large discrepancies between recorded alcoholic beverage consumption and potentially alcohol-related mortality can be found. One example is Hungary where mortality from liver disease is approximately fourfold higher than that in countries with similar per-capita consumption of alcohol (e.g. Szücs *et al.*, 2005; Rehm *et al.*, 2007). One reason might be the particularly high unrecorded consumption in parts of eastern and central Europe (see Section 1.4), which may account for even more alcoholic beverage consumption from unrecorded sources in some countries than from recorded sources (Szücs *et al.*, 2005). In addition to smuggled commercial and illegally produced, home-made alcoholic beverages, the latter of which are commonly called ‘samogon’ in the

Russian Federation or 'moonshine' in the USA, a proportion of unrecorded consumption is so-called 'surrogate alcohol'.

Surrogate alcohol is not defined consistently in the literature. Some authors also include under 'surrogate alcohol' illegally produced alcoholic beverages that are intended for consumption as well as alcohols that are not initially intended for consumption (McKee *et al.*, 2005). Others define surrogate alcohol more strictly as substances that contain ethanol but are 'not intended' for consumption such as medicinal alcohol, aftershaves, technical spirits or fire-lighting liquids. Even more strictly, Nordlund and Osterberg (2000) divided the 'not intended for consumption alcohols' into alcohol produced for industrial, technical and medical purposes and what they call 'surrogate alcohol', namely denatured spirits, medicines and car chemicals that contain alcohol, but which are meant, for example, for car washing. In this section, only surrogate alcohol that is apparently not intended for consumption is discussed. In fact, as argued by McKee *et al.* (2005), in some countries, mainly in eastern Europe, it is questionable that part of the production of surrogate alcohols is truly not intended for consumption, e.g. medicinal alcohols sold in bottles with colourful labels that are much larger than those in western Europe or aftershaves that have no discernible warning labels such as 'for external use only'.

A few studies have used gas chromatography/mass spectrometry to analyse the compounds in such products, mainly in eastern Europe. In these, surrogate alcohol commonly consisted of relatively pure ethanol but at a very high concentration: medicinal spirits contained 60–70% vol ethanol, aftershaves slightly less and other non-medicinal (fire-lighting liquids) contained very high concentrations of > 90% (McKee *et al.*, 2005; Lang *et al.*, 2006). Methanol was undetected in theses studies. This, however, might be related to the kind of surrogate alcohol that was analysed, namely medicines, aftershaves and fire-lighting liquids and not industrial alcohol, and to the way in which the alcohol was denatured (e.g. by bitter constituents or methanol) to make it undrinkable. [The Working Group noted that the usual denaturing agents were not analysed in these studies, but the undetected methanol points to the fact that only bitterants were used.] Alcohol is denatured for the purposes of exemption from excise duty. Different substances may be used, e.g. 5 L methylene per 100 L ethanol. Methylene is raw methanol and is produced from the dry distillation of wood that contains at least 10% by weight acetone or a mixture of methylene and methanol. Other denaturing substances include methylethylketone (approx. 1 L per 100 L alcohol) or bitterants such as denatonium benzoate (Lachenmeier *et al.*, 2007).

Industrial alcohol is often denatured by addition of up to 5% methanol (methylated). So-called 'meths' drinking is known all over the world and often has fatal consequences. One of the problems is unintentional 'meths' drinking. Alcohol that is offered for consumption on the illegal market is often adulterated by non-drinkable alcohol (e.g. sold as aquardiente in Mexico) (Medina-Mora, 1999), and thus consumers are not aware of the potential risks. However, there is also evidence that some heavy drinkers, commonly the most economically disadvantaged, mix beverage alcohol with industrial

methylated alcohol. Although there is no comprehensive review of 'meths' drinking worldwide, it probably occurs in numerous countries. Examples are mainly found in developing countries such as Papua New Guinea (Marshall, 1999), Mexico (Medina-Mora, 1999) and India (Saxena, 1999). However, 'meths' drinking was also reported not to be uncommon in New Zealand (Meyer *et al.*, 2000), and the use of denatured alcohol, particularly in form of hairspray and spray disinfectants ('Montana Gin'), was reported to be widespread among native Americans, at least in the 1980s (Burd *et al.*, 1987). Ingestion of hairspray still seems to exist in the USA (Carnahan *et al.*, 2005). The use of industrial alcohol denatured by bitterants (bitrex) was also reported in the late 1980s in Sweden among heavily intoxicated drivers. According to Nordlund and Osterberg (2000), the phenomenon of drinking surrogate alcohol (mainly medicinal alcohol) still exists in Nordic countries but only on a very small scale.

1.6 Chemical composition of alcoholic beverages, additives and contaminants

1.6.1 *General aspects*

Ethanol and water are the main components of most alcoholic beverages, although, in some very sweet liqueurs, the sugar content can be higher than that of ethanol. Ethanol for human consumption is exclusively obtained by the alcoholic fermentation of agricultural products. The use of synthetic ethanol manufactured from the hydration of ethylene for food purposes is not permitted in most parts of the world. However, surrogate alcohol, denatured alcohol or illegally produced alcohol may be used for consumption in certain parts of the world because they may be less expensive than food-grade alcohol.

Some physical and chemical characteristics of anhydrous ethanol are as follows (O'Neil, 2001):

Chem. Abstr. Services Reg. No.: 64–17.5
Formula: C_2H_5OH
Relative molecular mass: 46.07
Synonyms: Absolute alcohol, anhydrous alcohol, dehydrated alcohol, ethanol, ethyl alcohol, ethyl hydrate, ethyl hydroxide
Description: Clear, colourless, very mobile, flammable liquid; pleasant odour; burning taste
Melting-point: –114.1 °C
Boiling-point: 78.5 °C
Density: d_4^{20} 0.789
Refractive index: n_D^{20} 1.361

Ethanol is widely used in laboratories and in industry as a solvent for resins, fats and oils. It is also used in the manufacture of denatured alcohol, in pharmaceuticals and cosmetics (lotions, perfumes), as a chemical intermediate and as a fuel, either alone or in mixtures with gasoline.

In addition to ethanol and water, wine, beer and spirits may contain volatile and non-volatile compounds. Although the term 'volatile compound' is rather diffuse, most of the compounds that occur in alcoholic beverages can be grouped according to whether they are distilled with alcohol and steam or not. Volatile compounds include aliphatic carbonyl compounds, alcohols, monocarboxylic acids and their esters, nitrogen- and sulfur-containing compounds, hydrocarbons, terpenic compounds, and heterocyclic and aromatic compounds. Non-volatile extracts of alcoholic beverages comprise unfermented sugars, di- and tribasic carboxylic acids, colouring substances, tannic and polyphenolic substances and inorganic salts. The flavour composition of alcoholic beverages has been described in detail in several reviews (Rapp, 1988, 1992; Jackson, 2000; Ribéreau-Gayon *et al*., 2000; Briggs *et al*., 2004). During maturation, unpleasant flavours disappear. Extensive investigations on the maturation of wine and distillates in oak casks have shown that many compounds are liberated by alcohol from the walls of the casks (Mosedale & Puech, 1998).

The distillation procedure influences the occurrence and concentration of volatile flavour compounds in the distillate. Particularly in the manufacture of strong spirits, it is customary to improve the flavour of the distillate by the removal of low-boiling and high-boiling compounds to a greater or lesser degree.

Extensive literature is available on aroma components that are usually present at low levels. A list of more than 1100 aroma compounds in wine has been provided (Rapp, 1988). Approximately 1300 substances were listed in Appendix 1 of the previous IARC monograph on alcohol drinking (IARC, 1988). Due to advances in analytical chemistry with improved detection limits down to the picograms per litre range, the compilation of such a list would now go beyond the scope of this monograph.

The following text gives only a summarized overview of the main components of individual alcoholic beverages. For further information, the publications of Jackson (2000) and Ribéreau-Gayon *et al.* (2000) on wine, those of Briggs *et al.* (2004) and Bamforth (2004) on beer and those of Kolb (2002) and Bryce and Stewart (2004) on spirits are recommended.

The main focus of this section is on additives and contaminants of alcoholic beverages and especially potentially carcinogenic substances.

1.6.2 *Compounds in grape wine*

Other than alcohol, wines generally contain about 0.8–1.2 g/L aromatic compounds, which constitute about 1% of their ethanol content. The most common aromatic compounds are fusel alcohols, volatile acids and fatty acid esters. Of these, fusel alcohols often constitute 50% of all volatile substances in wine. Although present in

much smaller concentrations, carbonyls, phenols, lactones, terpenes, acetals, hydrocarbons and sulfur and nitrogen compounds are more important to the varietal and unique sensory features of wine fragrance (Jackson, 2000).

The taste and oral/lingual sensations of a wine are primarily due to the few compounds that occur individually at concentrations above 0.1 g/L. These include water, alcohol (ethanol), fixed acids (primarily tartaric and malic or lactic acids), sugars (glucose and fructose) and glycerol. Tannins are important sapid substances in red wines, but they rarely occur in significant amounts in white wines without maturation in oak casks (Jackson, 2000).

(a) Alcohols

Ethanol is indisputably the most important alcohol in wine. Under standard conditions of fermentation, ethanol can reach up to about 14–15% vol. The prime factors that control ethanol production are sugar content, temperature and strain of yeast (Jackson, 2000). The alcoholic strength of wine is generally about 100 g/L (12.6% vol) (Ribéreau-Gayon *et al*., 2000).

Methanol is not a major constituent in wines, nor is it considered important in the development of flavour. Within the usual range (0.1–0.2 g/L), methanol has no direct sensory effect. The limited amount of methanol that is found in wine is primarily generated from the enzymatic breakdown of pectins. After degradation, methyl groups associated with pectin are released as methanol. Thus, the methanol content of fermented beverages is primarily a function of the pectin content of the fermentable substrate. Unlike most fruit, grapes have a low pectin content. As a result, wine generally has the lowest methanol content of any fermented beverage (Jackson, 2000). Red wines have a higher methanol concentration than rosé wines, while white wines contain even less (Ribéreau-Gayon *et al*., 2000).

Alcohols that have more than two carbon atoms are commonly called higher or fusel alcohols. Most of the higher alcohols that are found in wine occur as by-products of yeast fermentation. They commonly account for about 50% of the aromatic constituents of wine, excluding ethanol. Quantitatively, the most important higher alcohols are the straight-chain alcohols, 1-propanol, 2-methyl-1-propanol (isobutyl alcohol), 2-methyl-1-butanol and 3-methyl-1-butanol (isoamyl alcohol). 2-Phenylethanol is the most important phenol-derived higher alcohol (Jackson, 2000).

(b) Sugars

Unfermented sugars are collectively termed residual sugars. In dry wines, the residual sugar content consists primarily of pentose sugars, such as arabinose, rhamnose and xylose, and small amounts of unfermented glucose and fructose (approximately 1–2 g/L). These levels may increase slightly during maturation in oak casks through the breakdown of glycosides in the wood. The residual sugar content in dry wine is generally less than 1.5 g/L (Jackson, 2000).

(c) Polyols and sugar alcohols

The diol 2,3-butanediol can be found in wine. By far the most prominent polyol in wine is glycerol. In dry wine, it is commonly the most abundant compound, after water and ethanol. Glycerol has a slightly sweet taste but this is probably not noticeable in a sweet wine. It may be slightly noticeable in dry wines, in which the concentration of glycerol often surpasses the sensory threshold for sweetness (> 5 g/L).

Sugar alcohols, such as alditol, arabitol, erythritol, mannitol, myo-inositol and sorbitol, are commonly found in small amounts in wine (Jackson, 2000).

(d) Acids

For the majority of table wines, a range of 5.5–8.5 g/L total acidity is desired. It is typically preferred that white wines be at the higher end of the scale and that red wines be at the lower end. Thus, a pH range of 3.1–3.4 is the goal for white wines and that of 3.3–3.6 for most red wines.

Acidity in wine is customarily divided into two categories—volatile and fixed. Volatile acidity refers to acids that can readily be removed by steam distillation, whereas fixed acidity describes those acids that are only slightly volatile. Total acidity is the combination of both categories. As a group, acids are almost as important to wines as alcohols. They not only produce a refreshing taste (or sourness, if in excess), but they also modify the perception of other tastes and oral/lingual sensations.

Acetic acid is the main volatile acid but other carboxylic acids, such as formic, butyric and propionic acids, may also be involved. Small amounts of acetic acid are produced by yeasts during fermentation. At normal levels in wine (< 300 mg/L), acetic acid is a desirable flavourant and adds to the complexity of taste and odour. It is equally important for the production of several acetate esters that give wine a fruity character.

Fixed acidity is dominated by tartaric and malic acid. However, lactic acid may also occur if so-called malolactic fermentation by lactic acid bacteria is encouraged. The major benefit of malolactic fermentation is conversion of the harsher-tasting malic acid to the smoother-tasting lactic acid (Jackson, 2000).

(e) Aldehydes and ketones

Acetaldehyde (ethanal) is the major aldehyde found in wine, and often constitutes more than 90% of the aldehyde content. It is one of the early metabolic by-products of fermentation. As fermentation approaches completion, acetaldehyde is transported back into yeast cells and is reduced to ethanol. Thus, the acetaldehyde content usually falls to a low level by the end of fermentation. [The Working Group noted that it is therefore not possible to specify an average acetaldehyde content in wine.] For information on acetaldehyde as a direct metabolite of ethanol in the human body, see Section 4 of this monograph. Other aldehydes that occur in wine are hexanal, hexenal, furfural and 5-(hydroxymethyl)-2-furaldehyde. Phenolic aldehydes such as cinnamaldehyde and vanillin may accumulate in wines that have matured in oak casks.

Only few ketones are found in grapes, but those that are present usually survive fermentation. Examples are the norisoprenoid ketones, β-damascenone, α-ionone and β-ionone. Diacetyl (2,3-butanedione) and 2,3-pentanedione may be produced during fermentation (Jackson, 2000).

(f) Esters

Of all the functional groups in wine, esters are the most frequently encountered. Over 160 specific esters have been identified (Jackson, 2000).

The most prevalent ester in wine is ethyl acetate. A small quantity is formed by yeast during fermentation, but larger amounts result from the activity of aerobic bacteria, especially during maturation in oak barrels. Ethyl acetates of fatty acids, mainly ethyl caproate and ethyl caprylate, are also produced by yeast during fermentation. Ethyl acetates of fatty acids have very pleasant odours of wax and honey, which contribute to the aromatic finesse of white wines. They are present at total concentrations of a few milligrams per litre. The formation of esters continues throughout the ageing process due to the presence of many different acids and large quantities of ethanol. In vintage wines, approximately 10% of the acids are esterified (Ribéreau-Gayon *et al.*, 2000).

(g) Lactones

Volatile lactones are produced during fermentation and probably contribute to the aroma of wine. The best known is γ-butyrolactone, which is present in wine at milligram-per-litre concentrations. Lactones may also derive from the grapes, as is the case in Riesling wines in which they contribute to the varietal aroma. Lactones are released into wine during ageing in oak barrels. The *cis* and *trans* isomers of 3-methyl-γ-octalactone are known as 'oak lactones' or 'whisky lactones'. Concentrations in wine are of the order of a few tens of milligrams per litre (Ribéreau-Gayon *et al.*, 2000).

(h) Terpenes

Approximately 40 terpene compounds have been identified in grapes. Some of the monoterpene alcohols are among the most odiferous, especially linalool, α-terpineol, nerol, geraniol, citronellol and ho-trienol. Furthermore, the olfactory impact of terpene compounds is synergistic. They play a major role in the aromas of grapes and wines from the Muscat family (Ribéreau-Gayon *et al.*, 2000). The monoterpenes found in wine have been reviewed (Mateo & Jiménez, 2000).

(i) Nitrogen-containing compounds

Many nitrogen-containing compounds are found in wine. These include inorganic forms, such as ammonia and nitrates, and diverse organic forms, including amines, amides, amino acids, pyrazines, nitrogen bases, pyrimidines, proteins and nucleic acids (Jackson, 2000). Red wines have average nitrogen concentrations that are almost

twice those of white wines. The total nitrogen concentration in red wines varies from 143 to 666 mg/L, while values in white wines range from 77 to 377 mg/L (Ribéreau-Gayon *et al.*, 2000).

Several simple volatile amines have been found in wine, including ethylamine, phenethylamine, methylamine and isopentylamine. Wine also contains small amounts of non-volatile amines, the most well studied of which is histamine. Other physiologically active amines include tyramine and phenethylamine. Polyamines such as putrescine and cadaverine may be present as a result of bacterial contamination (Jackson, 2000).

Urea is found at concentrations of less than 1 mg/L in wine, and is significant in winemaking as it may be a precursor of ethyl carbamate (Ribéreau-Gayon *et al.*, 2000). For a detailed discussion of the occurrence of ethyl carbamate in wine, see Section 1 in the monograph on ethyl carbamate in this Volume.

(j) Sulfur-containing compounds

Hydrogen sulfide and sulfur-containing organic compounds generally occur in trace amounts in finished wines, except for non-volatile proteins and sulfur-containing amino acids (Jackson, 2000). Sulfur-containing compounds in wine have been studied extensively because of their effect on wine aroma. The significance of organic sulfur compounds in wine aroma has been reviewed (Mestres *et al.*, 2000).

(k) Phenols and phenyl derivatives

Phenols are a large and complex group of compounds that are of particular importance to the characteristics and quality of red wine. They are also significant in white wines, but occur at much lower concentrations (Jackson, 2000).

Phenolic compounds are partly responsible for the colour, astringency and bitterness of wine. The term ‘phenolic’ or ‘polyphenolic’ describes the compounds that possess a benzenic ring substituted by one or several hydroxyl groups (-OH). Their reactivity is due to the acidic character of the phenolic function and to the nucleophilic character of the benzene ring. Based on their carbon skeleton, polyphenols are classified in non-flavonoid and flavonoid compounds. Grapes contain non-flavonoid compounds mainly in the pulp, while flavonoid compounds are located in the skin, seeds and stems. The phenolic composition of wines is conditioned by the variety of grape and other factors that affect the development of the berry, such as soil, geographical location and weather conditions. In contrast, winemaking techniques play an important role in the extraction of polyphenols from the grape and in their further stability in wine; the duration of maceration and fermentation in contact with grape skins and seeds, pressing, maturation, fining and bottle ageing are all factors that affect the phenolic composition of wines (Monagas *et al.*, 2005).

In recent years, much effort has been devoted to the study of grape and wine polyphenols, an area that is essential to evaluate the potential of different varieties of

grape, to optimize enological processes, to obtain products with peculiar and improved characteristics and to achieve a better understanding of the polyphenolic properties of wine. The main types of phenolic compound found in wine include hydroxybenzoic and hydroxycinnamic acids, stilbenes, flavones, flavonols, flavanonols, flavanols and anthocyanins (Monagas *et al.*, 2005).

Phenolic compounds in wine have been reviewed (Ribéreau-Gayon *et al.*, 2000; Monagas *et al.*, 2005; Makris *et al.*, 2006).

(l) Inorganic anions and cations

The chloride concentration in most wines is below 50 mg/L, but may exceed 1 g/L in wine made from grapes that are grown near the sea. Natural wine contains only low concentrations of sulfates (between 100 and 400 mg/L), but these may gradually increase during ageing due to repeated sulfuring and oxidation to sulfur dioxide. In heavily sulfured sweet wines, sulfate concentrations may exceed 2 g/L after a few years of barrel ageing. White wine contains 70–500 mg/L phosphate, whereas concentrations in red wines range from 150 mg/L to 1 g/L. These wide variations are related to the addition of diammonium phosphate to must to facilitate alcoholic fermentation.

Potassium is the dominant cation in wine, and concentrations range between 0.5 and 2 g/L, with an average of 1 g/L. Sodium concentrations range from 10 to 40 mg/L, and calcium concentrations range between 80 and 140 mg/L in white wines, but are slightly lower in red wines. Wine contains more magnesium (60–150 mg/L) than calcium and concentrations do not decrease during fermentation or ageing (Ribéreau-Gayon *et al.*, 2000).

Further inorganic constituents and contaminants are discussed in detail in Section 1.6.7 of this monograph.

1.6.3 *Compounds in beer*

Beer is currently a highly consistent commodity. Despite its reliance on agricultural products, the control and predictability of the processes by which beer is made provide that seasonal and regional variations can be overcome such that the taste, appearance and composition of a beer are generally consistent from batch to batch. Vintage in brewing does not exist (Bamforth, 2004).

Most beers comprise at least 90% water, with ethanol and carbon dioxide being quantitatively the next major individual components. Beer also contains a wide range of chemical species in relatively small quantities that determine its properties in respect to appearance and flavour (Bamforth, 2004). More than 450 constituents of beer have been characterized; in addition, it contains macromolecules such as proteins, nucleic acids, polysaccharides and lipids (Briggs *et al.*, 2004).

(a) Alcohols

Beers vary substantially in their alcoholic strength from brand to brand; however, most are in the range of 3–6% vol. In the United Kingdom, the mean alcohol content of all beers is 4.1% vol whereas, in the USA, the average alcoholic strength is 4.6% vol (Bamforth, 2004). Other authors reported a mean alcoholic strength of 5.5% vol for ales and 5.3% vol for lagers on the US market (Logan *et al.*, 1999; Case *et al.*, 2000). In the United Kingdom, the average alcoholic strength of the top five best-selling brands was 3.7% vol for ales and 4.5% vol for lagers (Thomas, 2006).

(b) Carbon dioxide

Carbon dioxide is produced together with ethanol during fermentation, and plays a substantial role in establishing the quality of beer. Apart from its influence in oral/lingual sensation, carbon dioxide determines the extent of foam formation and naturally influences the delivery of volatiles into the headspace of beers. Most cans or bottles of beer contain between 2.2 and 2.8 volumes of carbon dioxide (that is, between 2.2 and 2.8 cm^3 carbon dioxide is dissolved in every cubic centimetre of beer) (Bamforth, 2004).

(c) Non-volatile constituents

While most of the sugar found in wort is fermented to ethanol by yeast, some carbohydrates remain in the beer. The carbohydrates that survive in beer from the wort are non-fermentable dextrins and some polysaccharide material (Bamforth, 2004).

Quantitatively, glycerol is an important constituent of beers, in which a range of 436–3971 mg/L has been found. Significant amounts of higher polyols have not been found, but beer contains butane-2,3-diol (up to 280 mg/L) and smaller amounts of pentane-2,3-diol together with 3-hydroxybutan-2-one (acetoin; 3–26 mg/L) and 3-hydroxypentan-2-one. These are reduction products of volatile vicinal diketones. Cyclic acetals (1,3-dioxolanes) may be formed between butan-2,3-diol and acetaldehyde, isobutanal or isopentanal. Another non-volatile alcohol found in beer is tyrosol (Briggs *et al.*, 2004).

A range of non-volatile acids (C_4–C_{18}) was found in beer. The highest levels of lactic acid were found in Belgian 'acid' beers (Briggs *et al.*, 2004). The normal levels of lactic acid in uninfected bottom-fermented beers are up to 200–300 mg/L, whereas top-fermented beer may contain up to 400–500 mg/L (Uhlig & Gerstenberg, 1993). The native content of citric acid in beer is in the range of 140–232 mg/L (average, 187 mg/L). Lower contents may be found due to decomposition of citrate by lactic acid bacteria or by the use of adjuncts (e.g. rice, maize or sugars) (Gerstenberg, 2000).

Autoxidation of linoleic acid gives rise to isomers of dihydroxy- and trihydroxyoctadecenoic acids. These hydroxyl acids are potential precursors of 2-*trans*-nonenal, which contributes a cardboard flavour to stale beer (Briggs *et al.*, 2004). The formation of 2-*trans*-nonenal and other stale flavours has been reviewed (Vanderhaegen *et al.*,

2006). During storage, the chemical composition may change, which alters the sensory properties. In contrast to some wines, the ageing of beer is usually considered to be negative for flavour quality.

(d) Volatile constituents

One hundred and eighty-two volatile compounds were recently detected in beer samples (Pinho *et al.*, 2006). The majority of the volatile constituents of beer are fermentation products. As in wine, the largest group of volatile constituents in beer are higher alcohols, principally 3-methylbutanol (isoamyl alcohol), 2-methylbutanol, isobutyl alcohol, propanol and phenylethanol. Other volatile constituents are 4-vinylphenol and 4-vinylguaiacol, which are regarded as off-flavours in most beers. However, 4-vinylguaiacol, which has a clove-like flavour, provides part of the essential character of wheat beer (Briggs *et al.*, 2004).

Only low levels of aldehydes are found in beer, the principal of which is acetaldehyde. During the storage of bottled beer, higher alcohols are oxidized to aldehydes by melanoidins. During fermentation, acetaldehyde is normally reduced to ethanol but it can be oxidized to acetic acid, which is the major volatile acid in beer (Briggs *et al.*, 2004). Minor aldehydes identified in beer include the so-called Strecker aldehydes—2-methylpropanal, 2-methylbutanal, 3-methylbutanal, methional and phenylacetaldehyde. The increase in these aldehydes may play a central role in flavour changes during the ageing of beer. Aldehydes related to the autoxidation of linoleic acid are pentanal and hexanal (Vesely *et al.*, 2003).

Flavour-active esters have been reviewed (Verstrepen *et al.*, 2003). Ethyl acetate is the major ester found in beer (8–32 mg/L); further aroma-active esters in lager beer include isoamyl acetate (0.3–3.8 mg/L), ethyl caproate (0.05–0.3 mg/L), ethyl caprylate (0.04–0.53 mg/L) and phenyl ethyl acetate (0.10–0.73 mg/L).

Odour-active compounds derived from hops include linalool, geraniol, ethyl 2-methylbutanoate, ethyl 3-methylbutanoate and ethyl 2-methylpropanoate (Kishimoto *et al.*, 2006); 40 odour-active constituents were identified in Pilsner beer, among which ethanol, β-damascenone, linalool, acetaldehyde and ethyl butanoate had the highest values for odour activity, followed by ethyl 2-methylpropanoate and ethyl 4-methylpentanoate (Fritsch & Schieberle, 2005). The concentration of linalool was found to be correlated with the intensity of the aroma of hops (Steinhaus *et al.*, 2003).

(e) Nitrogen-containing compounds

Most beers contain 300–1000 mg/L total nitrogen (Briggs *et al.*, 2004). The breakdown of a wide range of amino acids was determined during the ageing in beer. The content of phenylalanine, histidine and tyrosine decreased most rapidly followed by that of isoleucine, leucine and lysine. The decrease in amino acids was greater in beers that had a higher content of dissolved oxygen (Basarová *et al.*, 1999).

The presence of biogenic amines in beer is important toxicologically. During brewing, the types of amine are dependent on the raw materials used in the beverage as well as the method of brewing and any microbiological contamination that may have occurred during the brewing process or during storage. The amines in beer can be divided into two groups. One includes putrescine, spermidine, spermine and agmatine and can be considered as natural beer constituents that primarily originate from the malt, while the other, which includes mainly histamine, tyramine and cadaverine, usually indicates the activity of contaminating lactic acid bacteria during brewing (Kalac & Križek, 2003). The level of biogenic amines in beer was found to reflect the microbiological quality of the fermentation process (Loret *et al.*, 2005).

(f) Sulfur-containing compounds

Beer contains 100–400 mg/L sulfate. The major non-volatile organic sulfur compounds in beer are the amino acids, cysteine and methionine, and the peptides and proteins that contain them. Dimethyl sulfide is an important flavour component of lager beers. It is mainly formed by the breakdown of *S*-methylmethionine which is present in malt (Briggs *et al.*, 2004). Sulfur compounds, including thioesters, thiophenes, polysulfides, terpens and thiols, may also derive from hops (Lermusieau & Collin, 2003). Polyfunctional thiols were recently detected in lager beers (Vermeulen *et al.*, 2006).

(g) Flavours and constituents from hops

Of all the herbs that have been used to flavour and preserve beer over the ages, only the hop (*Humulus lupulus* L.) is now regarded as a raw material that is essential to brewing throughout the world (Moir, 2000).

α-Acids can account for between 2% and 15% of dry weight of hops, depending on the variety and the environment. When wort is boiled, α-acids are isomerized to form *iso*-α-acids, which are much more soluble and stable than α-acids. In addition to imparting bitterness to beer, *iso*-α-acids also promote foaming by cross-linking the hydrophobic residues on polypeptides with their own hydrophobic side-chains. Furthermore, they have strong antimicrobial properties (Bamforth, 2004). Bitter acids in beer have been reviewed (de Keukeleire *et al.*, 1992; Schönberger, 2006). The amount of *iso*-α-acids varies significantly between different types of beer; Pilsner-type beers usually contain the largest amount of bitter hop substances (Lachenmeier *et al.*, 2006a).

Hop is the raw material in beer that serves as an important source of phenolic compounds (see below). A recent review summarized 78 known phenolic constituents of beer (Gerhäuser, 2005). Xanthohumol and related prenylflavonoids have also been reviewed (Stevens & Page, 2004).

(h) Phenolic compounds and antioxidants

Phenolic constituents of beer are derived from malt (70–80%) and hops (20–30%). Structural classes include simple phenols, benzoic and cinnamic acid derivatives, coumarins, catechins, di-, tri- and oligomeric proanthocyanidins, (prenylated) chalcones and flavonoids as well as the previously mentioned α- and *iso*-α-acids derived from hops (Gerhäuser, 2005).

According to some studies, levels of antioxidants in beer are of the same order of magnitude as those found in fruit juices, teas and wines (Vinson *et al.*, 1999; Gorinstein *et al.*, 2000). Beer may provide more antioxidants per day than wine in the US diet (Vinson *et al.*, 2003). More than 80% of the antioxidant activity of beer *in vitro* derives from non-tannin non-flavonoid compounds (mainly phenolic acids). However, there is some concern about the activity of different classes of phenols *in vivo* due to low bioavailability and breakdown into inactive fragmentation products (Fantozzi *et al.*, 1998).

(i) Vitamins

Beer contains many water-soluble vitamins, notably folate, riboflavin, pantothenic acid, pyridoxine and niacin. As much as 10% of the daily intake of folate may derive from beer in some countries. Fat-soluble vitamins do not survive in beer and are lost with insoluble components during processing. Some beers contain vitamin C, because this material may be added to protect the beer from oxidation (Bamforth, 2004). Half a litre of beer could cover 20–25% of the daily requirements of riboflavin, niacin and pyridoxine (Billaud & Delestre, 2000).

(j) Minerals

Beer is rich in magnesium and potassium but relatively deficient in iron, zinc and calcium. The presence of iron in beer is avoided deliberately by brewers because it acts as a pro-oxidant (Bamforth, 2004). Beer may also be a main nutritional source of selenium (Darret *et al.*, 1986). The inorganic composition of beer has been reviewed (Briggs *et al.*, 2004). Further inorganic constituents and contaminants in beer are discussed in detail in Section 1.6.7 of this monograph.

1.6.4 *Compounds in spirits*

A large range of very diverse products constitute the category ‘spirits’. The alcoholic strength of spirits is usually higher than 15% vol and may be up to 80% vol in some kinds of absinthe. The typical alcoholic strength of the most common spirits (e.g. brandy, whisky and tequila) is ~40% vol.

A classification of spirits can be made according to their sugar content. Several spirits contains no sugar, or sugar is used only to soften the final taste of the product (up to 10 g/L of sugar). Spirits with high sugar contents (> 100 g/L) are commonly designated as ‘liqueurs’.

Another differentiation can be made between spirits produced exclusively by alcoholic fermentation and distillation of natural products (e.g. sugar cane, fruit and cereals) and products that are made from highly rectified ethanol of agricultural origin (so-called neutral alcohol; e.g. gin, aniseed-flavoured spirit drinks and most liqueurs).

The volatile compounds in alcoholic beverages are usually expressed in units of 'g/hL pure alcohol' or 'g/hL of 100% vol alcohol' (i.e. the concentrations are standardized with regard to alcoholic strength). This enables high-proof distillates and distillates diluted to drinking strength to be compared directly.

Because the chemical compositions of the various types of spirits differ significantly (e.g. the methanol content may vary from not detectable concentrations in vodka up to about 1000 g/hL pure alcohol in certain fruit spirits), some types of spirits are discussed separately in the following sections. The groups of spirits were selected on the basis of knowledge of their production methods and constituents and not necessarily because of their prevalence in the world market. [The Working Group noted that the major focus of research in the past has been on European-style spirits, and found a lack of information on Asian-type products.]

(a) Sugar-cane spirits (rum, cachaça)

The two most important types of sugar-cane spirits are rum (usually produced in the Carribean) and cachaça from Brazil.

The production of rum has been reviewed (Delavante, 2004). The sugar in cane molasses is used as the fermentation substrate in the production of rum. The chemical constituents of rum were found to be so heterogeneous that it was not possible to determine an average composition. The contents of 1-propanol, isobutanol and amyl alcohols were < 10–400, 70 and 100 g/hL pure alcohol, respectively. Some samples also showed high levels of acetaldehyde and 1,1-diethoxyethan, whereas these constituents were not detected in other samples. The number of detectable esters in rum was smaller than that in brandies, whiskies or fruit spirits (Postel & Adam, 1982a). The concentrations of volatile fatty acids, acetic acid and formic acid varied greatly between different samples of rum. The maxima were 12 mg/L propionic acid, 5.1 mg/L butyric acid and 24 mg/L decanoic acid (Sponholz *et al.*, 1990). Low concentrations of ethyl hexanoate, ethyl octanoate, ethyl decanoate and ethyl dodecanoate were found in white rums (Pino *et al.*, 2002). The average level of ketones in rum was 2.15 mg/L acetone, 0.35 mg/L cyclopentanone and 1.75 mg/L 2,3-butanedione (Cardoso *et al.*, 2003).

The production of cachaça has been reviewed (Faria *et al.*, 2004). The Brazilian spirits, cachaça, caninha and aguardente de cana, are made from fermented sugar-cane juice. The term caipirinha refers to the lemon drink made from cachaça. The major volatile compounds in cachaça are the higher alcohols, isoamyl alcohol, isobutyl alcohol and propanol; however, significant variations were detected depending on the strain of yeast used for fermentation (Souza Oliveira *et al.*, 2005). During ageing in wood casks, the levels of higher alcohols decrease, whereas the concentrations of aldehydes, ethyl

acetate and acetic acid increase (Bolini *et al.*, 2006). The most abundant acid in cachaça is acetic acid, which represents up to 90–95% of the total content of acids found. The concentration of acids (C_2–C_{18}) in cachaça is in the same order of magnitude as that in whiskies, rums and cognacs (Ferreira Do Nascimento *et al.*, 2000). The major aldehyde in cachaça is acetaldehyde (average, 11 g/hL pure alcohol). Minor aldehydes include formaldehyde, 5-hydroxymethylfurfural, acrolein, furfural, propionaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde and *n*-valeraldehyde (all below 5 g/hL pure alcohol) (Nascimento *et al.*, 1997). The levels of 5-hydroxymethylfurfural can be attributed to the use of very old barrels or barrels that undergo no treatment before re-utilization. Other markers of ageing detected in cachaça include gallic acid, vanillic acid, syringic acid, vanillin, syringaldehyde, coniferaldehyde, sinapaldehyde and coumarin (de Aquino *et al.*, 2006). Quantification of ketones in cachaças yielded the following average levels: 3.31 mg/L acetone, 1.24 mg/L acetophenone, 1.15 mg/L cyclopentanone and 4.34 mg/L 2,3-butanedione. Except for acetophenone, cachaça and rum exhibited the same qualitative profile of ketones (Cardoso *et al.*, 2003). Large variations in the phenol content of cachaça were noted. Concentrations of total phenols were between 1.5 and 70 mg/L, and those of flavonoids were from below detection to 3.5 mg/L (Bettin *et al.*, 2002).

Differences in the composition of cachaça and rum were found using multivariate data analysis. Protocatechuic acid, propanol, isobutanol, isopentanol, copper, manganese and magnesium were selected as chemical discriminators from a range of volatile components, acids, polyphenols and metals (Cardoso *et al.*, 2004). Flavour differences between cachaça and rum were easily recognizable; the flavour compounds β-damascenone, ethyl butyrate, isobutyrate and 2-methylbutyrate were found at the same levels in both cachaça and rum, whereas levels of spicy-smelling eugenol, 4-ethylguaiacol and 2,4-nonadienal were much higher in cachaça (de Souza *et al.*, 2006).

(b) Whisky or whiskey

Scotch whisky has been reviewed (Halliday, 2004). Further important international types of whisky include American whiskey (e.g. bourbon) and Canadian whiskey, and the production of whiskey has also been reviewed (Ströhmer, 2002).

Scotch whisky and Irish whiskey are produced exclusively from the distillation of a mash made from malted cereals that has been saccharified, fermented by the action of yeast and distilled by one or more distillations at less than 94.8% vol, so that the distillate has an aroma and taste derived from the raw materials. The final distillate must mature for at least 3 years in wooden casks that do not exceed 700 L in capacity. The minimum alcoholic strength of such beverages is 40% vol (European Council, 1989).

The composition of the different whiskies was compared and significant differences in their volatile composition were detected (Postel & Adam, 1977, 1978, 1979). The American bourbons contained the largest amount of volatile compounds (> 500 g/hL pure alcohol), followed by Scotch (~250 g/hL pure alcohol) and Canadian blends (~100

g/hL pure alcohol) (Postel & Adam, 1982b). In a more recent study, 40 blended Scotch whiskies were characterized, and four categories could be distinguished. Deluxe blends contained higher concentrations of ethyl (C_6–C_{10}) esters, isoamyl hexanoate and alcohol. Standard blends were differentiated by their contents of acetate esters (dodecyl, phenyl ethyl and 3-methylbutyl acetates). In contrast, retailer blends were dominated by high contents of longer (> C_{10}) aliphatic esters, alcohols and unsaturated fatty acid ethyl esters. Furfural, ethyl benzoate, isobutyl octanoate and medium-chain esters, notably ethyl nonanoate, were characteristic of West Highland blends (Lee *et al.*, 2001). Seventy volatile compounds were identified in Scotch whisky—mainly fatty acid ethyl esters, higher alcohols, fatty acids, carbonyl compounds, monoterpenols, C_{13} norisoprenoids and some volatile phenols. The ethyl esters form an essential group of aromatic compounds in whisky, to which they confer a pleasant aroma with fruity odours. Qualitatively, isoamyl acetate, which has a 'banana' aroma, was the most interesting. Quantitatively, significant components were ethyl esters of caprilic, capric and lauric acids. The highest concentrations of fatty acids were observed for caprilic and capric acids. Of the higher alcohols, fusel oils (3-methylbutan-1-ol and 2-phenylethanol) were the most abundant (Câmara *et al.*, 2007). The nature and origin of flavours in whiskies have been reviewed (Lee *et al.*, 2001). Furfural and 5-hydroxymethyl-2-furaldehyde were proposed as a standard to identify authentic straight American whiskeys as opposed to those blended with neutral spirit (Jaganathan & Dugar, 1999).

(c) Brandy

The production of brandy has been reviewed (Ströhmer, 2002). Brandies are typically derived from distilled wine. Traditional products include the French 'cognac' and 'armagnac', the Spanish 'brandy de Jerez' and the German 'Weinbrand'. European legislation prescribes that brandy must be produced from wine spirit (the term 'brandy' may not be used for other products such as fruit spirits). Brandies must be matured for at least 1 year in oak receptacles or for at least 6 months in oak casks with a capacity of less than 1000 L. They must contain a quantity of volatile substances (other than ethanol and methanol) that is equal to or exceeds 125 g/hL pure alcohol and derived exclusively from the distillation or redistillation of the raw materials used. The maximum methanol content is 200 g/hL pure alcohol. The minimum alcoholic strength of brandy is 36% vol (European Council, 1989).

The volatile composition of brandy differs according to the region of origin. In all brandies, acetaldehyde, 1,1-diethoxyethan and furfural are the main carbonyl compounds, amyl alcohols, isobutanol, propanol-1 and methanol are the major alcohols and ethyl acetate and ethyl lactate are the major esters. German brandies showed a larger variation in their volatile composition than cognac and armagnac. Brandies usually contain a larger amount of volatile substances than that legally required of about 500 g/hL pure alcohol (Postel & Adam, 1982c). The amounts of ethyl ester vary widely, depending on the different raw materials used and the technology applied.

Methyl esters are present in very small amounts only, generally less than 0.05 g/hL pure alcohol. Ethyl heptoate and ethyl nonanoate contents are generally less than 0.1 g/hL pure alcohol (Postel & Adam, 1984). In comparison with German and French brandies, Spanish brandies contain on average larger amounts of methanol, acetaldehyde and 1,1-diethoxyethane and smaller amounts of higher alcohols and higher esters (Postel & Adam, 1986a,b). Later investigations showed that the average composition of German or French brandy had not changed considerably; however, considerable differences exist between the various brands (Postel & Adam, 1987, 1990a,b,c). In German brandy, the methanol content was in the range of 46–110 g/hL pure alcohol, the content of higher alcohols varied between 235 and 382 g/hL pure alcohol (Postel & Adam, 1987), acetaldehyde content was in the range of 18–45 g/hL pure alcohol, the sum of carbonyls and acetals was in the range of 30–77 g/hL pure alcohol, the concentrations of terpenes were in the range of 0.06–0.38 g/hL pure alcohol (Postel & Adam, 1988a) and the amount of esters was between 27 and 101 g/hL pure alcohol (Postel & Adam, 1988b). Trace volatile compounds in cognac were studied by Ledauphin *et al.* (2004, 2006a). Compounds specific to cognac include numerous hexenyl esters and norisoprenoidic derivatives.

Esterification and formation of methyl ketone may be two of the most important processes in the ageing of cognac over a long time period. Using multivariate regression of 17 volatile compounds (13 ethyl esters and four methyl ketones), it was possible to predict the age of a cognac with a high degree of accuracy (Watts *et al*., 2003). In brandy de Jerez, an increase in sugar concentration during ageing was detected, and arabinose was especially strongly correlated with ageing (Martínez Montero *et al*., 2005). Caramel, which is used as a colouring agent, may be detected by the ratio between furfural and 5-hydroxymethylfurfural which is greater than 1 in brandies that do not contain caramel and lower than 1 in those that do contain caramel (Quesada Granados *et al*., 1996). Genuine ageing in oak is also indicated by a total syringyl compound content that is higher than the total vanillyl compound content. An increase in vanillin concentration indicates added substances, possibly almond shells (Delgado *et al*., 1990). The quality control of cognacs and cognac spirits was recently reviewed and methods to detect adulterated samples were given (Savchuk & Kolesov, 2005).

(d) Grape marc spirit

Grappa is the most prominent example of grape marc spirit, and may be produced solely in Italy (European Council, 1989). Marc spirit contains a significantly higher content of volatile compounds than brandy (about 2000 g/hL pure alcohol) (Postel & Adam, 1982c). The maximum methanol content is 1000 g/hL pure alcohol and the minimum alcoholic strength of marc is 37.5% vol.

Fusel alcohols were quantitatively the largest group of flavour compounds in Portuguese marcs of the Alvarinho and Loureiro varieties, and their concentrations ranged from 395 to 2029 mg/L. Ethyl acetate and ethyl lactate were the most abundant

esters, with concentrations ranging from 176 to 9614 and from 0 to 310 mg/L, respectively. The duration of fermentation most strongly affected the composition of marcs in terms of higher alcohols, while the addition of pectinases and the material of the containers most strongly affected composition in terms of methanol (concentration range, 2694–6960 mg/L) and 2-butanol (concentration range, 0–279 mg/L). The addition of pectinase had the most statistically significant effect on methanol content, whereas duration of fermentation time had the most significant effect on the 2-butanol content (Luz Silva & Xavier Malcata, 1998).

(e) Fruit spirits

Fruit spirits (formerly sometimes called 'fruit brandies') are relatively inhomogeneous chemically, because their composition varies greatly between the different types of fruit. In Europe, fruit spirits must be produced exclusively by the alcoholic fermentation and distillation of fleshy fruit or must of such fruit, with or without stones. In general, the quantity of volatile substances (other than ethanol and methanol) should exceed 200 g/hL pure alcohol and the maximum methanol content is 1000 g/hL pure alcohol (European Council, 1989).

Methanol is quantitatively the main component of stone and pome fruit spirits in addition to water and ethanol. Plum, mirabelle and Williams distillates generally contain more than 1000 g/hL pure alcohol (an exception to the maximum methanol content was made for these fruits), whereas cherry distillates contain less. Since a certain minimum amount of methanol is formed by enzymatic cleavage of pectin during fermentation of the fruit mash, the methanol content of fruit spirits may be used to evaluate their authenticity and possible adulteration such as by the addition of neutral alcohol (Postel & Adam, 1989). These high methanol concentrations in fruit spirits are nevertheless below the concentration of 2% vol that was proposed as a tolerable concentration in alcoholic beverages (Paine & Davan, 2001). However, with regard to the toxicological effects of methanol, a reduction is desirable to ensure a greater margin of safety. Several ways to decrease the methanol content have been discussed, such as heat treatment of the mash to inactivate proteolytic enzymes (Postel & Adam, 1989). Other authors demonstrated that acid treatment of the mash might delay methanol de-esterification and reduce methanol content by up to 50% (Glatthar *et al.*, 2001). A significant linear decrease in methanol in cherry spirits was noted between 1980 and 2003 (Lachenmeier & Musshoff, 2004).

In comparison with other groups of spirits, fruit spirits contain large amounts of 1-propanol, 1-butanol, 2-butanol and 1-hexanol. Concentrations of isobutanol and amyl alcohols are approximately in the same range as those in other groups of spirits such as whiskies and brandies. Some terpene compounds, such as α-terpineol, geraniol, linalool, *cis*- and *trans*-linalooloxide, were found in fruit spirits (< 1 g/hL pure alcohol). Among the carbonyl compounds, acetaldehyde and 1,1-diethoxyethane dominate; the mean values of their concentrations range from 9 to 17 and 4.5 to 9.5 g/hL pure alcohol,

respectively. Other carbonyl compounds present in fruit spirits are propionaldehyde, isobutyraldehyde, acrolein, benzaldehyde, furfural, acetone, methylethylketone, acetoin and 1,1,3-triethoxypropane and some others in minor amounts. There are marked differences between stone-and pome-fruit distillates. Stone-fruit distillates are characterized by relatively large amounts of benzyl alcohol and benzaldehyde and pome-fruit distillates by large amounts of 1-hexanol. In general, terpenes were found at higher concentrations in stone-fruit spirits than in pome-fruit spirits (Postel & Adam, 1989).

The main ester component of fruit spirits is ethyl acetate followed by ethyl lactate; together, these two compounds amount to ~80% or more of the total ester content. The number of other esters is large, but their concentrations are relatively small. Most of the esters are ethyl esters beginning with formate up to palmitate, phenylacetate, benzoate and cinnamate, including some hydroxyl esters. The number of isoamyl and methyl esters is smaller; in addition, propyl, butyl, hexyl, 2-phenethyl and benzyl esters (mainly acetates) are also present. Moreover, fruit spirits (as well as pomace distillates) are the only groups of spirits that have higher levels of methyl acetate, which occurs only in traces in grape wine brandies and whiskies (Postel & Adam, 1989).

The ethyl carbamate content of stone-fruit spirits is reviewed in Section 1 of the monograph on ethyl carbamate in this Volume.

(f) Mexican spirits (mezcal, tequila)

The *Agave* genus comprises more than 200 species that are native to arid and tropical regions from southern USA to northern South America and throughout the Carribean. The most important economic use of *Agave* is the production of alcoholic beverages such as mezcal (*Agave angustifolia* Haw., *A. potatorum* Zucc., *A. salmiana* Otto, and other species), sotol (*Dasylirion ssp.*,) and bacanora (*A. angustifolia* Haw.). All of these spirits are obtained from the fermentation of agavins (fructooligosaccharides) from the different *Agave* species (Lachenmeier *et al.*, 2006b). However, the most popular contemporary alcoholic beverage made from *Agave* is tequila, which is recognized worldwide. The production of tequila is restricted to the blue *Agave* (*A. tequilana* Weber var. *azul*, Agavaceae) and to defined geographical areas, primarily to the State of Jalisco in West Central Mexico (Lachenmeier *et al.*, 2006b). Two basic categories of tequila can be distinguished: '100% agave' and 'mixed' tequila. For the high-quality category, '100% agave', only pure agave juice is permitted to be fermented and distilled (Cedeño, 1995).

Following the bestowal of the appellation of origin of tequila, other distilled *Agave* beverages from the States of Oaxaca, Guerrero, San Luis Potosi, Chiapas, Guajanuato and Zacatecas (mezcal), Chihuahua, Coahuila and Durango (sotol) and Sonora (bacanora) were granted equal recognition. All of these regional drinks are subject to official standards, and their production is supervised by the Mexican Government. Until now, only tequila, and more recently, mezcal have reached international recognition. Especially in the last decade, the consumption of tequila has increased

tremendously worldwide. Tequila and mezcal are protected under the North American Free Trade Agreement and an agreement between the European Union and the United Mexican States on the mutual recognition and protection of designations for spirit drinks (Lachenmeier *et al.*, 2006b).

Due to their production from plant material that contains oxalate, all *Agave* spirits contain significant concentrations of this compound (0.1–9.7 mg/L). The composition of Mexican *Agave* spirits was found to vary over a relatively large range. The two tequila categories ('100% agave' and 'mixed') showed differences in concentrations of methanol, 2-/3-methyl-1-butanol and 2-phenylethanol, with lower concentrations in the 'mixed' category (Lachenmeier *et al.*, 2006b).

Quantitative differences in ethyl esters were found in tequila depending on the duration of ageing. Ethyl hexadecanoate and octadecanoate were the most abundant ethyl esters in all tequila types; Añejo (extra aged) tequila presented the highest concentration of ethyl esters (Vallejo-Cordoba *et al.*, 2004). Isovaleraldehyde, isoamyl alcohol, β-damascenone, 2-phenylethanol and vanillin were the most powerful odourants of tequila from a range of 175 components identified (Benn & Peppard, 1996). The most potent odourants were: phenylethanol and phenylethyl acetate in Blanco tequila; phenylethanol, phenylethyl acetate and vanillin in Reposado (aged) tequila; and phenylethanol, vanillin and an unknown substance in Añejo tequila (López & Dufour, 2001).

Considerably higher concentrations of 2-furaldehyde and 5-methylfuraldehyde were found in tequilas than in brandies. Furthermore, 100% agave tequilas contained higher levels of these two compounds (mean values, 18.6 and 5.97 mg/L, respectively) than the mixed brands (mean values, 6.46 and 3.30 mg/L). The profile of furanic aldehydes depends on the type of fructans contained in the raw material and also on heat treatment before fermentation. In contrast to other polysaccharides, inulin hydrolyses at elevated temperature and the contribution of Maillard browning reactions increases the production of furanic compounds (Munoz-Rodriguez *et al.*, 2005).

Saturated alcohols, ethyl acetate, ethyl 2-hydroxypropanoate and acetic acid are the major compounds in mezcal produced from *A. salmiana*. Minor compounds in mezcal include other alcohols, aldehydes, ketones, large-chain ethyl esters, organic acids, furans, terpenes, alkenes and alkynes. Most of the compounds found in mezcals are similar to those present in tequilas and other alcoholic beverages. However, mezcals contain unique compounds such as limonene and pentyl butanoate, which can be used as markers for the authenticity of mezcal produced from *A. salmiana*. Mezcals (but not tequilas) are sometimes conditioned with one to four larvae of Agave worms. Only mezcals with worms contained the compounds 6,9-pentadecadien-1-ol, 3-hexen-1-ol, 1,8-nonadiene and 1-dodecine. Thus, it may be possible that these unsaturated compounds come from the larvae (De León-Rodríguez *et al.*, 2006).

(g) Wood maturation of distilled beverages

A wide range of distilled beverages, including whisky and cognac, are matured for many years in oak barrels. Other spirits, such as rum, cachaça, tequila and fruit spirits, are also often matured in oak. During maturation, a range of physical and chemical interactions take place between the barrel, the surrounding atmosphere and the maturing spirit which transform both the flavour and composition of the drink. The effects and time required for maturation are highly variable and are influenced by a wide range of factors, particularly the type of barrel used (Mosedale & Puech, 1998). Wood ageing is the most probable source of phenols and furans in distilled spirits. Ellagic acid was the phenol present at the highest concentration in 12 categories of spirit. Moderate amounts of syringaldehyde, syringic acid and gallic acid, as well as lesser amounts of vanillin and vanillic acid, were measurable in most samples of whisky, brandy and rum. 5-Hydroxymethylfurfural was the predominant furan, notably in cognac, followed by 2-furaldehyde. Beverages that are subjected to wood ageing also contain significant antioxidant activity, the level of which is between the ranges observed in white and red wines. Highest total antioxidant values were exhibited in armagnac, cognac and bourbon whiskey, and no antioxidants were found in rum, vodka, gin and miscellaneous spirits, correlating with low or undetectable phenol concentrations in these spirits (Goldberg *et al.*, 1999).

(h) Vodka

Vodka is a spirit beverage produced by rectifying ethanol of agricultural origin or filtering it through activated charcoal, possibly followed by straightforward distillation or an equivalent treatment. This selectively reduces the organoleptic characteristics of the raw materials. Flavouring may be added to give the product special organoleptic characteristics, such as a mellow taste (European Council, 1989). The raw spirit put through rectification is usually produced from grain (rye and wheat) and potatoes. In the production of vodka, the quality of the water used is of the utmost importance. For premium vodka brands, demineralized water is filtered through activated carbon to absorb unwanted organic and inorganic materials.

The contents of anions in Russian vodkas usually lie in the ranges of 0.5–10 mg/L chloride, 0.5–3.5 mg/L nitrate, 3.5–30 mg/L sulfate and < 0.1 mg/L phosphate (Obrezkov *et al.*, 1997). Vodkas bottled in Germany were found to contain significantly higher amounts of anions (up to 147.6 mg/L) (Lachenmeier *et al.*, 2003).

Since vodkas are manufactured in such a way that they have no distinctive aroma or taste, residual congeners are present at levels much lower than those found in other spirits that have various flavour characteristics. The congeners present at microgram per litre levels were isolated using solid-phase microextraction. Ethyl esters of C_8–C_{18} fatty acids were detected and differentiation between Canadian and American vodkas was possible (Ng *et al.*, 1996).

Table 1.10 Properties of neutral alcohol in Europe

Alcoholic strength	>96.0% vol
Total acidity (expressed as acetic acid)	<1.5 g/hL pure alcohol
Esters (expressed as ethyl acetate)	<1.3 g/hL pure alcohol
Aldehydes (expressed as acetaldehyde)	<0.5 g/hL pure alcohol
Higher alcohols (expressed as 2-methyl-1-propanol)	<0.5 g/hL pure alcohol
Methanol	<50 g/hL pure alcohol[a]
Dry extract	<1.5 g/hL pure alcohol
Volatile bases that contain nitrogen (expressed as nitrogen)	<0.1 g/hL pure alcohol
Furfural	Not detectable

From European Council (1989) [a] The methanol content of commercial neutral alcohol is usually significantly below the limit of 50 g/hL pure alcohol.

(i) Spirits produced from neutral alcohol

In contrast to spirits such as whisky or brandy, which are manufactured by fermentation and retain the organoleptic properties of the raw materials, a range of spirits is manufactured using highly rectified alcohol (so-called 'neutral alcohol' or 'ethanol of agricultural origin'). The European requirements for neutral alcohol are shown in Table 1.10. Neutral alcohol contains significantly lower concentrations of volatile constituents than the spirits discussed previously (e.g. whisky, rum, brandy). However, the composition of vodka is relatively similar to that of neutral alcohol. The typical components and flavour characteristics of spirits manufactured from neutral alcohol derive from other materials and not from the alcohol or fermentation products.

A prominent type of a spirit manufactured from neutral alcohol is gin. The most popular is London Dry Gin. It belongs to the 'distilled gin' class in European legislation and is produced by redistillation of neutral alcohol in the presence of juniper berries (*Juniperus communis*) and other natural ingredients (European Council, 1989). Gin was found to contain over 70 components (mainly mono- and sesquiterpenic compounds) (Vichi *et al.*, 2005).

Most liqueurs are also produced by mixing neutral alcohol with sugars and a wide range of plant extracts or fruit juices. For example, Italian lemon liqueurs (Limoncello) are obtained by alcoholic extraction of essential oils from lemon peel and dilution with sugar syrup. The liqueur, therefore, shows a composition similar to lemon essential oil with a high content of β-pinene, myrcene, trans-α-bergamottene and β-bisabolene (Versari et al., 2003). Another example is traditional walnut liqueur that contains phenolic compounds extracted from walnut husks (Stampar *et al.*, 2006).

Table 1.11 Differences in the composition of ciders from England, France and Germany

	English cider	French cidre	German Apfelwein
Alcoholic strength	1.2–8.5% vol	>1.5% vol	>5% vol
Sugar-free extract	>13 g/L	>16 g/L	>18 g/L
Volatile acidity	<1.4 g/L	<1 g/L	<1 g/L
Sulfur dioxide	<200 mg/L	<175 mg/L	<300 mg/L
Raw materials	Apple juice, concentrate, glucose syrup, water	Apple juice, concentrate (up to 50%)	Apple juice, concentrate, certain amounts of sugar
Additives	Organic acids, sugars, sweeteners, colours, sorbic acid	Organic acids, sugars, colours	Lactic acid (<3 g/L), sugar (<10 g/L), caramel sugar, sorbic acid

From Anon. (1992)

1.6.5 *Compounds in other alcoholic beverages*

(a) Cider (apple wine)

Cider is an alcoholic beverage made from apples and has very different characteristics according to the origin of the fruit and methods of production. French cider (Breton and Norman) has a low alcohol content and contains significant residual unfermented sugar. German cider, mostly from the state of Hessen, is fully fermented and very dry. Spanish (mostly Asturian) cider is characterized by a high volatile acidity and by its foaming characteristics when served. Modern English ciders are for the most part characterized by light flavours, which arise from chaptalization with glucose syrup before fermentation to give high-alcohol apple wines, which are then diluted with water and sweetener before retailing (Lea, 2004).

The differences between English, French and German ciders are compared in Table 1.11.

The standard German 'apple wine' should have an alcoholic strength of 7.0% vol, a total dry extract of 25 g/L, a sugar content of 2 g/L, a pH of 3.1, a volatile acidity of 0.5 g/L, a glycerine content of 4.7 g/L, a potassium content of 1100 mg/L, a magnesium content of 60 mg/L, a calcium content of 60 mg/L and a copper content of 0.3 mg/L (Scholten, 1992).

French ciders can be classified according to their residual sugar content into 'brut' (< 28 g/L of residual sugar), 'demi-sec' (28–42 g/L of residual sugar) and 'doux' (< 3% vol alcohol and > 35 g/L of residual sugar) (Anon., 1992).

During the fermentation of apple juice, organic acids undergo several changes. It was shown that concentrations of malic and citric acid decrease, while those of lactic and succinic acid increase (Blanco Gomis *et al.*, 1988).

More than 200 volatile flavour components, 100 of which could be identified, were found in apple wines manufactured from Turkish apples (Yavas & Rapp, 1992). The flavour composition of two Spanish ciders was studied by Mangas *et al.* (1996a). The major aromatic components were amyl alcohols (134–171 mg/L) and 2-phenylethanol (57–185 mg/L); minor compounds were alcohols, esters and fatty acids.

Forty-three compounds identified in Chinese Fuji apple wine were mainly esters, alcohols and lower fatty acids, as well as lesser amounts of carbonyls, alkenes, terpenes and phenols. Total concentrations of esters, alcohols and lower fatty acids were 242 mg/L, 479 mg/L and 297 mg/L, respectively. The highest concentration of aromatic components in apple wine was for isoamyl alcohol (232 mg/L) which constituted 32% of the total esters and alcohols (Wang *et al.*, 2004).

A total of 16 phenolic compounds (catechol, tyrosol, protocatechuic acid, hydrocaffeic acid, chlorogenic acid, hydrocoumaric acid, ferulic acid, (–)-epicatechin, (+)-catechin, procyanidins B2 and B5, phloretin-2'-xyloglucoside, phloridzin, hyperin, avicularin and quercitrin) were identified in natural ciders from the Asturian community (Spain). A fourth quercetin derivative, one dihydrochalcone-related compound, two unknown procyanidins, three hydroxycinnamic derivatives and two unknown compounds were also found. Among the low-molecular-mass polyphenols, hydrocaffeic acid was the most abundant compound, and represented more than 80% of total polyphenolic acids. Procyanidins were the most important family among the flavonoid compounds. Discriminant analysis allowed correct classification of more than 93% of the ciders according to the year of harvest; the most discriminant variables were an unknown procyanidin and quercitrin (Rodríguez Madrera *et al.*, 2006).

The polyphenolic profile was used to identify ciders according to their geographical origin (Basque or French regions). Polyphenolic contents of Basque ciders are lower than those of French ciders, which indicates that Basque cider-making technology involves a higher loss of native apple polyphenols, probably due to oxidation processes and microflora metabolism (Alonso-Salces *et al.*, 2004). The polyphenolic composition may also be used to distinguish ciders made with Basque apples from those made with apples imported from other parts of Europe to Spain (Alonso-Salces *et al.*, 2006).

Free amino acids were studied in Spanish sparkling ciders. The amount of amino acids significantly decreased during second fermentation in the bottle, and their composition was dependent on the yeast strain and the duration of ageing (Suárez Valles *et al.*, 2005). The average level of total biogenic amines in Spanish ciders was 5.9±8.4 mg/L. Putrescine, histamine and tyramine were the prevailing amines and were present in 50, 38 and 33% of the ciders studied, respectively; very small amounts of ethylamine and phenylethylamine were observed in only one sample. Ciders that had lower glycerol contents and larger amounts of 1,3-propanediol had much higher levels of histamine, tyramine and putrescine, which suggests a high activity of lactic acid bacteria during cider making and thus the need for their effective control (Garai *et al.*, 2006).

Acrolein may be formed in apple-derived products through the degradation of glycerol. Due to its high volatility and high reactivity, acrolein disappears rapidly

from ciders. The concentration of acrolein in two French ciders was 7 and 15 μg/L. Acrolein was also detected in freshly distilled calvados (a distillate of cider) at concentrations of between 0.7 and 5.2 mg/L; however, the concentrations decreased during ageing (Ledauphin *et al.*, 2006b). Ledauphin *et al.* (2004, 2006a) provided information on a range of volatile compounds in distilled calvados. The method of production of cider (by traditional methods or from concentrates) influences the composition of the resulting calvados. The spirits manufactured from traditional ciders had higher concentrations of decanoic and dodecanoic esters and long-chain fatty acids (Mangas *et al.*, 1996b).

(b) Other fruit wines

Berry fruit or stone fruit are predominantly used to manufacture wine. The manufacture of fruit wine has been reviewed (Röhrig, 1993).

Fruit wines produced from different varieties of sour cherry contained 7.7–9.6% vol alcohol, 8.4–9.9 g/L total acid and 35–60 g/L residual sugar. The concentrations of colourless polyphenols varied considerably. Neochlorogenic acid (48–537 mg/L), chlorogenic acid (31–99 mg/L) and 3-cumaroylquinic acid (43–196 mg/L) were the predominant phenolcarbonic acids followed by the flavonoids, procyanidin B1 (6–32 mg/L), catechin (2–27 mg/L) and epicatechin (8–130 mg/L). Quercetin glycosides were present at concentrations of 12–46 mg/L. The four major anthocyanins were identified as cyanidin-3-(2^G-glucosylrutinoside), cyanidin-3-(2^G-xylosylrutinoside), cyanidin-3-rutinoside and peonidin-3-rutinoside and were present at concentrations of 147–204 mg/L and in a rather constant ratio of 72:3:22:3. Among aromatic substances, the secondary aroma arising during the fermentation process was dominant. The main components were ethyl esters of hexanoic acid, octanoic acid and decanoic acid, as well as the fruity esters, isoamyl acetate, butanoic acid ethyl ester, acetic acid butyl ester and acetic acid hexyl ester. The endogenous fruit aroma was mainly composed of acetic acid ethyl ester, phenylethyl alcohol, decanal, benzaldehyde, 1-hexanol, 1-octanol, nonanal, *trans*-nerolidol and linalool (Will *et al.*, 2005).

The mineral composition of different fruit wines was generally comparable with that of red wine, and potassium was the most abundant mineral found in all wine categories. However, the level of calcium was significantly higher in cranberry wine than in other wines. The biogenic amine histamine was present only in small amounts in non-traditional fruit wines compared with red wines (Rupasinghe & Clegg, 2007).

Mandarin wine obtained from clementines (*Citrus reticula* Blanco) was studied by Selli *et al.* (2004); 19 volatile compounds were identified including esters, higher alcohols, monoterpenes and furfural compounds. The major compounds were ethyl octanoate, ethyl decanoate, isoamyl alcohol, ethyl hexanoate and isoamyl acetate.

The composition of wines made from blackcurrants and cherries was studied by Czyzowska and Pogorzelski (2002, 2004). Blackcurrant musts contained 4800–6600 mg/L and cherry musts contained 3060–3920 mg/L total polyphenols. The fermentation

process caused a decrease in polyphenol content of approximately 25%. During the production of fruit wines, the method of treatment of the pulp had a considerable effect on the total polyphenol content. The highest extraction of polyphenols was obtained after enzymatic pectinolysis. In musts and wines, the presence of the following derivatives of hydroxycinnamic acid was determined: neochlorogenic, chlorogenic, caffeic, *para*-coumaric and ferulic acids. The content of neochlorogenic acid was the highest and amounted to 24.7–35.3 mg/L for blackcurrants and 44.5–71.4 mg/L for cherries. Furthermore, the flavan-3-ols, catechin, epicatechin, dimer B_2 and trimer C_1, were identified in cherry musts and wines. In the cherry wines studied, the variants subjected to pectinolysis and fermentation of the pulp contained smaller amounts of epicatechin than catechin whereas it was predominant in the wines subjected to thermal treatment. In the blackcurrant musts and wines, the flavanols, gallocatechin, catechin, epigallocatechin, dimer B_2, epicatechin and trimer C_1, were identified. In cherry musts and wines, the anthocyanin pigments, cyanidin 3-glucoside, cyanidin 3-rutinoside and cyanidin 3-glucosylrutinoside, have been identified, the last of which was the most abundant. Anthocyanins identified in blackcurrant musts and wines were delphinidine and cyanidine glycosides: delphinidin 3-glucoside, delphinidin 3-rutinoside, cyanidin 3-glucoside and cyanidin 3-rutinoside; their aglycones were also found.

The antioxidant effects of fruit wines were studied by Pinhero and Paliyath (2001). On the basis of specific phenolic content, summer cherry, blackberry and blueberry wines were 30–40% more efficient at scavenging superoxide radicals than red grape wine. From among several different fruit wines, elderberry, blueberry and blackcurrant wines were identified by Rupasinghe and Clegg (2007) as having the highest concentrations of phenolic compounds compared with red wine.

In contrast, Lehtonen *et al.* (1999) found that the amounts of phenolic compounds in berry and fruit wines were much smaller than those in red grape wines, which indicates that these compounds are more effectively extracted from red grapes than from berries and fruits. The total amount of phenolic compounds ranged from 18 to 132 mg/L in berry and fruit wines and liqueurs derived from apples, blackcurrants, bilberries, cowberries, crowberries, cherries, strawberries and arctic brambles. Anthocyanins and flavan-3-ols were the most abundant. The main anthocyanins were cyanidin and delphinidin in wine made from blackcurrants and black crowberries. Wines made from crowberries and from blackcurrants and strawberries were richest in flavan-3-ols and contained 79 and 76 mg/L, respectively. In addition, ellagic acid was found in strawberry and blackcurrant wines (44 mg/L) and in cherry liqueur (117 mg/L).

Fruit wines may also be manufactured from guava (Anderson & Badrie, 2005), peach (Joshi *et al*., 2005), banana (Brathwaite & Badrie, 2001; Jackson & Badrie, 2002; Akubor *et al.*, 2003; Jackson & Badrie, 2003), mango (Reddy & Reddy, 2005), cashew apples (Garruti *et al.*, 2006) or Brazilian jabuticaba fruit (Asquieri *et al.*, 2004) but their composition has not been studied in detail.

(c) Alcoholic beverages produced in Asia

In general, information on the composition of Asian alcoholic beverages is scarce but spirits produced in Japan and other East Asian countries have been reviewed (Minabe, 2004).

Shochu is a traditional Japanese distilled spirit. The category consists of two types of product. It is produced either from barley, maize or sugar cane by continuous distillation using a column still (the product is very similar to vodka) or from barley, rice or sweet potato using a pot-still. Saccharification in the second type is accomplished using fungi cultures (so-called koji—a mould grown on rice). The role of koji is analogous to that of malt in beer and whisky production (Iwami *et al.*, 2005). Barley shochu contains 20–30% vol alcohol. The flavour of shochu is closely associated with ethyl acetate, isoamyl acetate and ethyl caproate (Iwami *et al.*, 2006).

Another well known Japanese alcoholic beverage is sake. Despite its relatively high average alcoholic strength of 15% vol, sake is not a distilled beverage. It is manufactured from rice, koji and yeast. The koji degrades the starch to form glucose, which is immediately converted by yeast to form alcohol. Over 300 components have been identified in sake (Yoshizawa, 1999). Apart from ethanol, the main contributors to the flavour of sake are alcohols (1-propanol, isoamyl alcohol, 2-phenylethanol and isobutanol), esters (ethyl acetate, ethyl caproate and isoamyl acetate) and acids (succinic, malic, citric, acetic and lactic acids) (Bamforth, 2005).

Korean traditional lotus spirit made from lotus blossom and leaves contained 14% ethanol, 0.95% organic acids, 1.4% carbohydrate and polyphenol compounds (1063 mg/L) (Lee *et al.*, 2005).

An overview of alcoholic beverages from China was given by Chen and Ho (1989) and Chen *et al.* (1999). Alcoholic drinks from Nepal were discussed by Dahal *et al.* (2005).

In India, so-called 'Indian-made foreign liquors' are manufactured. They include the typical European spirit groups such as whisky, rum or brandy (Baisya, 2003). Due to problems of availability of cereals, Indian-made foreign liquors are generally manufactured from molasses, contrary to the practices followed in other countries (Sen & Bhattacharjya, 1991). In addition, 'country liquor' is manufactured in India, and is so named to indicate its local origin and to differentiate from the more expensive foreign liquor (Narawane *et al.*, 1998). Country liquors are the most popular alcoholic beverage consumed among low socioeconomic groups in India. It is either brewed locally or made in distilleries by distilling molasses supplied by sugar factories. A popular country liquor that is consumed by the lower socioeconomic group in South India is toddy, which is a non-distilled alcoholic beverage. It is obtained by natural fermentation of coconut palm (*Cocos nucifera*) sap, which is collected by tapping the unopened inflorescence of the coconut palm (Lal *et al.*, 2001). Several other types of country liquor are produced in India: for example, tharrah in Uttar Pradesh, chang in Punjab, arrack in Tamil Nadu, mahua in West Bengal, laopani in Assam and darru in Rajasthan. The

Bureau of Indian Standards had difficulty in identifying every type of country liquor and devising individual standards. However, requirements have been set for the three major types of distilled country liquor. Plain country liquor is an alcoholic distillate of fermented mash of different agricultural products (e.g. cereals, potatoes, fruit, coconut). Blended country liquor is a pot-still distillate, rectified spirit and/or neutral alcohol. Spiced country liquor is plain or blended country liquor that is flavoured and/or coloured (Sen & Bhattacharjya, 1991).

(d) Alcopops

Alcopops are also known as 'ready-to-drink' or 'flavoured alcoholic beverages'; they tend to be sweet, to be served in small bottles (typically 200–275 mL) and to contain between 5 and 7% vol alcohol.

In a recent study, the alcoholic strength of alcopops was in the range of 2.4–8% vol with an average of 4.7% vol. A significant deviation was detected in the volatile composition of alcopops that contain beer, wine and spirits. Alcopops derived from wine alcohol showed concentrations of volatile compounds (especially methanol, 1-propanol and 2-/3-methylbutanol-1) that were 10–100 times higher than those in products derived from spirits. However, this study noted the variability in alcopop composition, and the possibility of changes in recipes has to be taken into consideration even if the brand name of a given product has not been changed (Lachenmeier *et al.*, 2006c).

The recent practice of combined consumption of alcohol and so-called energy drinks has rapidly become popular. The main components of the marketed energy drinks are caffeine, taurine, carbohydrates, gluconolactone, inositol, niacin, pantenol and B-complex vitamins (Ferreira *et al.*, 2006). The levels of taurine in such alcoholic energy drinks were recently determined and large variations were detected. Ready-mixed energy drinks with spirits contained 223–4325 mg/L taurine (median, 314 mg/L), energy drinks with beer contained 112–151 mg/L taurine (median, 151 mg/L) and energy drinks with wine contained 132–4868 mg/L taurine (median, 305 mg/L) (Triebel *et al.*, 2007). However, valid scientific information on interactions between the ingredients of energy drinks (for example, taurine and caffeine) and alcohol was not available.

Another category of alcoholic beverages that is relatively similar to alcopops in their presentation is hemp beverages. Typical products are so-called hemp beers, which are flavoured with dried hemp (*Cannabis*) inflorescences, and hemp liqueurs. Δ9-Tetrahydrocannabinol, the main psychoactive substance found in the *Cannabis* plant, was not detected in hemp beers (Lachenmeier & Walch, 2005).

Table 1.12 Additives suitable for alcoholic beverages and maximum levels (mg/kg)

	Beer	Cider/ perry	Grape wine	Wines (other than grape)	Mead	Distilled spirituous beverages (>15% vol alcohol)	Aromatized alcoholic beverages
Benzoates	–	1000	–	1000	1000	–	1000
Carmines	100	200	–	200	–	200	–
Carotenes, vegetable	600	600	–	600	–	600	600
Colourants							
Brilliant Blue FCF	–	200	–	200	–	200	200
Caramel Colour, Class III	GMP	GMP	–[a]	GMP	–	GMP	GMP
Caramel Colour, Class IV	GMP	GMP	–	GMP	–	GMP	GMP
Fast Green FCF	–	–	–	–	–	100	100
Diacetyltartaric and fatty acid esters of glycerol	–	5000	–	5000	–	5000	10 000
Dimethyl dicarbonate	–	250	200	250	200	–	–
EDTA	25	–	–	–	–	25	–
Lysozyme		500	500	–	–	–	–
Polydimethylsiloxane	10	10	–	–	–	–	10
Polyvinylpyrrolidone	10	2	–	–	–	–	–
Riboflavins	–	300	–	300	–	–	100
Sulfites	50	200	350	200	200	200	–

From Codex alimentarius (2006) EDTA, ethylene diamine tetraacetate; GMP, good manufacturing practice (the quantity of the additive is limited to the lowest possible level necessary to accomplish its desired effect) [a] Additives are not suitable for this food category.

1.6.6 *Additives and flavourings*

(a) Additives

The Codex Standard for Food Additives includes several additives that are recognized as suitable for use in alcoholic beverages (*Codex alimentarius*, 2006) (Table 1.12). In addition, a list of 179 additives that are permitted for use in food in general is provided. These additives (including organic acids, alginates, salts, gases (e.g. carbon dioxide, nitrogen) and sugars) may be used in alcoholic beverages with the exception of grape wine that is excluded from the general conditions. The additives listed in this standard were determined to be safe by the Joint FAO/WHO Expert Committee on Food Additives.

Many countries provide stricter regulations on food additives than the *Codex alimentarius*. For example, the German beer purity law of 1516, which is still in force

today, states that only barley malt, hops, yeast and water are permitted in beer production (Donhauser, 1988). According to European law, no additives are permitted in most traditional spirits, e.g. rum, whisky, brandy, fruit spirits and many other types (European Council, 1989). In contrast, additives are regularly added to liqueurs (artificial colourings) or alcopops (artificial colourings, preservatives). Some national regulations also permit the use of additives other than those listed by the *Codex alimentarius*, e.g. a multitude of artificial colourings, sweeteners or further preservatives (e.g. sorbic acid). Caramel colouring is frequently used to ensure colour consistency of aged products (Boscolo *et al.*, 2002).

The most frequent additives in alcoholic beverages are sulfur dioxide and sulfites. Sulfite additives have been associated with allergic-like asthmatic responses in certain individuals (Vally & Thompson, 2003). For this reason, many countries require the labelling of sulfur dioxide and sulfites used as ingredients at concentrations of more than 10 mg/L (expressed as sulfur dioxide) (Lachenmeier & Nerlich, 2006).

In conjunction with added sulfite, natural sulfite may evolve in alcoholic beverages during fermentation by the metabolism of yeasts (Ilett, 1995).

Sulfite is a desirable component in beer because it has an antioxidative effect as a scavenger and binds to carbonyl compounds that cause a stale flavour. In contrast, during the early phases of fermentation, high concentrations of sulfite may cause an undesirable flavour (Guido, 2005). The formation of sulfite is strongly influenced by predisposition of the yeast and parameters that affect yeast growth during fermentation, such as the physiological state of the yeast and the availability of nutrients and oxygen (Wurzbacher *et al.*, 2005). The average residual quantities of sulfur dioxide were 7.5 mg/L in French beer and 25 mg/L in cider (Mareschi *et al.*, 1992). In a recent study, the average concentrations expressed as sulfur dioxide were 4.2 mg/L for beer (195 samples) and 1.0 mg/L for spirits (101 samples). The concentrations of sulfite in spirits were found to be significantly lower than those in beer ($P < 0.0001$) (Lachenmeier & Nerlich, 2006).

Generally higher levels of sulfur dioxide were determined in wine than in spirits or beer. However, during the last decade, a decrease in the sulfite content of wine has been detected that is probably due to new technological processes that improve the stability of wine using a smaller quantity of sulfite (Leclercq *et al.*, 2000). In a large survey of wines conducted in the 1980s, 3655 samples of Italian wine and 8061 samples of French wine that were analysed had mean sulfite contents of 135 mg/L and 136 mg/L, respectively (Ough, 1986). In later studies, an average of 92 mg/L sulfite was determined in 85 samples of wine in Italy (Leclercq *et al.*, 2000), whereas in France, the mean concentrations were 75 mg/L (Mareschi *et al.*, 1992).

(b) Flavourings

The *Codex alimentarius* (1987) provides general requirements for natural flavourings. Some flavourings contain biologically active substances for which maximum

Table 1.13 Maximum levels for biologically active substances contained in natural flavourings

Biologically active substance	Maximum level in alcoholic beverages (mg/kg)
Agaric acid	100
Aloin	50
β-Azarone	1
Berberine	10
Coumarin	10
Hydrocyanic acid, total (free and combined)	1 per % vol
Hypericine	2
Pulegone	100 (beverages in general) 250 (peppermint- or mint-flavoured beverages)
Quassine	50
Quinine	300
Safrole	2 (<25% vol) 5 (>25% vol)
Santonin	1 (>25% vol)
Thujones (α and β)	5 (<25% vol) 10 (>25% vol) 35 (bitters)

From Codex alimentarius (1987)

levels are specified (Table 1.13). It must be noted that the biologically active substances (with the exception of quinine and quassine) should not be added as such to food and beverages, and may only be incorporated through the use of natural flavourings, provided that the maximum levels in the final product ready for consumption are not exceeded.

Of the biologically active substances listed, the largest body of information available is on thujone. This derives from the fact that the prohibition of absinthe was overruled after adoption of the *Codex alimentarius* recommendation into European law in 1988. The thujone-containing wormwood plant (*Artemisia absinthium* L.) gave absinthe its name and is, together with alcohol, the main component of this spirit drink. Currently, more than 100 types of absinthe are legally available in Europe. Absinthe was recently reviewed by Lachenmeier *et al.* (2006d) and Padosch *et al.* (2006). The majority of 147 absinthe samples examined (95%) did not exceed the *Codex alimentarius* maximum level for thujone of 35 mg/kg for bitters. In fact, more than half of the samples examined (55%) contained less than 2 mg/kg thujone. This emphasized that thujone values in absinthes produced according to historical recipes can be conform to the *Codex alimentarius* maximum levels. Several studies on the experimental production of absinthes and the analyses of vintage absinthes consistently showed that they contained only relatively low concentrations of thujone (< 10 mg/L) (Lachenmeier

et al., 2006e). The thujone content of absinthe is irrespective of the quality of the spirit as there are several different wormwood chemotypes that have a large variance in thujone content (0–70.6% in essential oil) (Lachenmeier, 2007a). The easiest way to avoid thujone totally is to use the thujone-free wormwood herb, which is available in certain cultivation areas and appears to be perfect for use in the spirits industry. Some authors concluded that thujone concentrations of both pre-prohibition and modern absinthes may not cause detrimental health effects other than those encountered in common alcoholism (Strang *et al.*, 1999; Padosch *et al.*, 2006).

The Joint FAO/WHO Expert Committee on Food Additives has evaluated the safety of approximately 1150 individual flavouring agents (Munro & Mattia, 2004). Similarly, the expert panel of the Flavor and Extract Manufacturers' Association of the USA has evaluated the safety of nearly 1900 substances (Smith *et al.*, 2005). As a result of these evaluations, certain flavourings used in alcoholic beverages now have the status of 'generally recognized as safe' (GRAS).

In alcoholic beverages, the most prominent GRAS substance is (*E*)-1-methoxy-4-(1-propenyl)benzene (anethole). Anethole is a volatile substance that occurs naturally in several herbs and spices. Macerates, distillates or extracts of the plants star-anise (*Illicium verum* Hook. Fil.), aniseed (*Pimpinella anisum* L.) or fennel (*Foeniculum vulgar*e Mill.), the essential oils of which contain approximately 80–90% anethole, are used to flavour spirits. After extensive toxicological evaluations, anethole was determined to be GRAS (Newberne *et al.*, 1998, 1999). Certain spirits that contain anise, such as pastis, sambuca or mistrà, must contain minimum and maximum levels of anethole (usual range, 1–2 g/L) (Lachenmeier *et al.*, 2005a). Raki spirits from Turkey contained 1.5–1.8 g/L anethole (Yavas & Rapp, 1991). In arak from the Lebanon, levels of anethole varied from 1.2 to 3.8 g/L in commercial and from 0.5 to 4.2 g/L in artisanal samples. The variations in levels of anethole were found to be in direct relation to the amounts of aniseed used in the anization step of arak manufacture (Geahchan *et al.*, 1991). Twenty-one different brands of pacharán (a traditional Spanish beverage obtained by maceration of sloe berries (*Prunus spinosa L.*)) contained between 0.015 and 0.069 g/L anethole (Fernández-García *et al.*, 1998).

(c) Acetaldehyde

In addition to being an intermediate product of the metabolism of ethanol in humans and animals, acetaldehyde (ethanal) is a potent volatile flavouring compound found in many beverages and foods (Liu & Pilone, 2000). No current systematic surveys of acetaldehyde in alcoholic beverages were available. In general, the concentration of acetaldehyde in alcoholic beverages is below 500 mg/L and the flavour threshold varies between 30 and 125 mg/L (Liu & Pilone, 2000). During the production of spirits, acetaldehyde is enriched in the first fraction of the distillate, which is generally discarded due to its unpleasant flavour.

The levels of acetaldehyde in alcoholic beverages vary considerably. However, the acetaldehyde formed from the metabolism of alcohol in the oral cavity and the further digestive pathway is many times higher than the levels specified above.

Acetaldehyde at low levels gives a pleasant fruity aroma, but at high concentrations it possesses a pungent irritating odour (Miyake & Shibamoto, 1993). In alcoholic beverages, acetaldehyde may be formed by yeasts, acetic acid bacteria and coupled autooxidation of ethanol and phenolic compounds (Liu & Pilone, 2000). In other foods, acetaldehyde may be added as a flavouring substance. The JECFA included acetaldehyde in the functional class 'flavouring agent' and commented that there is no safety concern at current levels of intake when it is used as a flavouring agent (Joint FAO/WHO Expert Committee on Food Additives 1997). Acetaldehyde is formed in mild beer as a result of light oxidation. It is also a degradation product of poly(ethylene terephthalate), which is increasingly used as packaging choice for milk and beverages. The migration of acetaldehyde from the container into the product is an issue to be explored, particularly in the water industry, for which low acetaldehyde grades of poly(ethylene terephthalate) have been developed (van Aardt *et al.*, 2001).

Acetaldehyde is extremely reactive and binds readily to proteins, the peptide glutathione (GSH) or individual amino acids to generate various flavour compounds (Miyake & Shibamoto, 1993; Liu & Pilone, 2000).

(d) Illegal additives, adulteration and fraud

Occasionally, illegal additives, which may be very toxic and which are not permitted for use in commercial production in most countries, have been identified in alcoholic beverages. These include methanol, diethylene glycol (used as sweetener) and chloroacetic acid or its bromine analogue, sodium azide and salicylic acid, which are used as fungicides or bactericides (Ough, 1987). The fungicide methyl isothiocyanate has been added illegally to wine to prevent secondary fermentation (Rostron, 1992).

The authenticity of wine and detection of its adulteration have been reviewed (Médina, 1996; Arvanitoyannis *et al.*, 1999; Guillou *et al.*, 2001; Ogrinc *et al.*, 2003). Beet sugar, cane sugar or concentrated rectified must are added to grape must or wine before or during fermentation to increase the natural content of ethanol and therefore the value of the wine. Another type of economic fraud is mixing high-quality wines with low-quality wines that often originate from other geographical regions or countries. Nuclear magnetic resonance spectroscopy in combination with chemometric methods is a suitable approach to study the adulteration of wine in terms of varieties, regions of origin and vintage and also to detect the addition of undesirable or toxic substances (Ogrinc *et al.*, 2003). The $^{13}C/^{12}C$ isotope ratio of ethanol and the $^{18}O/^{16}O$ isotope ratio of water determined by isotopic ratio mass spectrometry can be used to detect adulteration of wine that involves the addition of cane sugar and watering (Guillou *et al.*, 2001). Wine differentiation is also possible using multivariate analysis of differ-

ent constituents such as minerals, phenolic compounds, volatile compounds or amino acids (Médina, 1996; Arvanitoyannis *et al.*, 1999).

The detection of illicit spirits has been reviewed (Savchuk *et al.*, 2001). The adulteration of spirits includes blending high-quality distillates with ethanol made from a cheaper raw material, adding synthetic volatile components to neutral alcohol or misleading labelling of the variety and origin of the raw material (Bauer-Christoph *et al.*, 1997). The classic approach to the authentication of spirits is gas chromatographic analysis of volatile compounds (congeners of alcoholic fermentation). However, the wide range of components in each type of spirit and the considerable overlap between them renders the unambiguous identification of many spirit types difficult. In addition, if a high degree of rectification takes place during distillation, the content of volatile components will be reduced and the application of gas chromatography for the identification of the raw material becomes inappropriate. In these cases, the natural isotope ratios may be used as discriminant analytical parameters (Bauer-Christoph *et al.*, 1997). For example, rums and corn alcohols from C_4 plants (cane and corn) can easily be distinguished from alcohols from C_3 plants such as grape, potato or beet or C_3 cereal alcohols (pure malt whisky). Isotopic criteria may also be used for short-term dating of brandies and spirits (i.e. the time of storage in casks) (Martin *et al.*, 1998).

Recently, infrared spectroscopy with multivariate data analysis was successfully applied for the authentication of fruit spirits and other spirits, (Lachenmeier, 2007b; Lachenmeier *et al.*, 2005b). Direct infusion electrospray ionization mass spectrometry was applied for chemical fingerprinting of whisky samples for type, origin and quality control (Moller *et al.*, 2005).

Another problem of premium spirits is the economic incentive to mix or completely substitute one brand with another less expensive brand. In such cases, the brand fraud can often be easily determined by analysing the composition of inorganic anions (Lachenmeier *et al.*, 2003). A mobile device that measures ultraviolet/visible absorption spectra was used for the authentication of Scotch whisky under field test conditions (MacKenzie & Aylott, 2004).

The same approaches as those in wine and spirit analysis were used for the authentication of beer. More recently, high-resolution nuclear magnetic resonance spectroscopy in combination with multivariate analysis was found to be adequate to distinguish beers according to their composition (e.g. differentiation between beers made with pure barley or adjuncts) or according to brewing site and date of production (Almeida *et al.*, 2006).

1.6.7 *Contaminants, toxins and residues*

For the purposes of this section of the monograph, the term ‘contaminant’ is used according to the definition given by the *Codex alimentarius*. A contaminant is any substance that is not intentionally added to food but which is present in such food as a result of the production, manufacture, processing, preparation, treatment, packing,

packaging, transport or holding of such food, or as a result of environmental contamination. The *Codex* definition of a contaminant implicitly includes naturally occurring toxicants such as those produced as toxic metabolites of certain microfungi that are not intentionally added to food (mycotoxins) (*Codex alimentarius*, 1997). Some of these contaminants have known toxic properties and, in some cases, carcinogenic effects (see Table 1.14).

(a) Nitrosamines

The chemical class of nitrosamines includes the Group 2A carcinogen *N*-nitrosodimethylamine (NDMA) (IARC 1978; IARC, 1987). The occurrence and formation of *N*-nitroso compounds in food and beverages have been reviewed (Tricker & Kubacki, 1992; Lijinsky, 1999).

In alcoholic beverages, NDMA was first found in German beers in 1978 (Spiegelhalder *et al.*, 1979), when concentrations of up to 68 μg/L caused worldwide concern. Subsequent research established that NDMA was a contaminant of malt that had been kilned by direct firing, which was the predominant production method at that time. Once the source of the contaminant and the mechanism of its formation had been elucidated, control was achieved by changing to indirect firing of the malt kiln. The possibilities for minimizing nitrosamine formation during malt kilning have been reviewed (Flad, 1989; Smith, 1994). As a result of the improvements in the quality of malt, a technical threshold value of 0.5 μg/kg NDMA in beer was established as a recommendation to the brewing industry. In Germany, this value was exceeded by 70% of all samples in 1978. In the most recent reports (2001–05), the technical threshold value was exceeded by only one of 363 German beers (0.2%) (Baden-Württemberg, 2006). Fig 1.5 demonstrates the decrease in levels of NDMA in German beers.

The concentrations of NDMA in beer that have been determined in different countries are summarized in Table 1.15. The data reflect the successful efforts of the malting and brewing industries to reduce the formation of NDMA.

Shin *et al.* (2005) analysed nitrosamines in a range of alcoholic beverages in the Republic of Korea in two surveys in 1995 and 2002, and included the first reports on the traditional Korean beverages chungju (fermented rice alcohol), takju (fermented cereal alcohol) and soju (distilled from fermented cereal alcohol). NDMA was detected in the 1995 survey in chungju (< 0.1 μg/kg) and soju (mean, 0.2 μg/kg) but in none of the samples in the 2002 survey. For domestic Korean beers, an average of 0.8 μg/kg and 0.3 μg/kg were reported in 1995 and 2002, respectively. Whisky and liqueurs contained an average of less than 0.1 μg/kg in both surveys.

Sen *et al.* (1996) noted that higher levels of NDMA might be present in beers in developing countries than in those in North America or Europe. The malt-drying techniques in various countries are unknown, and continuous monitoring and control of imported beers might therefore be necessary. As an example, high levels of nitrosamines were found in a survey of 120 Indian beers with an average of 3.2 μg/kg and a

Figure 1.5. Development of maximum concentration of N-nitrosodimethylamine (µg/kg) in German beer (data from Table 1.15)

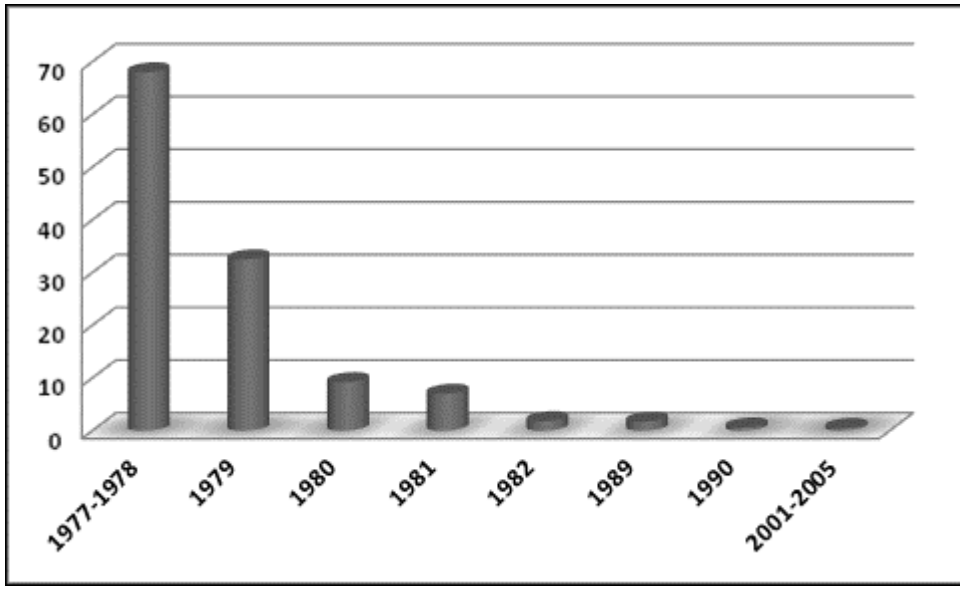


Table 1.14 Summary of carcinogens that may be present in alcoholic beverages

Agent	Amount in alcoholic beverages[a]	*IARC Monographs* evaluation of carcinogenicity			*IARC Monographs* volume, year
		In animals	In humans	IARC group	
Acetaldehyde	Lower mg/L range	Sufficient	Inadequate	2B	**71**, 1999
Acrylamide	Beer; <10 µg/kg	Sufficient	Inadequate	2A	**60**, 1994
Aflatoxins	Beer (Table 1.22)	Sufficient	Sufficient	1	**56**, **82**, 2002
Arsenic	(Table 1.25)	Sufficient	Sufficient	1	**84**, 2004
Benzene	(no sufficient data)	Sufficient	Sufficient	1	**Suppl. 7**, 1987
Cadmium	(Table 1.24)	Sufficient	Sufficient	1	**58**, 1993
Deoxynivalenol	Beer (Table 1.19)	Inadequate	Inadequate	3	**56**, 1993
Ethanol	(2–80% vol)	Inadequate	Sufficient	1	**44**, **96**, 2010
Ethyl carbamate (urethane)	See monograph in this volume	Sufficient	Inadequate	2A	**7**, **96**, 2010
Furan	Beer; <20 µg/kg	Sufficient	Inadequate	2B	**63**, 1995
Lead	(Table 1.23)	Sufficient	Limited	2A	**87**, 2006
N-Nitrosodimethylamine	Beer: <0.5 µg/kg (Table 1.16)	Sufficient	Inadequate	2A	**Suppl. 7**, 1987
Nivalenol	Beer (Table 1.20)	Inadequate	Inadequate	3	**56**, 1993
Ochratoxin A	Wine, beer (Table 1.17)	Sufficient	Inadequate	2B	**56**, 1993
Organolead compounds	Wine; limited data	Inadequate	Inadequate	3	**87**, 2006
Patulin	Apple cider	Inadequate	Inadequate	3	**Suppl. 7**, 1987

[a] Most carcinogens are contained at very different concentration ranges depending on the origin and different production technologies, so that no average concentration can be derived.

maximum of 24.7 µg/kg (Prasad & Krishnaswamy, 1994). [The Working Group noted the lack of data on nitrosamine contents of beer in developing countries.]

In a single study, volatile *N*-nitrosamines in mixed beverages containing beer (e.g. beer-cola, shandy) were reported. The contents were below 0.3 µg/kg in all samples. The formation of nitrosamines that might arise due to the low pH value of these beverages was not detected (Fritz *et al.*, 1998).

Tricker and Preussmann (1991) reviewed food surveys on NDMA. Dietary intake of NDMA was approximately 0.5 µg/day or less in most countries, which is about one-third of the intake in 1979–80. Previously, beer was the major source of NDMA in human nutrition (65% contribution). In 1990, beer was estimated to contribute to about 31% of total NDMA intake.

Table 1.15 *N*-nitrosodimethylamine in beer

Country	Year	No. of samples	Positive (%)	Concentration (µg/kg)		References
				Mean	Range	
Brazil	1997	60	43	0.09	0–0.32	Glória *et al*. (1997)
Canada	1978	13	100	1.4	0.60–4.9	Sen *et al*. (1982)
	1980	55	100	0.73	0.36–1.52	Sen *et al*. (1982)
	1982	24	No data	0.31	0–1.9	Sen *et al*. (1982)
	1989	46	59	0.095	0–0.59	Scanlan *et al*. (1990)
China	1981	26	77	2.7	0–6.5	Yin *et al*. (1982)
	1987	176	83	0.5	0–6	Song & Hu (1988)
Estonia	2003–04	158	No data	0.20	0–1.31	Yurchenko & Mölder (2005)
Former USSR	1980	165	53	No data	0–56	Kann *et al*. (1980)
Germany	1977–78	158	70	2.7	0–68	Spiegelhalder *et al*. (1979)
	1979	92	63	No data	0–32.5	Frommberger & Allmann (1983)
	1980	401	No data	0.28	0–9.2	Frommberger (1985)
	1981	454	24	0.44	0–7.0	Spiegelhalder (1983)
	1982	228	No data	0.075	0–1.8	Frommberger (1985)
	1989	514	41.2	0.16	0–1.7	Frommberger (1989)
	1990	14	No data	0.17	0–0.6	Tricker & Preussmann (1991)
	2001–05	363	No data	No data	0–0.5	Baden-Württemberg (2006)
India	1994	120	84	3.6	0–24.7	Prasad & Krishnaswamy (1994)
Italy	1982	6	67	0.4	0–0.79	Tateo & Roundbehler (1983)
	1986	15	87	0.3	0–0.71	Gavinelli *et al*. (1988)
Japan	1980	29	93	5.1	Tr–13.8	Kawabata *et al*. (1980)
	1982	12	0	0	–	Yamamoto *et al*. (1984)
Korea	1995	29	79	0.8	0.2–4.2	Shin *et al*. (2005)
	2002	18	56	0.3	0.1–0.7	Shin *et al*. (2005)
Netherlands	1978	32	No data	1.4	0–3.9	Ellen & Schuller (1983)
	1979	108	No data	2.0	0–7.4	Ellen & Schuller (1983)
	1980	86	No data	0.2	0–1.2	Ellen & Schuller (1983)
Poland	1989	12	83	0.2	0–0.3	Kubacki *et al*. (1989)
Spain	1994	21	52	0.11	0–0.55	Izquierdo-Pulido *et al*. (1996)
	2002	44	20	0.16	0–1.05	Cárdenes *et al*. (2002)

Table 1.15 (continued)

Country	Year	No. of samples	Positive (%)	Concentration (µg/kg)		References
				Mean	Range	
Sweden	1980–86	258	59	0.3	0–6.5	Österdahl (1988)
United Kingdom	1988–89	171	34	0.18	0.1–1.2	Massey *et al*. (1990)
USA	1979	6	100	3.1	0.9–7	Goff & Fine (1979)
	1980	52	No data	3.4	0.4–7.7	Fazio *et al*. (1980)
	1980	25	92	5.9	0–14	Scanlan *et al*. (1980)
	1988	10	100	0.28	0.03–0.99	Billedeau *et al*. (1988)
	1989	148	55	0.067	0–0.59	Scanlan *et al*. (1990)
	1997	28	50	0.07	0–0.50	Glória *et al*. (1997)

Tr, trace

(b) Mycotoxins

Mycotoxins are fungal secondary metabolites produced by many important phytopathogenic and food-spoilage fungi including *Aspergillus, Penicillium*, *Fusarium* and *Alternaria*. Various control strategies to prevent the growth of mycotoxigenic fungi and inhibit mycotoxin biosynthesis have recently been reviewed (Kabak *et al*., 2006). Mycotoxins survive ethanol fermentation to different degrees but are not carried over to distilled ethanol (Bennett & Richard, 1996). Therefore, alcoholic beverages manufactured without distillation (e.g. wine, cider, beer) are the main focus of research on mycotoxins.

(i) *Mycotoxins in wine*

Recent research on wine has been focused on ochratoxin A, which has been classified Group 2B—possibly carcinogenic to humans (IARC, 1993a). Human ochratoxicosis has been reviewed (Creppy, 1999). Ochratoxin A survives the fermentation process (Kabak *et al*., 2006) and is stable in wine for at least 1 year (Lopez de Cerain *et al*., 2002). It was indicated that fungi that produce ochratoxin A are already present on grapes in the vineyard before the harvest. Location of the vineyard has more influence on the levels of ochratoxin A than the variety of grape. Weather patterns also seem to influence these levels (Kozakiewicz *et al*., 2004). A study of Spanish wines reflected very different levels of contamination by ochratoxin A between 2 years of harvest: 85% of 1997 wine samples versus 15% of 1998 wine samples (Lopez de Cerain *et al*., 2002). The 1997 harvest was judged to be worse than that of 1998 probably because of differences in the weather conditions during the summer that led to lower production and several problems of contamination with fungi. On the contrary, in 1998, no sanitary problems were encountered during cultivation of the grapevines. The storage

conditions and subsequent processing of grapes were very similar in both cases. These results corroborate the notion that ochratoxin A is present in the grapes before the wine is produced and demonstrate the great importance of climate, which obviously depends on the latitude but also on the particular circumstances in any given year. The occurrence, legislation and toxicology of ochratoxin A have been reviewed (Höhler, 1998). Systematic surveys of ochratoxin A in wine are summarized in Table 1.16.

Otteneder and Majerus (2000) reported the results of a meta-analysis that evaluated more than 850 wine samples tested for ochratoxin A. According to these data, ochratoxin A is detected much more commonly and its concentration is remarkably higher in red wines than in rosé and white wines: it was detected in 25% of white, 40% of rosé and 54% of red wine samples. The same result was found when wines from southern and northern regions of Europe were compared. Red wine samples from the northern area showed a contamination of 12% in contrast to those from the southern area, which showed a contamination of about 95%. The differences were explained by wine-making procedures that are totally different with respect to red and white wines. White grapes are pressed out directly, whereas red grapes are left mashed for a certain length of time, which obviously permits fungal growth and production of the toxin (Höhler, 1998).

There is only limited information on the occurrence of other mycotoxins in wine. The occurrence of trichotecin from *Trichotecium roseum* in German wine was studied by Majerus and Zimmer (1995). Results showed that most samples were free from trichotecin. Low concentrations (~28 μg/L) were detected in a small proportion of samples from a vintage that was severely affected by fungal spoilage. Lau *et al.* (2003) reported the occurrence of alternariol from *Alternaria alternata* in a single wine sample (1.9 μg/L). In a limited survey of 66 wines on the Canadian market (Scott *et al.*, 2006), alternariol was found in 13/17 Canadian red wines at levels of 0.03–5.02 μg/L and in all of seven imported red wines at 0.27–19.4 μg/L, usually accompanied by lower concentrations of alternariol monomethyl ether. White wines (23 samples) contained little or no alternariol.

(ii) *Mycotoxins in apple cider*

Patulin, a mycotoxin produced in apples by several *Penicillium* and *Aspergillus* species, may be found in apple cider. To date, inadequate data are available for the classification of patulin (Group 3) (IARC, 1987). Although patulin is a fairly reactive compound in an aqueous environment, it is especially stable at low pH and survives the processes involved in the commercial production of apple juice. The complete destruction of patulin occurs during alcoholic fermentation of apple juice to cider (Moss & Long 2002). However, Wilson and Nuovo (1973) detected patulin in five of 100 samples of apple cider at levels of up to 45 mg/L. These very high levels were only found in cider that was produced when decayed apples had not been discarded or when apples had been stored in bins for very long periods. When these practices were changed, patulin was no longer detected. Tsao and Zhou (2000) found that infected apples may contain

Table 1.16 Ochratoxin A in wine

Country	Year	No. of samples	Positive (%)	Concentration (μg/L)		References
				Mean	Range	
Canada	1999–2002	79	19	0.012	0–0.393	Ng *et al*. (2004)
Europe	2003	38	34	0.032	0–0.057	Rosa *et al*. (2004)
Greece (dry)	1998–2000	242	61	0.28	0–2.69	Stefanaki *et al*. (2003)
Greece	1995–99	35	63	No data	0–3.2	Soufleros *et al*. (2003)
Imported to Canada	1999–2002	101	48	0.160	0–3.720	Ng *et al*. (2004)
Imported to Poland	2005	53	92	0.4775	0.0022–6.710	Czerwiecki *et al*. (2005)
Italy (red)	1995–97	96	85	0.419	0–3.177	Pietri *et al*. (2001)
Mediterranean	1999	31	100	No data	No data	Markaki *et al*. (2001)
Mediterranean	1999–2002	78	59	0.207	0–3.720	Ng *et al*. (2004)
Morocco	2001	30	100	0.65 median	0.028–3.24	Filali *et al*. (2001)
South Africa	2000–01	24	100	0.2	0.04–0.39	Shephard *et al*. (2003)
South America	2003	42	24	0.037	0–0.071	Rosa *et al*. (2004)
Spain	1997	20	85	0.195	0.056–0.316	Lopez de Cerain *et al*. (2002)
Spain	1998	20	15	0.153	0.074–0.193	Lopez de Cerain *et al*. (2002)
Swiss retail	1990–94	118	No data	No data	0–0.388	Zimmerli & Dick (1996)
Worldwide origin	1996	144	42	No data	0–7.0	Majerus & Otteneder (1996)
Worldwide origin	1997–99	420	48	0.177	0–3.31	Otteneder & Majerus (2000)
Worldwide origin	2000	281	40	No data	0–7.0	Majerus *et al*. (2000)
Worldwide origin	2001	942	12	No data	No data	Soleas *et al*. (2001)

extremely high concentrations of patulin (> 100 μg/L), and that one ‘bad’ apple could cause the maximal acceptable level of 50 μg/L in apple cider to be exceeded.

A recent study confirmed that patulin is a good indicator of the quality of apples used to manufacture cider. Patulin was not detected in cider pressed from culled tree-picked apples stored for 4–6 weeks at 0–2 °C, but was found at levels of 0.97–64.0 μg/L in cider pressed from unculled fruit stored under the same conditions. Cider from apples that were culled before pressing and stored in controlled atmospheres contained 0–15.1 μg/L patulin, while cider made from unculled fruit contained 59.9–120.5 μg/L. The washing of ground-harvested apples before pressing reduced levels of patulin in cider by 10–100%, depending on the initial levels and the type of wash solution used. The avoidance of ground-harvested apples and the careful culling of apples before pressing are good methods for reducing the levels of patulin in cider (Jackson *et al.*, 2003).

(iii) *Mycotoxins in beer*

Mycotoxins in beer have been reviewed (Odhav, 2005). Mycotoxins may be transmitted to beers from contaminated grains during brewing. Various surveys have indicated that a variety of mycotoxins reach the final product, but generally in limited concentrations (Odhav, 2005).

Advances in methodology have enabled detection and quantitation of much lower levels (< 1 μg/L) of important mycotoxins such as ochratoxin A and aflatoxins in beer. Consequently, in recent years, reported incidences of ochratoxin A have increased in European and North American beers (Table 1.17). The highest levels of contamination with mycotoxin in beer from these parts of the world is caused by deoxynivalenol. Local beer brewed in Africa may have high incidences and concentrations of aflatoxins and zearalenone (Scott, 1996).

Mycotoxins—aflatoxins, ochratoxin A, patulin, *Fusarium* toxins (zearalenone, fumonisins, trichlothecenes, nivalenol, desoxynivalenol)—that originate from barley or grain adjuncts survive malting and brewing processes to different extents (Scott, 1996; Dupire, 2003).

Deoxynivalenol, nivalenol and zearalenone are not classifiable as to their carcinogenicity to humans (Group 3) (IARC, 1993a). Surveys of the occurrence of deoxynivalenol and nivalenol in beer are summarized in Tables 1.18 and 1.19, respectively. Papadopoulou-Bouraoui *et al.* (2004) observed that the level of alcohol as well as the type of fermentation had a significant effect on the amount of deoxynivalenol in beer. In general, beers that contained higher levels of alcohol contained significantly larger amounts of deoxynivalenol. Spontaneously fermenting beers contained significantly higher levels of deoxynivalenol than top- or bottom-fermenting beers, while top-fermenting beers contained significantly higher concentrations than bottom-fermenting beers. A positive correlation between original gravity and levels of deoxynivalenol was reported by Curtui *et al.* (2005).

The most abundant naturally occurring fumonisin analogues produced by *Fusarium* species are fumonisins B_1, B_2 and B_3 (Rheeder *et al.*, 2002). Fumonisin B_1 was classified as a Group 2B carcinogen (IARC, 2002). Concentrations of fumonisin B_1 in beer are

Table 1.17 Ochratoxin A in beer

Country	Year	No. of samples	Positive (%)	Concentration (µg/L)		References
				Mean	Range	
Belgium	1998–2001	62	97	0.033	0.010–0.185	Tangni *et al*. (2002)
Canada (including 11 imports)	1995	41	63	0.06	0–0.2	Scott & Kanhere (1995)
Europe	1983	92	0	–	–	Majerus & Woller (1983)
Germany	1987–92	194	41	0.10	No data	Jiao *et al*. (1994)
Germany	1990–92	108	18	No data	0.1–1.5	Majerus *et al*. (1993)
Germany	1992	56	29	No data	0–1.53	El-Dessouki (1992)
Germany	1999	35	86	0.08	0–0.26	Degelmann *et al*. (1999)
Japan	1998	22	96	0.013	0.002–0.045	Nakajima *et al*. (1999)
South Africa	2002	35	31	No data	0–2340[a]	Odhav & Naicker (2002)
Worldwide origin	1998	94	92	0.010	0.001–0.066	Nakajima *et al*. (1999)
Worldwide origin	2001	107	2	No data	No data	Soleas *et al*. (2001)

[a] The Working Group was unable to verify this unusually high value with the authors.

shown in Table 1.20. Shephard *et al*. (2005) showed that fumonisin B_1 was the major fumonisin analogue present in South African home-brewed maize beer and accounted for a mean of 76% in samples that contained all three analogues. The amounts of fumonisin in maize beer were up to two orders of magnitude larger than those observed in beers from other parts of the world in which maize or maize products are not usual ingredients or are used merely as adjuncts. There is little information available on mycotoxin contamination of beer in Africa.

Naturally occurring aflatoxins are carcinogenic to humans (Group 1) (IARC, 2002). Studies on aflatoxins in beer are summarized in Table 1.21. Nakajima *et al*. (1999) conducted a worldwide survey of aflatoxins in beer. Aflatoxins were detected in beer samples from countries where aflatoxin contamination might be expected to occur because of the warm climate. Except for one sample, beers contaminated with aflatoxins were also contaminated with ochratoxin A. Generally, with the exception of a negative survey on 75 bottled Kenyan lager beers (Mbugua & Gathumbi, 2004), much higher concentrations of aflatoxins have been found in both commercial and home-brewed African beers (Scott, 1996; Odhav & Naicker, 2002). Mably *et al*. (2005) confirmed

Table 1.18 Deoxynivalenol in beer

Country	Year	No. of samples	Positive (%)	Concentration (µg/L)		References
				Mean	Range	
Argentina	1997	9	89	51	0–221	Molto *et al*. (2000)
Argentina	1998	26	31	7	0–43	Molto *et al*. (2000)
Argentina	1999	14	43	5	0–20	Molto *et al*. (2000)
Brazil	2001	72	5	No data	50–336	Garda *et al*. (2004)
Canada (and imported)	1993	50	29	No data	0–50	Scott *et al*. (1993)
Czech Republic	1994–95	77	77	13–25	0–70	Ruprich & Ostrý (1995)
Europe	2000–01	51	6	No data	0–41	Schothorst & Jekel (2003)
Germany	2001–04	794	90	7	0–353	Curtui *et al*. (2005)
Japan	2005	17	No data	No data	0.5–1.4	Suga *et al*. (2005)
Kenya	2004	75	100	3.42	1.56–6.40	Mbugua & Gathumbi (2004)
Korea (and imported)	1996	54	26	No data	No data	Shim *et al*. (1997)
Turkey	2002–03	39	0	–	–	Omurtag & Beyoglu (2007)
Worldwide origin	2000–02	313	87	13.5	4.0–56.7	Papadopoulou-Bouraoui *et al*. (2004)

in a large worldwide survey that beers from warmer countries such as Mexico have a higher median concentration of aflatoxin B_1. The highest incidence and concentrations of aflatoxins B_1 and B_2 occurred in beer from India. Other countries where aflatoxin

Table 1.19 Nivalenol in beer

Country	Year	No. of samples	Positive (%)	Concentration (µg/L)		References
				Mean	Range	
Argentina	1997–99	14	0	–	–	Molto *et al*. (2000)
Canada (and imported)	1993	50	6	No data	0–0.84	Scott *et al*. (1993)
Europe	2000–01	51	0	–	–	Schothorst & Jekel (2003)
Korea (and imported)	1995	54	80	4	0–38	Shim *et al*. (1997)

Table 1.20 Fumonisin B_1 in beer

Country	Year	No. of samples	Positive (%)	Concentration (µg/L)		References
				Mean	Range	
Canada (and imported)	1995	41	20	No data	0–59	Scott & Lawrence (1995)
Canada (and imported)	1996	46	48	No data	0–64.3[a]	Scott *et al*. (1997)
Kenya	2004	75	72	0.3	0–0.78	Mbugua & Gathumbi (2004)
South Africa (home-brewed maize beer)	1991–2004	18	100	281	38–1066	Shephard *et al*. (2005)
Spain	1996–97	32	44	No data	0–85.5	Torres *et al*. (1998)
USA (and imported)	1998	29	86 (total fumonisins)	4.0	0–12.7	Hlywka & Bullerman (1999)

[a] The higher incidence of fumonisin B_1 was a bias towards brands that were manufactured from corn grits or cornflakes.

B_1 was detected in beer were Mexico, Spain and Portugal, but levels found in positive samples were much lower. Beers from Canada and the USA were negative for aflatoxins in a reasonably large sampling from these countries.

(c) Ethyl carbamate (urethane)

Ethyl carbamate is evaluated in detail in a separate Monograph in this Volume.

(d) Inorganic contamination

The mineral content of wine depends on many factors, including the type of soil, variety of grape, climate conditions, viticultural practices and pollution (Frías *et al*., 2003). The mineral content of beer was found to be reduced during beer production by about 50–80% (lead, cadmium, copper and zinc). Primarily, the main fermentation and the absorption capacity of beer yeast are responsible for the reduction in the lead, cadmium and zinc contents. In contrast, the amount of copper is reduced during the filtration phase (Mäder *et al*., 1997).

(i) *Lead*

Metallic lead is considered to be a possible carcinogen (Group 2B) (IARC, 1987) whereas inorganic lead compounds are probably carcinogenic to humans (Group 2A) (IARC, 2006). Lead in wine has been reviewed (Eschnauer, 1992; Eschnauer & Scollary, 1996). The concentrations of lead in alcoholic beverages are given in Table 1.22.

Table 1.21 Aflatoxins in beer

Country	Year	No. of samples	Positive (%)	Concentration (μg/L)		References
				Mean	Range	
Canada (and imported)	1998–2002	304	4	0.002	0–0.230	Mably *et al.* (2005)
Czech Republic	1990	34	0	–	–	Fukal *et al.* (1990)
Europe	1982	174	0	–		Woller & Majerus (1982)
Japan	1998	22	9	No data	0.0005–0.0008	Nakajima *et al.* (1999)
Kenya	2004	75	0	–	–	Mbugua & Gathumbi (2004)
South Africa	2000	33	9	No data	12–400	Odhav & Naicker (2002)
Worldwide origin	1998	94	11	No data	0.0005–0.0831	Nakajima *et al.* (1999)

Many authors ascribed the main sources of contamination by lead in wine to winery equipment (Kaufmann, 1998; Rosman *et al.*, 1998), lead capsules (Eschnauer, 1986; Pedersen *et al.*, 1994), lead crystal wine glasses (Hight, 1996) and atmospheric pollution (Lobiński *et al.*, 1994; Teissedre *et al.*, 1994; Médina *et al.*, 2000). The levels of lead were significantly raised by pesticide treatment with azoxystrobin and sulfur (Salvo *et al.*, 2003). The *Codex alimentarius* recommends a maximum level of 0.20 mg/kg lead in wine (*Codex alimentarius*, 2003).

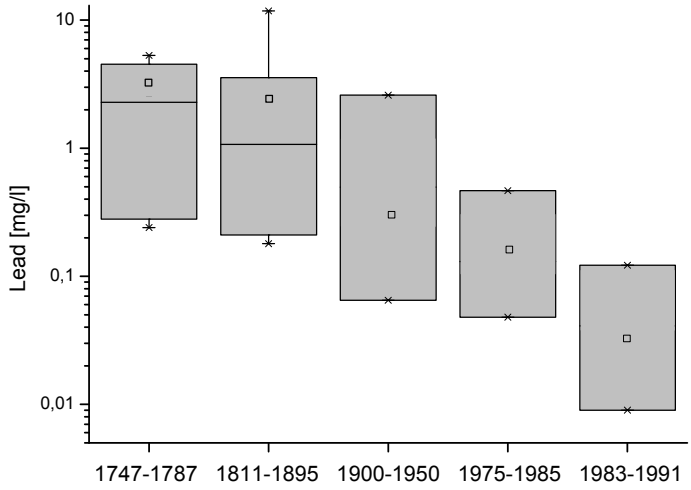
In a recent study, the contents of lead in wine were found to be very low (< 87 μg/L) in all samples. The mean values of lead in red wines (30 μg/L) were higher than those in white wines (22 μg/L), but there was no significant difference in lead content between red and white wines (Kim, 2004). Tahvonen (1998) reported means of 33 μg/L in white wines and of 34 μg/L in red wines. Previous studies have shown higher values of lead in wines (Sherlock *et al.*, 1986) compared with more recent results; the mean concentrations of lead in red wines were 106 μg/L, while those in white wines were 74 μg/L. Significant differences between red (65.7 μg/L), rosé (49.5 μg/L) and white (38 μg/L) wines were also determined by Andrey *et al.* (1992).

The lead content of wine has tended to decrease over the last few decades. Eschnauer and Ostapczuk (1992) detected a significant reduction in the content of lead in wines of various vintages between the eighteenth and twentieth centuries (see Fig. 1.6). A reduction was also detected in vintages of French wine between 1950 and 1991 (Rosman *et al.*, 1998).

Table 1.22 Lead in alcoholic beverages

Product Country	Year	No. of samples	Concentration (µg/L)		References
			Mean	Range	
Wine					
Argentina	1996	59	69	0–190	Roses *et al*. (1997)
Finland (and imported)	1994	19	No data	7–43	Tahvonen (1998)
France	1747–87	6	2680	240–5290	Eschnauer & Ostapczuk (1992)
France	1811–95	11	2610	180–11800	Eschnauer & Ostapczuk (1992)
France	1900–50	25	497	65–2600	Eschnauer & Ostapczuk (1992)
Germany	1975–85	250	130	48–467	Eschnauer & Ostapczuk (1992)
Germany	1983–91	56	41	9–122	Eschnauer & Ostapczuk (1992)
Germany	1993–94	150	50	4–254	Ostapczuk *et al*. (1997)
Greece	1989	113	230	50–560	Lazos & Alexakis (1989)
Italy	2002	68	No data	10–350	Marengo & Aceto (2003)
Canary Islands, Spain	1995–96	148	28.74	3.89–159.53	Barbaste *et al*. (2003)
Worldwide origin	1975–90	2500	No data	10–785	Kaufmann (1993)
Worldwide origin	1992	867	57.1	3–326	Andrey *et al*. (1992)
Worldwide origin	2000	60	29.16	5.26–87.04	Kim (2004)
Beer					
Brazil	2002	63	37	0–290	Valente Soares & Monteiro de Moraes (2003)
Finland (and imported)	1994	16	No data	2–7	Tahvonen (1998)
Germany	1987	100	1.6	0–15	Donhauser *et al*. (1987)
India	1994	5	13.2	10,4–15,7	Srikanth *et al*. (1995)
United Kingdom	1982–83	201	20	<5–330	Sherlock *et al*., (1986); Smart *et al*. (1990)
United Kingdom	1985–86	146	9.8	<5–85	Smart *et al*. (1990)
Spirits					
Cachaças and international	1998	100	No data	0–600	Nascimento *et al*. (1999)
Sherry brandies, Spain	2000	20	58	8–313	Cameán *et al*. (2000)
Whisky, Scotland	2002	35	3	0–25	Adam *et al*. (2002)

Figure 1.6. Lead concentrations in wine since the eighteenth century (data from Eschnauer & Ostapczuk, 1992)



Médina *et al.* (2000) showed a decrease from about 250 µg/L in the early 1950s to less than 100 µg/L. Kaufmann (1998) reported that the average wine in vintage 1990 contained 55 µg/L lead while the concentration in vintage 1980 was 109 µg/L. Statistical analysis revealed that the vintage and the colour but not the age of the wine were the most significant factors that correlated with the lead content.

The code of practice for the prevention and reduction of lead contamination in foods recommends that lead foil capsules should not be used on wine bottles because this practice may leave residues of lead around the mouth of the bottle that can contaminate wine upon pouring (*Codex alimentarius*, 2004). Currently, wine capsules are made from other materials.

Before leaded gasoline was banned in the 1990s, atmospheric deposition was a main source of lead in wines (Teissedre *et al.*, 1994; Médina *et al.*, 2000). During this period, organolead species from automotive sources were recorded in a series of wine collected in southern France (Lobiński *et al.*, 1994). At present, the contribution of road traffic to the levels of lead in the atmosphere is much smaller than in the past due to the reduction of natural lead content of the combustibles used in car engines (Kim, 2004). Kaufmann (1998) reported that brass (a lead alloy that was widely used in traditional wine cellars) was also a main source of lead contamination of wines. The gradual replacement of brass by stainless steel has resulted in a steady decrease in levels of lead in wine. Nevertheless, the wines produced at present still contain significant amounts of lead, and it is important that all of the sources of this metal be known to enable their removal or minimization (Kim, 2004). Almeida and Vasconcelos (2003) confirmed that marked reductions in the lead content of wines would occur if the sources of lead were removed from the tubes and containers used in the vinification system, particularly by using lead-free welding alloys and small fittings.

The lead contents of beers were negligible, and low values for beer were also reported in earlier studies (Tahvonen, 1998). Donhauser *et al.* (1987) found a mean content of 1.6 µg/L in 100 beer samples. Only three-piece tinplate cans with a soldered body seam, which must have been damaged, contained beer with higher lead values of up to 15 µg/L. The tin-coating of welded cans may also contribute some of the lead. According to Jorhem and Slorach (1987), foods packed in unlacquered welded cans contained substantially more lead than foods conserved in lacquered welded cans. Previously, old equipment was found to be a source of lead in draft-beer samples (Smart *et al.*, 1990). After the elimination of sources of lead contamination such as bronze and brass fittings, successful reduction was observed between two surveys in the United Kingdom (Sherlock *et al.*, 1986; Smart *et al.*, 1990).

(ii) *Cadmium*

Cadmium and cadmium compounds are carcinogenic to humans (Group 1) (IARC, 1993b). In a recent study, the mean contents of cadmium in red wines were higher than those in white wines but without statistically significant differences (Kim, 2004). The data (average, 0.5 µg/L) were in accordance with those reported previously (Table 1.23).

There was no significant difference in lead and cadmium contents of wines with different countries of origin (Kim, 2004). In contrast, Barbaste *et al.* (2003) reported significant differences in the mean cadmium content among the three types of wine: the lowest and the highest mean content were found for red and white wines, respectively. These differences may be related to variations in the wine-making process. The wide variability of these data may result from different factors, both natural and exogenous. Natural factors include soil composition and grape variety. Exogenous factors are the fermentation process, the wine-making system, processing aids (filter materials) or different types of contamination (Kim, 2004). The high concentration of cadmium found in some wine samples could be due to the use of pesticides or fertilizers that contained salts of this metal (Mena *et al.*, 1996).

In the samples of beer analysed by Mena *et al.* (1996), the mean concentration of cadmium was 0.21 μg/L. Canned beers contained the highest levels, probably due to the fact that low-quality cans had been used, with values that varied from 0.50 to 0.80 μg/L; lower concentrations were found in draft beers, with a mean value of 0.20 μg/L. In the other alcoholic beverages that were analysed, the highest concentrations were found in brandy (5.31 μg/L) and whisky (3.20 μg/L) samples; the lowest values were found in samples of liquor and anisette (0.13 and 0.04 μg/L, respectively) (Mena *et al.*, 1996).

(iii) *Arsenic*

Arsenic is included in the Group 1 of carcinogens (IARC, 1987).

The mean arsenic content of red wines was significantly lower than that of rosé and white wines (Barbaste *et al.*, 2003). These differences were attributed by Aguilar *et al.* (1987) to the different methods of vinification used for rosé and red wines. Typical arsenic concentrations in alcoholic beverages are shown in Table 1.24.

(iv) *Copper*

The copper contents of alcoholic beverages are summarized in Table 1.25.

Copper may occur in wine because copper alone or formulated with other agrochemicals is an important substance for the prevention of the outbreak of fungal diseases. During fermentation, the concentration of copper in wine may decrease due to sedimentation as insoluble sulfides together with yeasts and lees (García-Esparza *et al.*, 2006). The contents of metals were increased in samples treated with organic or inorganic pesticides. In particular, the use of quinoxyfen, dinocap-penconazole and dinocap considerably increased the copper(II) and zinc(II) contents of white and red wines (Salvo *et al.*, 2003).

In whisky, copper can be traced to two major sources: the copper stills used for distillation and the barley from which the spirit is distilled. However, the use of copper stills mainly determines the amount of copper, and the influence of the raw material can virtually be ignored (3%) (Adam *et al.*, 2002). In Brazilian sugar-cane spirits, the copper content was correlated with the acidity of the distillate and was higher in

Table 1.23 Cadmium in alcoholic beverages

Product Country	Year	No. of samples	Concentration (µg/L)		References
			Mean	Range	
Beer					
Brazil	2002	63	1.6	0–14.3	Valente Soares & Monteiro de Moraes (2003)
Germany	1987	100	0.2	0–6.5	Donhauser *et al*. (1987)
Wine					
Germany	1993–94	150	0.63	0.003–0.98	Ostapczuk *et al*. (1997)
Greece	1989	113	3	0–30	Lazos & Alexakis (1989)
Greece	2000	39	0.3	0.1–0,6	Karavoltsos *et al*. (2002)
Italy	2003	68	No data	0.01–0.95	Marengo & Aceto (2003)
Canary Islands, Spain	1995–96	146	0.63	0.20–1.73	Barbaste *et al*. (2003)
Spain	1995	70	No data	0.1–15.38	Mena *et al*. (1996)
Worldwide origin	1992	219	No data	0.3–6	Andrey *et al*. (1992)
Worldwide origin	2000	60	0.47	0.01–3.44	Kim (2004)
Spirits					
Sherry brandies, Spain	2000	20	6	0–40	Cameán *et al*. (2000)

the tail fractions. Therefore, the copper content may be reduced if the distillation is stopped at a higher alcoholic grade (Boza & Horii, 2000). Another possibility to reduce the copper levels in Brazilian sugar-cane spirits is storage in oak barrels. A significant reduction in copper levels of 74% was observed during 6 months of ageing (Ferreira Lima Cavalheiro *et al.*, 2003).

(v) *Chromium*

The amounts of chromium in Spanish wines varied widely, and differences in the chromium contents of red (32.5 g/L) and white (19.5 µg/L) wines have been reported (Lendinez *et al.*, 1998). Cabrera-Vique *et al.* (1997) found levels of chromium that ranged from 6.6 to 90.0 µg/L in French red wines (mean, 22.6 µg/L), from 6.6 to 43.9 µg/L in French white wines (mean, 21.3 µg/L) and from 10.5 to 36.0 µg/L in champagne (mean, 25.1 µg/L). On the basis of analyses of different vintage wines from the same vineyard and winery, it was suggested that concentrations of chromium significantly increase with the age of the wine. Italian wines contained 20–50 µg/L chromium (Marengo & Aceto, 2003) and Greek wines contained 0.01–0.41 mg/L chromium (Lazos & Alexakis, 1989).

Table 1.24 Arsenic in alcoholic beverages

Product Country	Year	No. of samples	Concentration (µg/L)		References
			Mean	Range	
Beer					
Croatia	1988–93	70	1	0–8	Sapunar-Postružnik *et al.* (1996)
Germany (and imported)	1987	100	6.4	0–102.4	Donhauser *et al.* (1987)
Spain	1999	21	8.3	1.5–28.4	Herce-Pagliai *et al.* (1999)
Wine					
Croatia	1988–93	82	0.8	0–6	Sapunar-Postružnik *et al.* (1996)
Italy	2003	68	No data	0.04–0.80	Marengo & Aceto (2003)
Spain	1995–96	148	3.13	0.58–8.45	Barbaste *et al.* (2003)
Spain	2002	45	8.3	2.1–14.6	Herce-Pagliai *et al.* (2002)
Spirits					
Sherry brandies, Spain	2000	20	13	0–27	Cameán *et al.* (2000)

Table 1.25 Copper in alcoholic beverages

Product Country	Year	No. of samples	Concentration (mg/L)		References
			Mean	Range	
Wine					
Germany	1993–94	150	0.250	0.050–0.394	Ostapczuk *et al.* (1997)
Greece	1989	113	0.23	0–1.65	Lazos & Alexakis (1989)
Italy	2002	68	No data	0.001–1.34	Marengo & Aceto (2003)
Italy	2003	34	0.71 (red) 1.01 (white)	No data	García-Esparza *et al.* (2006)
Worldwide origin	1992	250	0.228	No data	Andrey *et al.* (1992)
Spirits					
Cachaças and international	1998	100	No data	0–14.3	Nascimento *et al.* (1999)
Sherry brandies, Spain	2000	20	1.42	0.30–5.31	Cameán *et al.* (2000)
Sugar-cane, Brazil	2001	20	2.56	0.04–9.2	Bettin *et al.* (2002)
Whisky, Scotland	2002	35	0.48	0.1–1.7	Adam *et al.* (2002)

Significant differences were also observed among beer samples; in which the chromium content ranged from 3.94 to 30.10 µg/L. Canned and draft beers had the highest values, and lower concentrations were found in bottled beers. Among other alcoholic beverages, mean concentrations of chromium ranged from 7.50 µg/L in rum to 24.45 µg/L in anisette. The highest values were obtained for beverages that contained sugar (Lendinez *et al.*, 1998). The average chromium content of 100 German beers was given as 7.5 µg/L (range, 1–42 µg/L) (Donhauser *et al.*, 1987). Danish beers had a mean chromium concentration of 9 µg/L (range, < 2–32 µg/L) (Pedersen *et al.*, 1994). Fifty-two samples of Brazilian cachaça contained chromium at concentrations of 0.64–1.53 µg/L (Canuto *et al.*, 2003). A large variation in chromium levels from undetectable to 520 µg/L was reported in an international selection of beverages (Nascimento *et al.*, 1999).

(vi) *Other metals*

Selenium was determined in sweet and dry bottled wines from Spain; the concentration varied between 1.0 and 2.0 µg/L in sweet wines and between 0.6 and 1.6 µg/L in dry wines (Frías *et al.*, 2003). Another survey of Spanish beverages showed 0.15–0.38 µg/L selenium in wine (mean, 0.26 µg/L) and 0.89–1.13 µg/L in beer (mean, 1.007 µg/L) (Díaz *et al.*, 1997). The mean selenium concentration of 100 German beers was 1.2 µg/L (range, < 0.4–7.2 µg/L) (Donhauser *et al.*, 1987).

Concentrations of *mercury* ranged from 2.6 to 4.9 µg/L in sweet Spanish wines and from 1.5 to 2.6 µg/L in dry Spanish wines (Frías *et al.*, 2003). Mercury was detected in only two of 100 German beers at concentrations of 0.4 and 0.8 µg/L (Donhauser *et al.*, 1987). In wine and beer on the Danish market, all samples analysed for mercury were below the detection limit of 6 µg/L (Pedersen *et al.*, 1994).

Antimony levels in 52 samples of cachaça from Brazil varied from undetectable to 39 µg/L (Canuto *et al.*, 2003). Italian wines contained antimony at concentrations in the range of 0.01–1.00 µg/L (Marengo & Aceto, 2003).

Nickel concentrations in beverages on the Danish market have been reported. Average nickel contents were 49 µg/L in red wine, 42 µg/L in white wine, 93 µg/L in fortified wine and 23 µg/L in beer (Pedersen *et al.*, 1994). Italian wines contained 15–210 µg/L nickel (Marengo & Aceto, 2003) and Greek wines contained 0–0.13 mg/L (Lazos & Alexakis, 1989). Whisky contained 0.002–0.6 mg/L nickel (Adam *et al.*, 2002).

Iron concentrations in sugar-cane spirits from Brazil ranged between 0.01 and 0.78 mg/L with an average of 0.21 mg/L (Bettin *et al.*, 2002). The iron concentration in whisky varied considerably between 0.02 and 28 mg/L (Adam *et al.*, 2002). The large variance in iron levels in spirits was confirmed by Nascimento *et al.* (1999) (range, 0.009–2.24 mg/L) and Cameán *et al.* (2000) (range, not detected–2.03 mg/L). Wine contained concentrations of iron in a range of 1.35–27.8 mg/L (Marengo & Aceto, 2003) or 0.70–7.30 mg/L (Lazos & Alexakis, 1989).

Zinc was determined in 251 wine samples on the Swiss market, with a mean concentration of 614 µg/L (Andrey *et al.*, 1992), in Italian wine which had a range of

0.135–4.80 mg/L (Marengo & Aceto, 2003) and in Greek wines which had a range of 0.05–1.80 mg/L (Lazos & Alexakis, 1989). The concentrations of zinc in whisky ranged between 0.02 and 20 mg/L (Adam *et al.*, 2002). Various spirits contained concentrations of zinc between not detectable and 0.573 mg/L; manganese, cobalt and nickel were found in ranges of 0.002–0.657 mg/L, 0.003–0.063 mg/L and 0.001–0.684 mg/L, respectively (Nascimento *et al.*, 1999). Sherry contained zinc (0–0.829 mg/L), manganese (0–0.157 mg/L) and aluminium (0.02–1.37 mg/L) (Cameán *et al.*, 2000).

Thallium was regularly found in very low quantities in wine; red wines contained 0.2 μg/L, which was about half that in white wine (Eschnauer *et al.*, 1984). With a detection limit of 10 μg/L, thallium could be detected in none of 700 wines of worldwide origin (Kaufmann, 1993). More sensitive analyses showed a range of 10–95 ng/L thallium in Italian wine (Marengo & Aceto, 2003).

Only limited data are available on alkali metals and alkaline earth metals in alcoholic beverages. Wine was found to contain lithium (0.008–0.045 mg/L), sodium (3.4–200 mg/L), potassium (750–1460 mg/L), calcium (30–90 mg/L) and magnesium (70–115 mg/L) (Marengo & Aceto, 2003). Another study of wine reported the presence of lithium (0–0.09 mg/L), sodium (5.5–150 mg/L), potassium (955–2089 mg/L), calcium (14–47.5 mg/L) and magnesium (82.5–122.5 mg/L) (Lazos & Alexakis, 1989). Sodium (2–24 mg/L), calcium (0.5–4 mg/L) and magnesium (0.02–4 mg/L) were determined in whisky by Adam *et al.* (2002). In a survey of 100 spirits, lithium (0.004–1.26 mg/L), sodium (0.612–94.3 mg/L), potassium (0.34–31.3 mg/L), magnesium (0.40–80.7 mg/L) and calcium (1.36–44.6 mg/L) were detected (Nascimento *et al.*, 1999). Sherry brandies contained sodium (17.8–635 mg/L), potassium (0.11–70.06 mg/L), calcium (0–14.8 mg/L) and magnesium (0.19–11.2 mg/L) (Cameán *et al.*, 2000).

Further elements determined in Italian wines include aluminium, boron, iodine, phosphorus, rubidium, silicone, strontium and tin in the milligram per litre range, barium, beryllium, cerium, cesium, cobalt, gallium, germanium, lanthanum, neodymium, palladium, tellurium, tungsten, vanadium, yttrium and zirconium in the microgram per litre range and dyprosium, erbium, europium, gadolinium, hafnium, holmium, molybdenum, nobelium, praseodymium, rhodium, samarium, terbium, thorium, thulium, titanium, uranium and ytterbium in the nanogram per litre range (Marengo & Aceto, 2003).

(vii) *Inorganic anions*

The fluoride content of alcoholic beverages was found to be very variable. The mean concentration ranged from 0.06 to 0.71 mg/L in beer available in the United Kingdom. Ciders contained a mean of 0.086 mg/L fluoride and wines a mean of 0.131 mg/L fluoride (Warnakulasuriya *et al.*, 2002).

(viii) *Organometals*

Organolead compounds are not classifiable as to their carcinogenicity to humans (Group 3) (IARC, 2006).

As mentioned previously, organolead contamination in wine from automotive sources has rapidly decreased due to the use of unleaded fuel since the 1980s (Lobiński *et al.*, 1994; Teissedre *et al.*, 1994); only limited information is available on the presence of organometals in other alcoholic beverages. Organotin residues in wine and beer could result from the use of organotin pesticides, contaminated irrigation water or the use of non-food-grade polyvinyl chloride products in storage or production facilities (Forsyth *et al.*, 1992a,b). A preliminary survey of wines and beers on the Canadian market indicated that butyltins are the principal organotin contaminants present in these products. Very low levels of phenyl- and cyclohexyltin compounds were detected in both wine and beer (Forsyth *et al.*, 1992a). In a larger survey, 29 of 90 wines (32%) came out positive for organotin compounds. Dibutyltin (23%) and monobutyltin (16%) were the predominant species. Tributyltin, monooctyltin and dioctyltin were found in single instances (Forsyth *et al.*, 1994). In 44 samples of Chinese and international alcoholic beverages, the amounts of monobutyltin and dibutyltin ranged from < 0.016 to 5.687 and from < 0.0022 to 33.257 μg/L, respectively. Tributyltin concentrations were much lower, with a highest level of 0.269 μg/L (Liu & Jiang, 2002).

Organic arsenic species were studied in beer and wine (Herce-Pagliai *et al.*, 1999, 2002). In table wines and sherry, the percentages of total inorganic arsenic were 18.6 and 15.6% lower than those of the organic species; dimethylarsinic acid and monomethylarsonic acid were the predominant compounds, respectively. In most wine samples, dimethylarsinic acid was the most abundant species, but the total fraction of inorganic arsenic was considerable, and represented 25.4% of the total concentration of the element. In beer, a predominant occurrence of organic arsenic species was determined; the contribution of monomethyl arsonic acid was more significant in alcoholic beers than in alcohol-free beers.

(e) Pesticides

Pesticide residues in grapes, wine and their processing products have recently been reviewed (Cabras & Angioni, 2000). The principal parasites of vines in Mediterranean countries are the grape moth (*Lobesia botrana*), downy mildew (*Plasmopora viticola*), powdery mildew (*Uncinula necator*) and grey mould (*Botrytis cinerea*). To control these parasites, insecticides and fungicides were used and, at harvest time, pesticide residues were found on grapes and could pass into the processed products, depending on the technological processing and the concentration factor of the fruit. The application rates of fungicide were only a few tens of grams per hectare and, consequently, fungicide residues on grapes (cyproconazole, hexaconazole, kresoximmethyl, myclobutanil, penconazole, tetraconazole and triadimenol) were very low after treatment and were not detectable at harvest. Pyrimethanil residues were constant up to harvest, whereas fluazinam, cyprodinil, mepanipyrim, azoxystrobin and fludioxonil showed different disappearance rates (half-lives of 4.3, 12, 12.8, 15.2 and 24 days, respectively). The decay rate of organophosphorus insecticides was very fast with a half-life ranging

between 0.97 and 3.84 days. The residue levels of benalaxyl, phosalone, metalaxyl and procymidone on sun-dried grapes equalled those on fresh grapes, whereas residue levels were higher for iprodione (1.6 times) and lower for vinclozolin and dimethoate (one-third and one-fifth, respectively). In the oven-drying process, benalaxyl, metalaxyl and vinclozolin showed the same residue value in fresh and dried fruit, whereas iprodione and procymidone residues were lower in raisins than in fresh fruit.

The wine-making process begins with the pressing of grapes where pesticides on the grape surface come into contact with the must. After fermentation, pesticide residues in wine were always smaller than those on the grapes and in the must, except for those pesticides that did not show a preferential partition between the liquid and solid phase (azoxystrobin, dimethoate and pyrimethanil) and were present in wine at the same concentration as that on the grapes. In some cases (mepanipyrim, fluazinam and chlorpyrifos), no detectable residues were found in the wines at the end of fermentation. Comparison of residues in wine obtained by vinification with and without skins showed that their values generally did not differ. Among the clarifying substances commonly used in wine, charcoal completely eliminated most pesticides, especially at low levels, whereas the other clarifying substances were ineffective. The use of pesticides according to good agricultural practice guaranteed no residues, or levels lower than maximum residue limits at harvest.

Wine and its by-products (cake and lees) are used to produce alcohol and alcoholic beverages by distillation. Fenthion, quinalphos and vinclozolin passed into the distillate from the lees only if present at very high concentrations, but with a very low transfer percentage (2, 1 and 0.1%, respectively). No residue passed from the cake into the distillate, whereas fenthion and vinclozolin passed from the wine, but only at low transfer percentages (13 and 5%, respectively) (Cabras & Angioni, 2000).

The status of pesticide residues in grapes and wine in Italy has been reviewed (Cabras & Conte, 2001). The Italian Ministry of Health reported that, of 1532 grape samples analysed from 1996 to 1999, 1.0, 0.9, 1.8 and 1.9% in each year, respectively, were contaminated. The Italian National Residue Monitoring Programme found that, of 481, 1195 and 1949 grape samples analysed in 1996, 1998 and 1999, 7.9, 6.5 and 2.5%, respectively, were contaminated, while no residues were detected in 259 wine samples. Of the 846 grapes samples and 190 wine samples collected by the National Observatory on Pesticide Residues in 1998 and 1999, a total of 6.1 and 2.1%, respectively, of grapes and 0% of all wine samples were found to contain residues. The low incidence of pesticides in wine was explained by the combined effect of technological processes that lead to a decrease in residues and the fact that large wineries collect grapes from farmers who use different pesticides. Mixing these different grape batches causes a decrease in residues by dilution.

A total of 92 commercial Greek and Yugoslavian wine samples were screened for residues of 84 pesticides. No residues were detected in any of the wine samples from either country (Avramides *et al.*, 2003).

A total of 51 samples of wines imported in Germany (from Spain, Chile and South Africa) were analysed for residues of 27 pesticides. Overall, vinclozolin was detected in 80%, methidathion, captan, quintozene, iprodione and dichlofluanid were detected in 33–61% and tetradifon was found in 6% of the samples. Other pesticides were not detected in any sample. The wine samples from Spain contained no iprodione, but often contained quintozene and methidathion. South African wines contained no methidathion. All Spanish and South African wines, but only 68% of Chilean wines, contained vinclozolin. Most pesticides occurred more commonly in red than in white wines (Pietschman *et al.*, 2000).

A recent survey of pesticide residues in wines on the Swiss market was reported by Edder and Ortelli (2005); 176 wines from conventional cultures were analysed and residues were found in 95% of the samples, which indicated that pesticide treatments were frequently used. Approximately 25 active substances used as fungicides or insecticides were detected. For example, the fungicide fenhexamid was present in 61% of the samples at a maximum concentration of 0.59 mg/L and a Swiss maximum residue level of 1.5 mg/L. The following pesticides were found in less than 5% of the samples: spiroxamine, procymidone, diethofencarb, benodanil, chlorothalonil, cyproconazole, tebufenozide, metalaxyl, spinosad, dimethoate, fuberidazole, oxadixyl, pyrifenox and thiabendazol. The total pesticide residues measured ranged between 1 and 700 μg/L. All samples complied with the legal requirements and none exceeded the maximum residue level. It was observed that Swiss wines are generally more heavily contaminated than imported wines. This was explained by the fact that the climate in Switzerland is more favourable to fungal diseases than that in southern countries. The high level of pesticide residue in Swiss wines was mainly caused by one fungicide, fenhexamide, which is currently one of the fungicides most frequently used in vineyard protection.

Edder and Ortelli (2005) also reported results from 70 organic wines sold on the Geneva area market. Unlike conventional culture, the use of synthetic pesticides is totally forbidden in organic wine growing. Most of the samples were Swiss wines (52), particularly from Geneva producers, and the rest were mostly from France and Italy. Approximately half of the organic wines (33 samples) contained no detectable traces of pesticide residues and 29 samples contained only very low levels (below 10 μg/L). Traces were found, in eight samples, in concentrations ranging between 10 and 34 μg/L. The levels of pesticide residues found in organic wines were much lower than those in conventional wines. Traces below 10 μg/L in organic wines were probably due to environmental contamination.

In beer, pesticide residues may be present in the hops, barley or other cereals that are used as raw materials, and may remain in beer produced from contaminated ingredients. During the first steps (malting, mashing and boiling), pesticides on the barley can pass into the wort in various proportions, depending on the process used, although the removal of material in the form of trub and spent grain tends to reduce the level of contaminants, especially pesticides, that are often relatively insoluble in water. Recent research showed that dinitroaniline herbicide residues (pendimethalin and trifluralin)

practically disappeared (< 0.3%) after boiling the wort, whereas the percentages of the remaining insecticides (fenitrothion and malathion) ranged from 3.5 to 4.3%, respectively. No residues of dinitroaniline compounds were detected in young beer, whereas there was a significant reduction in fenitrothion (58%) and malathion (71%) residues during fermentation. Lagering and filtering processes also reduced the content of organophosphorus insecticides (33–37%). After the storage period (3 months), the content of fenitrothion was reduced by 75%, and malathion residues were below the limit of detection (Navarro *et al.*, 2006).

Miyake *et al.* (1999) showed that none of the agrochemicals spiked into hop pellets were detected in beer because of their loss during boiling and fermentation; however, the levels of these agrochemicals were sufficiently high to be detected in beer when they were not lost through these processes. The same was shown for commercially treated hops. Pesticide residues were not found to carry over into the beer at an appreciable level, except for dimethomorph. Nevertheless, the level of residue was still very low relative to the high levels found on the raw commodity. The potential risk of exposure to pesticide from the consumption of beer produced from hops treated with the agrochemicals studied is low (Hengel & Shibamoto, 2002).

(f) Thermal processing contaminants

In recent years, several heat-generated contaminants have been detected in food, including the chloropropanols, acrylamide and furan. The most probable alcoholic beverage to contain these substances is beer because malt, the main ingredient of beer, is manufactured through heating processes (e.g. kilning or roasting). All three groups of contaminants readily dissolve in aqueous foodstuffs such as beer (Baxter *et al.*, 2005a).

The most abundant chloropropanol found in foodstuff is 3-monochloropropane-1,2-diol (3-MCPD) and, to a lesser degree, 1,3-dichloropropan-2-ol; they have been the centre of scientific, regulatory and media attention as they are considered to be carcinogens (Tritscher, 2004). [3-MCPD is genotoxic *in vitro*, but there is no evidence of its genotoxicity *in vivo* (reviewed by Lynch *et al.* (1998).] The Scientific Committee on Food of the European Commission considered a level of 2 µg/kg bw as an allowable daily intake for 3-MCPD (Scientific Committee on Food, 2001).

3-MCPD is not present in lager or ale malts, but is formed when raw or malted cereals are exposed to temperatures above about 120 °C. 3-MCPD is soluble in water, is readily extracted during mashing and can persist into the beer. However, because of the relatively small proportions of specialty products used in the grist, most beers do not contain detectable levels of 3-MCPD. The precursors for 3-MCPD are lipid and chloride, which occur naturally in raw barley in sufficient quantities to allow the formation of 3-MCPD when the grain is heated; no other inputs are involved (Dupire, 2003).

3-MCPD was found in nine of 24 malt products analysed from food suppliers in the United Kingdom at concentrations above 0.01 mg/kg. Significantly, 3-MCPD was only found in coloured malts, and the highest levels were found in the most intensely

coloured samples. Additional heat treatments, which include heavy kilning or roasting, were assumed to be a significant factor in the formation of 3-MCPD in malt (Hamlet *et al.*, 2002). Breitling-Utzmann *et al.* (2003) analysed a series of German pale and dark brewing malts and malt flours. In the malt flours and the pale brewing malts, only trace amounts of 3-MCPD could be detected, whereas dark brewing malt contained 247 µg/kg 3-MCPD. However, 3-MCPD was not found at levels above 10 µg/kg in lightly or darkly coloured types of beer. The fact that 3-MCPD can react with other food ingredients such as alcohol, aldehydes or acids was given as the reason for the low concentrations in beer. Recent tests by Baxter *et al.* (2005a) found no 3-MCPD in 55 beers in the United Kingdom, with a quantification limit of 10 µg/L.

3-MCPD can occur in foods and food ingredients either as a free compound or esterified with higher fatty acids. Svejkovská *et al.* (2004) reported concentrations of free and bound 3-MCPD in Czech malts. A light malt sample (Pilsner type) contained a free 3-MCPD level of about 0.01 mg/kg and a bound 3-MCPD level of less than 0.05 mg/kg. A sample of dark malt had a free 3-MCPD level of about 0.03 mg/kg, while the bound 3-MCPD level reached 0.58 mg/kg.

Similar to 3-MCPD, highest levels of acrylamide were found in specialty malts. Acrylamide is formed in association with Maillard reactions that occur at two main stages in the malting and brewing process: during wort boiling and in the manufacture of specialty malts, which are made by the caramelization of green malts (Baxter *et al.*, 2005a).

Acrylamide is probably carcinogenic to humans (Group 2A) (IARC, 1994). Precursors of acrylamide formation (free sugars and amino acids) are generated during the 'stewing' phase of crystal malt manufacture, and acrylamide has been detected in these types of specialty malt (Baxter *et al.*, 2005a). Studies using a pilot scale roaster have identified heating conditions that produce crystal malts with significantly lower concentrations of acrylamide without increasing levels of 3-MCPD (Baxter *et al.*, 2005b).

There are only few reports on acrylamide contents in beer. Spiking experiments revealed that acrylamide remained stable in beer (Hoenicke & Gatermann, 2005). Tareke *et al.* (2002) analysed three beer samples from the Swedish market. All samples had acrylamide concentrations below the detection limit of 5 µg/kg. Gutsche *et al.* (2002) analysed 11 German beers and found that only one wheat beer had a detectable acrylamide concentration of 72 µg/kg. Dupire (2003) reported that acrylamide is found in many beers although at much lower concentrations than in other foods. There was a pronounced association with beer colour; little or no acrylamide was detected in either the very palest or the darkest beers, but higher levels were found in beers of intermediate colour. No beers tested contained more than 10 µg/kg. No acrylamide could be detected in ale or lager malt, or in very dark roasted barleys or malts. However, specialty products such as amber and crystal malts did contain significantly higher levels. It appeared that acrylamide is degraded or lost at higher roasting temperatures.

Furan, a very volatile and colourless liquid, has been classified by the IARC as a possible human carcinogen (Group 2B) (IARC, 1995).

EFSA (2004) reported furan concentrations between 5 and 13 μg/kg in six beer samples. Baxter *et al.* (2005a) found equally low levels in a range of beers; the maximum concentration detected was below 20 μg/L. The low levels of furan in beer, together with a lack of correlation with beer colour, suggest that much of the furan present in the raw materials is lost during brewing due to its high volatility.

Despite the relatively low concentrations of all three classes of thermal processing contaminants in beer, Baxter *et al.* (2005a) observed that beer could still make a significant contribution to dietary exposure because of the high volume of its consumption.

(g) Benzene

Benzene is carcinogenic to humans (Group 1) (IARC, 1987). Benzene has been reported in carbonated drinks due to contaminated industrial carbon dioxide. Because relatively low levels of carbonation are used in beer and since there is an indigenous source of carbon dioxide from the fermentation process, the average level of benzene found in products due to the use of contaminated gas was below 10 μg/L and did not exceed 20 μg/L (Long, 1999). In the presence of ascorbic acid and the preservative sodium benzoate, benzene might be formed under certain conditions (Gardner & Lawrence, 1993). Contamination of soft drinks with benzene was recently reported (Hileman, 2006). In mixtures of alcoholic beverages and soft drinks (e.g. alcopops, shandy), contamination with benzene may occur; however, the Working Group noted an absence of studies on this topic.

(h) Miscellaneous contaminants

Several contaminants have been found in single cases in alcoholic beverages. Due to a lack of systematic surveys, the relevance of these contaminants cannot be evaluated.

Monostyrene that may derive from polyester tanks was determined in 168 wines originating from 12 countries. The maximum level found was 7.8 μg/L. In 29% of all products, no monostyrene could be detected (Hupf & Jahr, 1990).

Contamination with polydimethylsiloxanes (0.15–0.35 mg/kg) was detected in four brands of Italian wine (Mojsiewicz-Pieńkowska *et al.*, 2003).

Traces of halogenated acetic acids in beers and wines may arise if the equipment is not cleaned diligently after use of such disinfectants (Gilsbach, 1986; Fürst *et al.*, 1987).

Analysis of nine beer and two wine samples showed the presence of the polycyclic aromatic hydrocarbons (PAH) benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, benz[*ghi*]perylene and indeno[1,2,3-*cd*]pyrene and, in some cases, traces of fluoranthene, benz[*a*]anthracene and dibenz[*a*,*h*]anthracene. Total contents of PAHs ranged from trace amounts to 0.72 μg/kg (Moret *et al.*, 1995). PAHs were also present in 18 brands of whisky. Concentrations of the indicator carcinogen benzo[*a*]pyrene were 0.3–2.9 ng/L (Kleinjans *et al.*, 1996). The sum of the analysed PAH concentrations

in 26 aged alcoholic beverages ranged from zero for a white wine to 172 ng/L for a 'brandy de Jerez solera'. Benzo[*a*]pyrene was found at concentrations below 10 ng/L (García-Falcón & Simal-Gándara, 2005).

1.7 Biomarkers, biomonitoring and aspects of survey measurement

In the following, two aspects of the measurement of alcohol are highlighted that are particularly relevant to epidemiological assessment of alcoholic beverage consumption: the use of biomarkers and the assessment of lifetime exposure. For a recent overview of other aspects of measurement, see Gmel and Rehm (2004).

1.7.1 *Biomarkers and biomonitoring*

(a) Blood alcohol concentration

No laboratory test is sufficiently reliable alone to support a diagnosis of alcoholism. Sensitivities and specificities vary considerably and depend on the population concerned. The merits and limitations of traditional and newer biomarkers for alcohol abuse (and abstinence) have been examined critically and reviewed (Sharpe, 2001; Musshoff, 2002).

Some conventional biomarkers are described briefly below (Sharpe, 2001).

(b) Ethanol in body fluids

Measurement of alcohol concentrations in blood, urine and breath has a limited, but important role. The results provide no information regarding the severity of alcohol drinking but, when positive, do give objective evidence of recent drinking and can identify increased tolerance.

(c) Serum γ-glutamyl transferase

Serum γ-glutamyl transferase (γGT) activity is increased in the serum of patients with hepatobiliary disorders and in individuals with fairly heavy consumption of alcohol. Serum levels of γGT have been found to be elevated in about 75% of individuals who are alcohol-dependent, with a range in sensitivity of 60–90%. In the general population, progressively higher serum γGT activities are associated with levels of alcohol consumption. Elevated serum γGT is found in 20% of men and 15% of women who consume ~40 g alcohol per day and in 40–50% of men and 30% of women who drink more than 60 g/day. γGT is primarily an indicator of chronic consumption of large amounts of alcohol and is not increased by binge drinking in non-alcohol abusers, unless there is concomitant liver disease. The half-life of γGT is between 14 and 26 days and its level usually returns to normal in 4–5 weeks after drinking ceases. As well as low sensitivity in some clinical situations, one of the major drawbacks to γGT as a marker of excessive alcohol consumption is its lack of specificity, which can vary

from 55 to 100%. Numerous other disorders and drugs can elevate γGT and produce false-positive results, including biliary tract disease, non-alcoholic liver disease, obesity, smoking, *diabetes mellitus*, inflammation and antidepressants. Although γGT is not an ideal screening marker, it is useful in the confirmation of a clinical suspicion of alcoholism.

(d) Serum transaminases

Aspartate aminotransferase (AST) and alanine aminotranferase (ALT) concentrations in serum are often higher in patients who are alcoholics, although generally not more than 2–4 times the upper normal limits; sensitivities are 25–60% for AST and 15–40% for ALT. Serum levels depend markedly on the degree of liver damage and how recently alcohol has been consumed. Acute alcohol intakes of 3–4 g/kg body weight (bw) can lead to a moderate transient increase in AST in healthy subjects within 24–48h. The AST:ATL ratio improves the test: a ratio > 1.5 strongly suggests, and a ratio > 2.0 is almost indicative of, alcohol-induced damage of the liver. One study has shown that the AST:ALT ratio is the best of several markers to distinguish between alcohol-induced and non-alcoholic liver diseases.

(e) Mean corpuscular volume

An increased mean corpuscular volume (MCV) follows chronic heavy alcohol drinking and correlates with both the amount and frequency of alcohol ingestion, but it may take at least 1 month of drinking more than 60 g alcohol daily to raise the MCV above the reference range. It then takes several months of abstinence for MCV to return to normal. The main weakness of MCV is its low sensitivity (40–50%), but its specificity is high (80–90%) and very few abstainers and social drinkers have elevated MCV values.

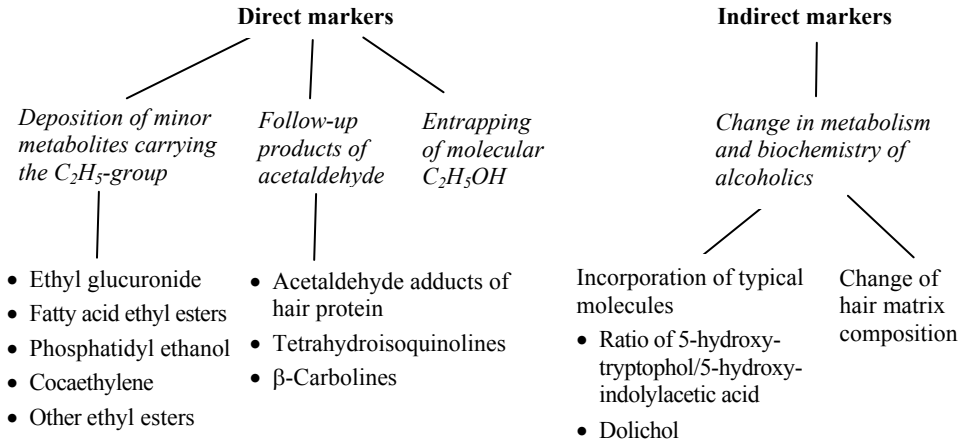
(f) Lipids

Although increased high-density lipoprotein cholesterol or triglycerides can raise suspicion of excessive alcoholic beverage consumption, neither has sufficient sensitivity or specificity to be of use in diagnosis and monitoring.

The conventional marker γGT continues to be the test that combines greatest convenience and sensitivity. Its diagnostic accuracy can be enhanced by combination with other traditional markers such as AST, ALT and MCV (Sharpe, 2001).

The development in chromatographic techniques has enhanced the possibilities for the determination of new and innovative biomarkers of alcohol abuse. New tests have been shown to be useful not only to indicate previous ethanol ingestion, but also to approximate intake and the time when ethanol ingestion has occurred. For such purposes, the determination of ethyl glucuronide in serum or urine samples, the analysis of 5-hydroxytryptophol in urine or the analysis of fatty acid ethyl esters appear to be useful (Musshoff, 2002). These new markers could also be detected in hair (Fig. 1.7).

Figure 1.7. Possible markers of chronically elevated alcohol consumption in hair



From Pragst *et al*. (2000)

A well known advantage of hair analysis is that compounds with a relative short lifetime in blood can be entrapped and are detectable for a long time and at a relatively high concentration in this sample material; hair analysis could provide a good test for the measurement of alcohol consumption (Pragst *et al.*, 2000)

1.8 Regulations on alcohol

1.8.1 *Regulations on the composition of alcoholic beverages*

The *Codex alimentarius* was created in 1963 by FAO and WHO to develop international food standards and guidelines. For alcoholic beverages, the Codex Standards for food additives (*Codex alimentarius*, 2006), for natural flavourings (*Codex alimentarius*, 1987) and contaminants (*Codex alimentarius*, 1997) are of special interest. These standards are discussed in detail in Sections 1.6.6 and 1.6.7. In general, the standards provide some information about suitable additives for alcoholic beverages with maximum levels for certain substances. Maximum levels are also given for certain biologically active substances in natural flavourings. Due to advances in food production and surveillance, the concentrations of some contaminants (e.g. nitrosamines in beer, lead in wine) have been significantly reduced over the past years (see Section 1.6.7 for details). The standards have been incorporated into the national legislation of the majority of countries. However, some countries may impose more specific or more stringent regulations. For example, the European Union has published detailed regulations for food additives and even defines certain categories of spirits such as whisky, rum and vodka (European Council, 1989).

1.8.2 *Regulations on alcoholic beverage consumption*

The available data on regulations for alcoholic beverages for the majority of the WHO Member States have been reviewed by the Global Status Report: Alcohol Policy (WHO, 2004), and the following brief discussion relies mainly on that report.

Regulations for alcoholic beverages are often referred to as alcohol policy or alcohol control policy. Alcohol policy can be defined as measures put in place to control the supply and/or affect the demand for alcoholic beverages, minimize alcohol-related harm and promote public health in a population. This includes education and treatment programmes, alcohol control and harm-reduction strategies. To alleviate or mitigate the burden of alcoholic beverages on societies, most countries have employed some strategies across time to limit or regulate alcoholic beverage consumption and the distribution of alcoholic beverages. Some of these measures have been due to public health concerns, and others have been based on religious considerations or quality control of products, or have been introduced to eliminate private-profit interest or increase government revenue. The different measures can be broadly divided into three main groups: population-based policies, problem-directed policies and direct interventions. The first group are policies that are aimed at altering levels of alcoholic beverage consumption among the population as a whole. They include taxation,

advertising, availability controls (from prohibition to state monopolies, regulations on density of outlets, hours and days of sale), drinking locations, minimum drinking age limits, health-promotion campaigns and school-based education. The second group of policies are aimed at specific alcohol-related problems such as drinking and driving (e.g. promoting random breath testing) or alcohol-related offences. The third group are interventions that are aimed at individual drinkers and include brief interventions, treatment and rehabilitation programmes.

Countries emphasize various policies differently, since each country is unique in its needs and requirements, but there is mounting evidence that strategies are available which clearly impact levels and patterns of alcoholic beverage drinking in a population when implemented with sufficient popular support and continuously enforced. Over the past 20 years, considerable progress has been made in the scientific understanding of the relationship between alcohol policies, levels of alcoholic beverage consumption and alcohol-related harm. The existing evidence ideally should be the basis for formulating polices that protect health, prevent disability and address the social problems associated with alcoholic beverage consumption.

A study of the alcohol policies of 117 WHO Member States looked at the following areas of alcohol policy: restrictions on availability, drink–driving, price and taxation, advertising and sponsorships, and alcohol-free environments. The following gives some examples of the measures implemented, but it should be noted that the study does not cover all countries (WHO, 2004).

About 15% of countries have retail state monopolies, while 74% have alcoholic beverage licensing requirements to sell or serve alcohol. For off-premises sales, many countries also have restrictions on places of sale (59%) and hours of sale (46%) and, to a lesser degree, on days of sale (27%) and density of the outlets (19%).

Only 18% of countries do not have any age requirements for the purchase and consumption of alcoholic beverages. In the majority of countries, the age limit is set at 18 years (61%).

Seven per cent of countries do not have a legal drink–driving limit in place, while most countries (39%) fall in the middle category of having a blood alcohol concentration level of 0.04–0.06 g/100 mL. Of the countries that have existing drink–driving legislation, 46% have no testing or only test rarely for the sobriety of drivers through random breath testing.

With regard to the pricing of alcoholic beverages, the 118 countries showed great differences; however, with regard to median values of relative prices across the countries, a bottle of wine would cost the same as two bottles of beer and a bottle of spirits the same as two bottles of wine. In general, relative price seems closely related to economic development—the more developed a country is, the lower are the prices relative to the average income. In addition, countries that have large domestic production of a beverage tend to have lower prices for this product.

Countries have banned or restricted the advertisement of alcoholic beverages in different media to a varying degree. Television and radio are more controlled than print

media and billboards, and advertising of spirits is more strictly controlled than that of beer and wine. About 24% of countries restrict sponsorship of youth or sports events by the alcohol industry. In countries where advertising of alcohol is allowed, 33% require a health warning of some sort on the advertisement.

Many countries ban drinking in different public domains such as in educational buildings (58%), health care facilities (55%), government offices (48%), workplaces (47%) and public transport (45%). Less controlled are sporting events (26%), parks/streets (24%) and leisure events such as concerts (16%).

Regulations on alcohol are occasionally beverage-specific. Some countries regulate and tax beer according to its strength—the stronger the beer, the higher the tax and the more strict are regulations, for example, on advertising. In a mainly European context, so called alcopops have received special attention. Media, politicians and public health advocates have called for legal restrictions specifically on alcopops, which have been introduced through increased prices, e.g. in France, Germany and Switzerland. The beverage industry avoids the legal restriction on alcopops by creating new designer drinks such as beerpops that do not fall under the special tax (Wicki *et al*., 2006). In Germany, solid alcopops in powder form were developed to evade the alcopop tax. The alcohol is bound to a sugar matrix and, after dissolution in water, the product contains about 4.8% vol alcohol (Bauer-Christoph & Lachenmeier, 2005).

1.9. References

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