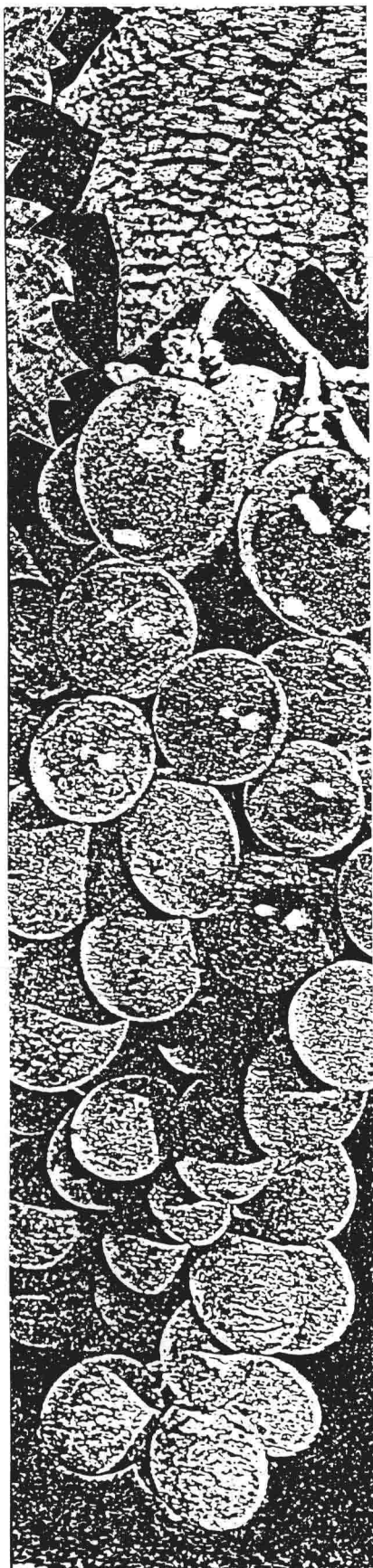


WINE SCIENCE

Principles and Applications



Ron S. Jackson



Wine Science

*Principles
and
Applications*

Ron S. Jackson

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Canada



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the volume.*

The book is dedicated
to the miraculous microbes
that can turn a marvelous fruit
into a seraphic beverage,
and to God, who has given us
the ability to savor its
finest qualities and pleasures.

Preface

The science of wine involves three major interrelated topics: grapevine growth, wine production, and wine sensory analysis. Although in most situations these topics can be covered separately, joint discussion of certain aspects of viticulture, enology, and wine assessment is valuable and reinforces the natural interrelationships of these subjects.

Consistent with modern biological thought, much of wine science is interpretable in terms of physics and chemistry. Because of the botanical nature of the raw materials and their microbial transformation into wine, the physiology and genetics of vine, yeasts, and bacteria are crucial to a current understanding the origins of wine quality. In addition, physical microclimatology and soil physicochemistry are revealing the vineyard origins of grape quality. Finally, knowledge of human sensory psychophysiology is essential to the interpretation of wine quality data. For those more interested in applications, much of the scientific discussion has been placed so that the practical aspects can be accessed without necessarily reading and understanding the scientific explanations.

I hope that this book will help place the present knowledge on these topics in perspective and illustrate where further study is needed. It was not possible in a text of this size to provide a detailed treatment of all the diverging views on the many topics covered. I have therefore presented those views that in my opinion have the greatest support or significance. With much of our information based on a comparatively few cultivars or yeast strains, making valid generalizations is difficult. In addition, several topics are quite contentious among grape growers and wine makers. For some issues, further study

will clarify the topic; for others, personal preference will always be the deciding factor. I extend my apologies to those who may feel that their views have been inadequately represented.

Where no common chemical name is available or currently preferred, IUPAC terminology has been used. For grape cultivar names, single quotes have been used around the name (i.e., 'Pinot noir'), in lieu of the other accepted practice of placing *cv.* before the name to conform to the International Code of Botanical Nomenclature. Except in tables, the current practice of naming rootstock cultivars with a number and the originator's name is used, in lieu of the number and a contraction of the originator's name (i.e., 3309 Couderc versus 3309 C).

A list of suggested readings is given at the end of each chapter to guide further study. Although several are in foreign languages, they are excellent sources of precise information. To have omitted them would have done disservice to those wishing to pursue the topics involved. In addition, references are given in the text where the information is very specific or not readily available in the suggested readings. Further details can be obtained from sources given for the figures and tables.

Wherefore it maye please your . . . gentlines to take these labours in good worthe, not according unto their unworthiness, but accordinge unto my good mind and will, offering and gevinge them unto you.

from William Turner's *Herbal*, 1568

Acknowledgments

Without the astute observations of generations of wine makers and grape growers, and the dedicated research of countless enologists and viticulturalists, this work would have been impossible. Thus, acknowledgment is given to those whose work has not been specifically mentioned. Appreciation also is given to constructive criticism given by W. N. Kliever, C. Belke, W. Koblet, R. M. Pool, T. Henick-Kling, F. Radler, T. C. Somers, R. E. Smart, A. Walker, W. H. N. Paton, E. F. Boller, P. G. Goussard, A. Tekaus, A. Noble, A. Rogosin, and D. Oleson. Gratitude is also expressed to the many researchers, companies, institutes, and publishers who freely donated photographs, data, diagrams, or figures

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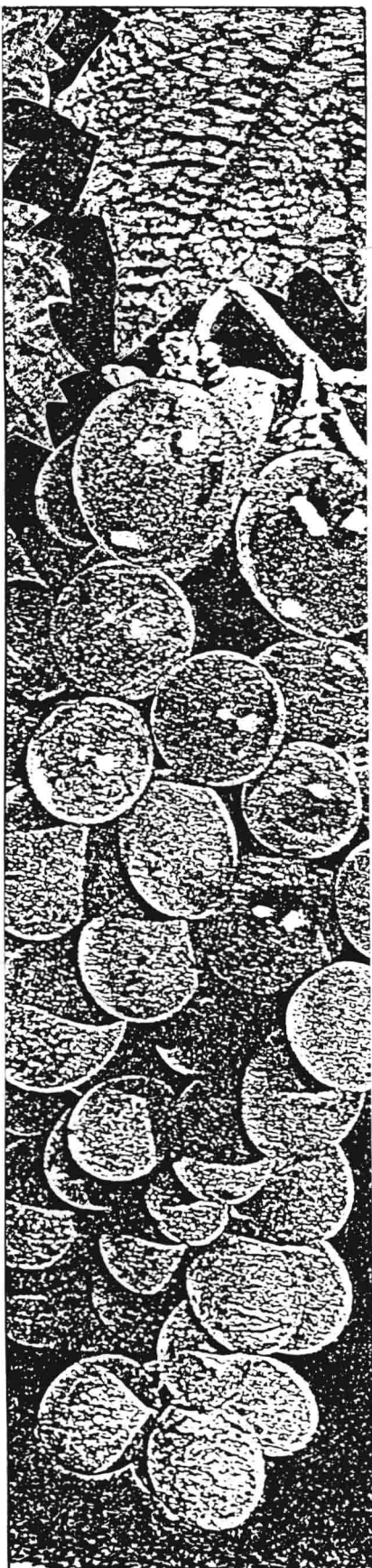
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1

Introduction

Grapevine and Wine Origins

Wine has a recorded history stretching back some 6000 years, with the earliest known wine residues dating from the late fourth millennium B.C. (Badler *et al.*, 1990). Hieroglyphic representations of wine presses some 5000 years old have been dated to the reign of Udimu in Egypt (Petrie, 1923). Most researchers think that the discovery of winemaking, or at least its development, began in southern Caucasia. This area presently includes parts of northwestern Turkey, northern Iraq, Azerbaijan, and Georgia. It also is generally thought that the domestication of the wine grape (*Vitis vinifera*) initially occurred within this area. It is here that the natural distribution of *V. vinifera* most closely approaches the probable origin of Western agriculture (Zohary and Hopf, 1988). Domestication also may have occurred independently in Spain (Núñez and Walker, 1989).

Although grapes readily ferment into wine, the wine yeast (*Saccharomyces cerevisiae*) apparently is not an indigenous member of the grape-skin flora. The natural habitat of the ancestral strains of *Sacch. cerevisiae* may

be the bark and sap exudate of oak trees (Phaff, 1986). If so, the growth of grapevines on oak trees, or the harvesting of both grapes and acorns as food, may have encouraged the inoculation of grapes and grape juice with *Sacch. cerevisiae*. The fortuitous overlap in the distribution of ancestral forms of *Sacch. cerevisiae* and *Vitis vinifera* with the origin of Western agriculture may have fostered the discovery of winemaking, as well as its subsequent development and spread. It may not be pure coincidence that most of the major yeast-fermented beverages and foods (wine, beer, mead, and bread) have their origins in the same Near Eastern regions.

The hypothesis of the Near Eastern origin and spread of winemaking is supported by the remarkable similarity between the words meaning *wine* in most Indo-European languages (see Table 2.1). It is commonly believed that the spread of agriculture into Europe resulted from the dispersion of peoples speaking Proto-Indo-European languages (Renfrew, 1989). In addition, most eastern Mediterranean myths locate the origin of winemaking in northeastern Asia Minor (Stanislawski, 1975).

Unlike the major cereal crops of the Near East (wheat and barley), cultivated grapes develop a high yeast-inoculum by maturity. Piled unattended for several days, grapes begin to self-ferment. On rupturing, the juice is rapidly colonized by the yeast flora, which convert the sugars in the juice into alcohol (ethanol). This is favored by the ability of *Saccharomyces cerevisiae* to grow in acidic grape juice and selectively ferment sugars to ethanol.

The fermentation of grapes into wine is expedited if the grapes are first crushed. Crushing releases and mixes the juice with yeasts on the grape skins. While yeast fermentation is more rapid in contact with air, continued air contact results in the wine turning vinegary. Although unacceptable as a beverage, vinegar probably was a valuable commodity in its own right. As a source of acetic acid, vinegar facilitated pottery production and the preservation (pickling) of perishable foods.

Of the many fruits gathered by ancient humans, only grapes store carbohydrates predominantly as soluble sugars. Thus, the major sources of nutrients in grapes is in a form readily metabolized by wine yeasts. Most other fleshy fruits store carbohydrates as starch and pectins, nutrients not fermentable by wine yeasts. The rapid production of ethanol by *Sacch. cerevisiae* quickly limits the growth of most bacteria and other yeasts in grape juice. Consequently, wine yeasts generate conditions that essentially give them exclusive access to grape nutrients.

Another unique property of grapes concerns the acids they contain. The major acid found in mature grapes is tartaric acid. This acid seldom occurs in other fruits but is commonly found in the leaves and other parts of

plants. Because tartaric acid is seldom metabolized by microbes, fermented grape juice (wine) remains sufficiently acidic to limit the growth of most bacteria and fungi. In addition, the acidity of wine gives it much of its fresh taste. The combined action of grape acidity and the accumulation of ethanol suppresses the growth and metabolism of most wine-spoilage organisms. This is especially true in the absence of air. For ancient humans, the result of grape fermentation was the transformation of a perishable, periodically available fruit into a beverage that could be preserved for several months and had interesting intoxicating properties.

Unlike many crop plants, the grapevine has required little modification to adapt it to cultivation. Its mineral and water requirements are low, permitting it to flourish on soils and hill sites unsuitable for other food crops. Its ability to climb trees and other supports meant it could be grown with little tending in association with other crops. In addition, its immense regenerative potential has allowed it to adapt to intense pruning. Intense pruning turned a trailing climber into a short, shrublike plant suitable for monoculture. The short stature of the shrubby vine minimized the need for supports and may have decreased water stress in semiarid environments. The regenerative powers and woody structure of the vine also have permitted it to withstand considerable winter-kill and still produce reasonable crops in cool climates. This favored the spread of viticulture into central Europe and the domestication of varieties from indigenous grapevines.

The major change that converted wild vines into a domesticated crop was the shift to a bisexual flowering habit. Wild vines are functionally unisexual but often possess both male and female parts. In some instances, conversion to functional bisexuality may have required only the inactivation of a single dominant gene. However, the complexity of sexual differentiation in some cultivars (Carbonneau, 1983) suggests that several independent mutations may have been involved in the development and spread of bisexuality in *Vitis vinifera*. Self-fertile flowers would have significantly improved crop production of vines isolated from insect pollinators and male vines. Although other modifications distinguish wild from domesticated forms of *V. vinifera*, the changes in seed and leaf shape that have been noted are not of obvious selective value (see Chapter 2). The lower acidity and higher sugar content that characterize domesticated forms of *V. vinifera* are not exclusively the properties of domesticated vines.

The evolution of winemaking from an infrequent, haphazard event to a common cultural practice presupposes the development of a settled life-style. A nomadic habit is incompatible with the accumulation of grapes to consistently produce significant quantities of

wine. As wine increasingly became associated with religious rites, the development of a steady supply of wine required the planting of grapevines in or around human settlements. Because grapevines begin to bear a significant crop only after 3 to 5 years, and require several additional years to reach full productivity, such an investment in time and effort would be logical only if the planter lived nearby. Under such conditions, grape collection for winemaking could have initiated the beginning of viticulture. If, as seems reasonable, wine production is dependent on a settled agricultural existence, then significant wine production cannot predate the agricultural revolution. Because grapevines are not indigenous to the Fertile Crescent, where Western agriculture had its origin, the beginnings of winemaking probably occurred after agricultural skills moved north into Caucasia. Present evidence suggests the southern Caucasus region, about 4000 B.C.

From its origins in Caucasia, grape growing and wine-making probably spread southward to Palestine, Syria, Egypt, and Mesopotamia. From this base, wine consumption, and its socioreligious connections, spread winemaking around the Mediterranean. However, new evidence suggests that an extensive system of grape culture already existed in southern Spain several centuries before Phoenician colonization (Stevenson, 1985). Nevertheless, colonization from the eastern Mediterranean is still viewed as the predominant source of grape growing and winemaking knowledge in southern and central Europe. In more recent time, European exploration and colonization have spread grapevine cultivation into most regions of the globe (see Fig. 2.7).

Throughout much of this period, current wine styles either did not exist or occurred in forms considerably different from their present expression. Most ancient wines probably resembled dry to semidry table wines, turning vinegary by spring. Protection from oxidation was generally poor and the use of sulfur unknown or infrequent. Thus, prolonged wine storage probably would have been avoided. However, various techniques were used to extend the drinkable life of some early wines. The addition of pitch (resin) was used by the ancient Greeks and Romans. Its use today is limited to the flavoring of a few wines such as *retsina*. Concentration by heating was occasionally used, as well as the addition of boiled-down grape juice and honey. The famous wines of ancient Greece or Rome, such as those from Chios, Lesbos, and Falernum, have often been thought of as being syrupy due to prolonged evaporation. However, the stoppering of wine amphoras with cork, and the prestige ascribed to aged wine by Roman authors, may require a reassessment of the characteristics of wines appreciated by the ancient Greeks and Romans (Tchernia, 1986). Wine amphoras also may have

been stored upside down, thus keeping the cork wet (Grace, 1979). Amphoras, still cork-sealed and containing wine remnants, have been excavated from the Mediterranean (Cousteau, 1954).

Wines began to take on their modern expressions about the seventeenth century. The widespread use of sulfur in barrel treatment seems to have occurred about this time. This would have greatly increased the likelihood of producing better quality wines and extending their life. Stable sweet wines also started to be produced in the mid 1600s, commencing with the famous Tokaji wines of Hungary.

Before the production of sparkling wine was possible, there had to be the invention of a process for producing strong glass. This development occurred in England in the late 1600s. With the production of bottles able to withstand the high internal pressures generated by trapped carbon dioxide, and the reintroduction of cork as bottle stopper, the stage was set for the rapid development of sparkling wines.

Vintage port production also depended on the production of inexpensive glass bottles. The evolution in bottle shape from bulbous to cylindrical permitted bottles to be laid on their sides. As the cork stayed wet in this position, the wine remained isolated from oxygen and potentially was able to develop a smooth character and complex fragrance. The development of port also depended on the perfection of wine distillation. Distilled spirits needed to be added to the fermenting juice to stop its fermentation prematurely. As a consequence, grape sugars were retained along with sufficient pigment to produce a dark red wine. Modern sherries also require the use of grape spirits. Although alcohol distillation was first developed by the Arabs about the eleventh century A.D., adoption of the technique in Medieval Europe was slow. Thus, most fortified wines are of relatively recent origin.

With mechanization, the widespread adoption of glass bottles for both wine transport and maturation was possible. The reintroduction of cork for stoppers in the seventeenth century provided conditions favorable for the production of modern wine maturation. The discovery by Pasteur in the 1860s of the importance of yeasts and bacteria in fermentation set in motion a chain of events that have produced the incredible range of wines which typify modern commerce.

Commercial Importance of Grapes and Wine

From its simple origins, grape production has developed into the most important fresh fruit crop in the world. Worldwide grape production in 1990 was about 60 million metric tons. That compares with about 52,

46, and 40 million metric tons for oranges, bananas, and apples, respectively (FAO, 1991). The area planted to grapevines in 1990 was estimated at about 8.7 million hectares (21.5 million acres). About 71% of the production was fermented into wine, 27% used as a fresh fruit crop, and the remaining 2% dried for raisins. Use varies widely from country to country, often depending on both the physical and politicoreligious (wine prohibition) climate of the region.

Grape production is largely restricted to climate zones similar to that of the indigenous range of *Vitis vinifera* in Eurasia. This zone approximates the region between the 10° to 20° annual isotherms (Fig. 1.1). Extension into cooler and warmer regions is possible when local conditions modify the climate or viticultural practice compensate for less than ideal circumstances. Commercial production even occurs in subtropical regions, where severe pruning stimulates year-round growth of the vine.

In Europe, where 70% of the world's vineyard hectareage is located, about 77% of the crop is fermented into wine. The latter percentage is slightly less for the world production (71%), owing to the predominant use of grapes as a table or raisin crop in Islamic countries. Since the 1970s, wine production has ranged from about 270 to 370 million hl (85 to 98 million gallons), with recent production levels being about 290 million hl. While Spain has the largest area under grape cultivation, France and Italy produce the largest volumes of wine. Together, France and Italy produce about 45% of the

world's wine but generate about 60% of world wine exports. Statistics on wine production and export for several countries are given in Fig. 1.2. Interestingly, several major wine-producing countries, such as Argentina and the former Soviet Union are little involved in wine export. In contrast, others with comparatively small productions, such as Germany and Australia, are very important in international wine export.

Although many European countries are major wine exporters, they are also the primary wine-consuming countries. For centuries, wine has been a significant caloric food source in the daily diets of many workers in France, Italy, Spain, and other Christian Mediterranean nations. As wine was an integral part of daily food consumption, drinking to excess has not had the tacit acceptance found in some northern portions of Europe. Alcohol abuse, especially in the United States, spawned both the prohibitionist and, now, neoprohibitionist movements. The views of neoprohibitionists that consuming any beverage containing alcohol is detrimental to one's health is in marked conflict with evidence supporting the benefits of moderate wine consumption (Katz, 1981; Rimm *et al.*, 1991; Friedman, 1992). In some countries such as the United States, statements suggesting possible harmful effects from wine consumption may be required on wine labels. The reticence of some governments to accept the beneficial consequences of moderate wine consumption conflicts with the wide and valid use of wine in medicine.

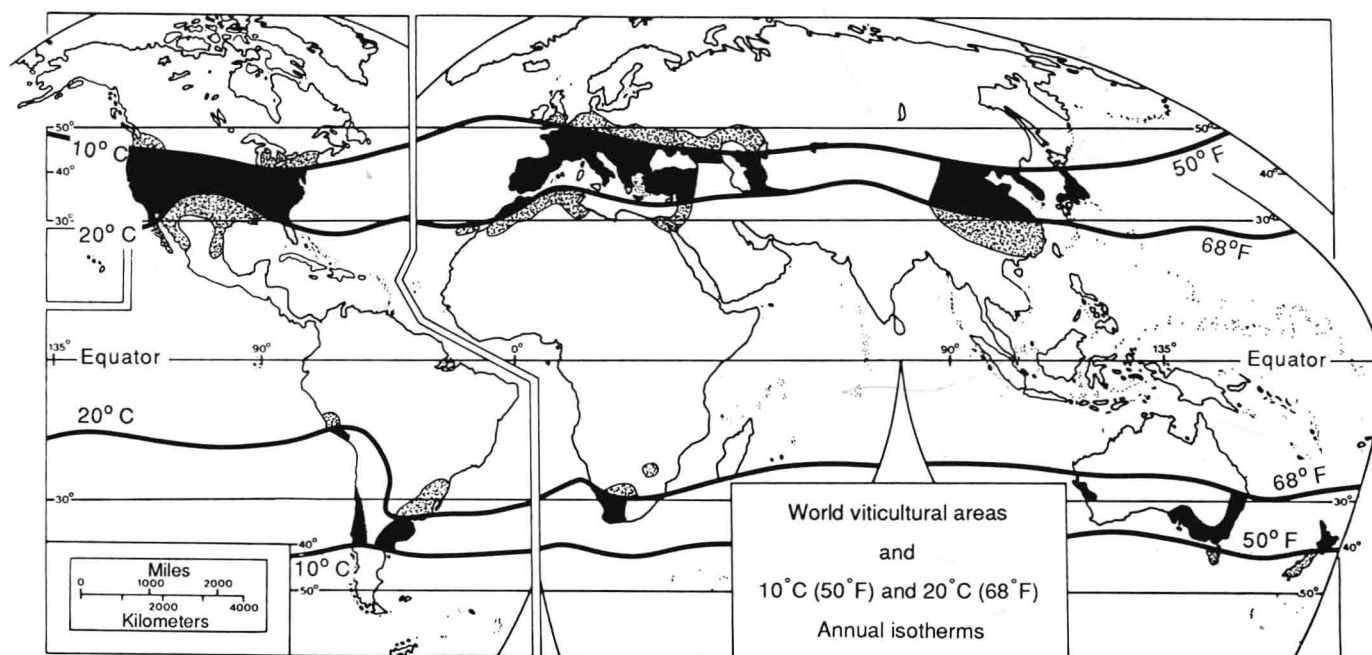


Figure 1.1 Comparison of the major viticultural areas of the world with the distribution of the 10°C (50°F) and 20°C (68°F) annual isotherms. (From de Blij, 1983, reproduced with permission.)

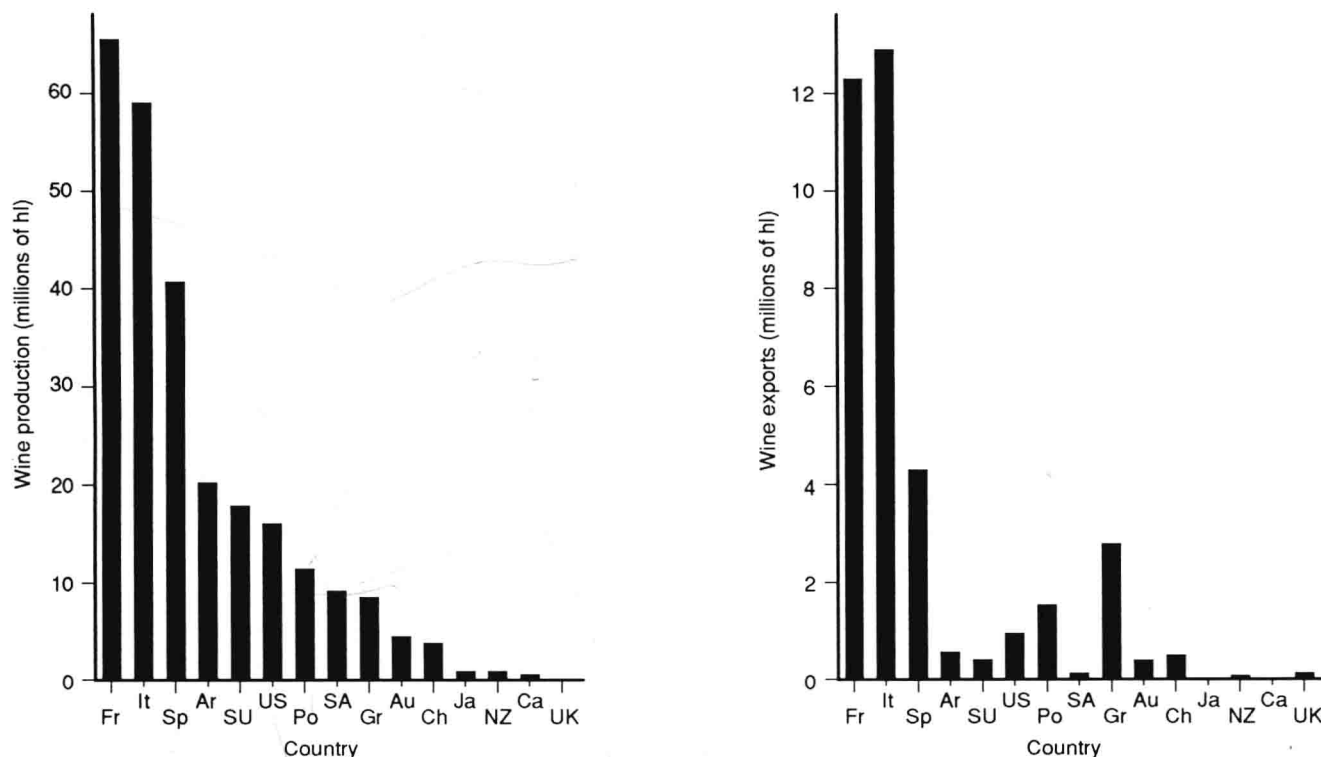


Figure 1.2 Production and export statistics (1990) for several countries: France (Fr), Italy (It), Spain (Sp), Argentina (Ar), Soviet Union (SU), United States (US), Portugal (Po), South Africa (SA), Germany (Gr), Australia (Au), Chile (Ch), Japan (Ja), New Zealand (NZ), Canada (Ca), United Kingdom (UK). (Data from OIV, 1991.)

Except for some New World and Asian countries, per capita consumption of wine is declining (Fig. 1.3). The reasons for these trends are complex and often region-specific. Nevertheless, decline in total consumption has been partially associated with a shift toward the consumption of less but better quality wine. Because of the finer quality of wines, there is less likelihood of their being denigrated as simply an “alcoholic beverage.”

Wine Classification

Except in the broadest sense, there is no generally accepted way of classifying wines. They may be grouped by sweetness, alcohol content, carbon dioxide level, color, grape variety used, fermentation or maturation processes involved, or geographic origin. For taxation purposes, wines often are divided into three basic categories, namely, still wines, sparkling wines, and fortified wines; the latter two typically are taxed at a higher rate. This division recognizes significant differences not only in production but also in use.

Wines commonly are subdivided by geographic origin. In many European countries this is associated with the

traditional use of particular grape cultivars, as well as grapegrowing and winemaking techniques. New World wines may be classified similarly, but few regions have become consistently associated with particular styles. Although use of European regional names, such as Cha-

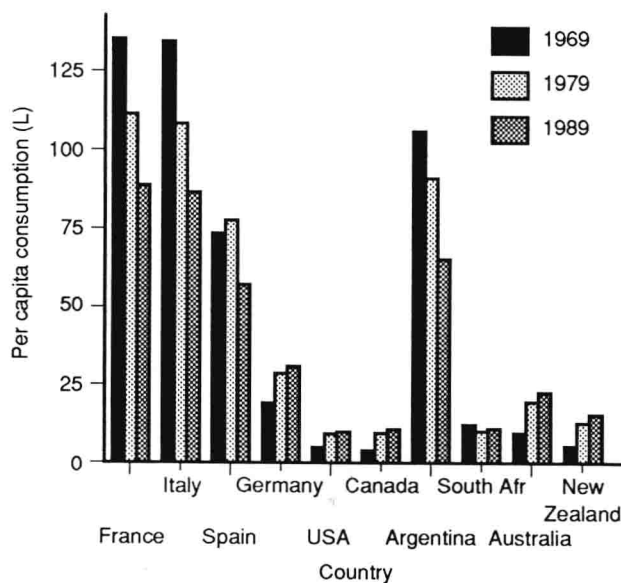


Figure 1.3 Changes in per capita wine consumption in selected countries. (Data from OIV, 1991.)