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EUGENE GARFIELD
INSTITUTE FOR SCIENTIFIC INFORMATION®
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# Enology. Part 1. Fortifying an Ancient Art with Modern Science

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For the past few years, Philadelphia has been experiencing a restaurant "boom"—a renaissance of creative dining establishments.[1,2] In addition to exotic foods prepared in unusual or extravagant ways, a significant part of this gastronomic revolution has been the prominence of wine as a part of the meal and an accompanying increase in interest in types of wines and how they are served.

One of my own favorites is Piesporter, a term that, according to the *Encyclopedia of Wine* by the eminent wine writer Frank Schoonmaker (1905-1976), refers to wines produced in the village of Piesport in the Moselle Valley of the Federal Republic of Germany—although some wines labeled "Piesporter" may come from "less celebrated townships nearby." Schoonmaker described Piesport as "one of the small yet deservedly one of the most famous wine-producing" sites along the Moselle and called genuine Piesporter wine "wonderfully delicate and fragrant, fruity, with an incomparable distinction all its own."[3] A truly great Moselle wine is created by a selection process that involves picking grapes colonized by the "noble mold" *Botrytis cinerea*, which grows naturally on late-harvested grapes and depletes them of their moisture, thus concentrating their inherent sugar and flavor.[4]

As a matter of fact, my preference for Piesporter is even more specific—Piesporter Goldtröpfchen (Golden Drops), of which there are at least a dozen brands that I've encountered. But to paraphrase the American humorist Will Rogers, I never met a Goldtröpfchen I didn't like. These sweet, white wines are about as low in alcohol as you can get in a true wine—if the alcohol content falls much below 7 or 8 percent, the beverage approaches what is now called a "wine cooler," a combination of undistinguished wine and unfermented fruit juice.

The alcohol content of wines varies, of course. In some cases, with grapes that are very high in sugar, alcohol levels may reach 14 percent; others can be as low as 7 percent.[5] (p. 43) The alcohol content of champagne and sparkling wines generally ranges from 10 to 12 percent.[5] (p. 178-90) If the bottle indicates alcohol content above 14 percent, then a neutral brandy has been added (as in port, sherry, and other dessert wines).[5] (p. 191-203) Wines that have not only a relatively high alcohol content (15 percent or more) but also other natural flavors—including herb flavors—are called aperitifs.[5] (p. 204-11)

Goldtröpfchen wines are sweet because not all of their natural grape sugars have been converted into alcohol during fermentation; they have no synthetic or natural sugar added to sweeten them. While my more sophisticated friends continue to "educate" me to the virtues of other wines, my particular chemical makeup doesn't react well to dry wines or stronger alcoholic drinks. Some of these friends helped in preparing this report, including my neighbor and good friend, wine enthusiast Arthur Bayard; Arthur Seidel, patent attorney and scholar *extraordinaire*; and Morley Kare, director of the Monell Chemical Senses Center, just across the street from ISI®.

Wine is the subject of considerable scientific interest. Part 1 describes some of this published scientific research. Part 2 will discuss the leading centers of enology research around the world. I imagine, however, that there is considerable "research" in this field that remains unpublished. Most likely, these trade secrets remain closely guarded because patents provide less than a generation of protection. For most inventors, this is inadequate incentive.

## Just What Is Wine?

Wine has been a part of human culture for millennia. The word "wine" derives from the ancient Greek word *oinos*, from which came the Latin *vinum* and the Old and Middle English forms of the word, *win* and *wyn*, respectively.[6] Also derived from *oinos* is the far more modern word "enology," the science of wine and wine making.[7]

"Wine" usually refers to the fermented juice of grapes—specifically, to the juice of the Old World wine grape, *Vitis vinifera.*[8] (*Vitis*, the name of the genus to which this plant belongs, is the Latin word for "grapevine"; *vinifera* is the species name.[9]) The variations of *V. vinifera*, which range from light greenish yellow through russet, pink, red, reddish violet, and purplish black, account for the vast majority of fine grape wines. Other factors contributing to the diversity of these wines (as well as those made from other grapes) include the climate and soil conditions under which the grapes are grown, the techniques of the wine makers, and the actual processes used during vinification (the conversion of juices into wine).

But while *V. vinifera* is the fruit of choice for most "noble" or distinguished wines—that is, those that are aged in the bottle—most wines are produced from hybrid vines. Wines are produced from an array of grape varieties. For instance, the Concord grape (*V. labrusca*)—also known as the wild American fox grape and a native of the eastern US—is one of the main alternatives to *V. vinifera.*[5] (p. 25) The juice of other grape varieties, such as the Muscadines (*V. rotundifolia*) and the desert grape (*V. girdiana*), as well as *V. rupestris*, *V. berlandieri*, and *V. riparia*—all of which are native to North America—is also used occasionally to make wine, although their main use lies in serving as rootstocks or as the parents of hybrid grape varieties.[5] (p. 25) [8]

In fact, the juice of any fruit can be fermented to produce wine. Indeed, in its broadest sense, "wine" refers to the fermented juice of any plant product; wine made from dandelions, a common lawn pest in North America, is popular in some parts of the US, and the Japanese produce a wine, called *sake*, from fermented rice. Another popular Japanese fruit wine is made from plums. It is close to a sherry in taste, and I've encountered at least a dozen brands in Japanese and Chinese restaurants in the US.

Fermentation, of course, is the process that makes wine possible. The chemistry of fermentation—the conversion of a molecule of grape sugar (glucose) to two molecules of alcohol (ethanol) and carbon dioxide—was first described by French chemist Joseph Louis Gay-Lussac in 1810.[10,11] However, Louis Pasteur demonstrated in 1857 that the process is due to the metabolic actions of yeast cells (generally of the *Saccharomyces cerevisiae* species).[12,13] The chemical equation for this process is reproduced in Figure 1.

But wine is a complex liquid whose final flavor is influenced by numerous factors. Of course, the amount of time the wine is allowed to ferment is one such factor, but there are many others that affect flavor because they affect the maturation of the grapes. These include moisture, sunlight, soil conditions (such as mineral content), as well as any fungi, molds, and diseases that may attack the vines (and thereby affect the ripening process). Even the temperature of the grapes when they are picked can influence the flavor of the final product.[11] Not surprisingly, two of the 1986 ISI research fronts we identified in relation to wine and wine making concern the yeast *S. cerevisiae* (see Table 1). Three other fronts describe new methods for the chromatographic and spectral analysis of the various constituents of wine.

## Research-Front Data

In 1986 there were 27 published papers concerning "Computer regulation of sugar metabolism in yeast" (#86-0359). Walter Beyeler, Swiss Federal Institute of Technology, Zurich, coauthored two of the four core papers that identified this topic. With colleagues Arthur Einsele and Armin Fiechter, he wrote a paper in 1981 describing a new,

**Table 1:** The 1986 *SCI®/SSCI®* research fronts on various aspects of enology. A = number of core papers. B = number of citing papers.

| Number | Name | A | B |
|---|---|---|---|
| 86-0359 | Computer regulation of sugar metabolism in yeast | 4 | 27 |
| 86-0360 | Ethanol-sensitive mutants of *Saccharomyces cerevisiae* | 4 | 35 |
| 86-2020 | Current trends in wine technology | 16 | 131 |
| 86-6056 | Determination of wine components by gas chromatography | 2 | 13 |
| 86-8351 | HPLC and spectral methods for separation of phenolic compounds | 2 | 15 |

**Figure 1:** The chemical equation for the conversion of glucose to alcohol.

1 glucose ($C_6H_{12}O_6$) $\rightarrow$ 2 ethanol ($CH_3CH_2OH$) + $2CO_2$ + about 56 kilocalories of energy

computerized probe for measuring fluorescence in cultures of microorganisms.[14] Ultraviolet light is used to cause the nicotinamide adenine dinucleotide phosphate (NADP, which mediates oxidation and reduction by carrying electrons) contained in yeast microorganisms to fluoresce; by measuring the intensity of this fluorescence, the amount of microorganisms contained in the sample and their rate of growth can be accurately estimated. Since different wines are made by varying the length of the fermentation process, measures of fluorescence allow the process to be more precisely arrested at any stage. Beyeler's other paper, coauthored with colleague C. Meyer in 1984, is an analysis of methods used to control the rate of microbial reactions in culture.[15]

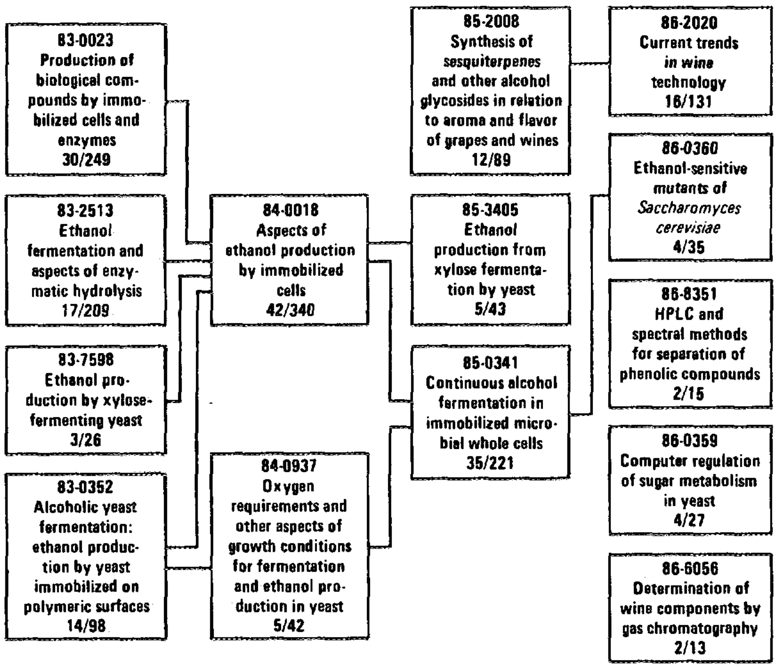
Another core publication for front #86-0359, published in 1968, discusses the actions of seven different enzymes (including NADP-linked glutamate dehydrogenase) in the growth of *S. cerevisiae* under various concentrations of glucose.[16] The interaction of yeast and glucose is the subject of a 1976 core paper by Shuichi Aiba, Shiro Nagai, and Yoshinori Nishizawa, Institute of Applied Microbiology, University of Tokyo, Japan.[17] It discusses a method of avoiding the "glucose effect," a phenomenon in which "aerobic fermentation" (the partial aerobic metabolism of glucose) occurs if the concentration of glucose rises above a certain level. By measuring the concentration of alcohol in the medium (an indirect measure of fermentation), the authors were able to keep track of the rate at which glucose was being metabolized and could add glucose as needed to keep the level optimal.[17]

Aiba also coauthored one of the four core papers for the research front on "Ethanol-sensitive mutants of *Saccharomyces cerevisiae*" (#86-0360). His 1968 paper discusses the growth rates of a specific strain of *S. cerevisiae* under various concentrations of alcohol.[18] Alcohol, the natural product of fermentation, inhibits the metabolic activity of the yeast cells in concentrations of more than 20 percent. This inhibitory effect was also the subject of two core papers coauthored by D. Susan Thomas and A.H. Rose, Zymology Laboratory, School of Biological Sciences, Bath University, UK. (Zymology is the study of enzymes and metabolic processes.) One paper, coauthored in 1978 with J.A. Hossack, discusses a method of increasing the resistance of *S. cerevisiae* to alcohol,[19] while the other, published a year later, followed up on the earlier work.[20] The fourth core paper, by Tilak W. Nagodawithana and Keith H. Steinkraus, Cornell University, New York State Agricultural Experiment Station, Geneva, discusses the effects of specific levels of alcohol on the growth of *S. cerevisiae*.[21]

Figure 2 is a historiograph showing the research leading up to front #86-0360. As noted previously, these historiographs, or microhistories of the research in a given field, demonstrate the continuity of research from year to year. But they can also show the consolidation of several lines of research or indicate where a new line breaks away from an old one.

Whereas the above research fronts address aspects of the biology of wine making, others concern the chemical analysis of wine. One emerged in 1986 and is entitled "Determination of wine components by gas

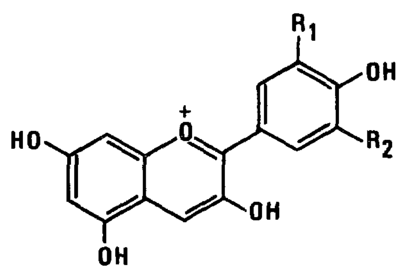
**Figure 2:** Historiograph of current research on ethanol production, yeast fermentation, and wine-making technology. The numbers of core/citing documents are at the bottom of each box. Variations from year to year in clustering methods may account for the discontinuous configuration of the historiograph.




chromatography" (#86-6056). It concerns methods of detecting diethylene glycol, a compound found in antifreeze and lubricants that "recently has been added illegally to certain wines in Austria, West Germany, and Italy," according to Cornelius S. Ough, professor of enology and chairman of the Department of Viticulture and Enology, University of California, Davis. "A relatively small amount of the material gives wine a mouth-filling feel and enhances its sweetness. However, it is highly toxic."[22]

One of the core publications for this front is *Clinical Toxicology of Commercial Products*, a book written by Robert E. Gosselin and Roger P. Smith, Dartmouth Medical School, Hanover, New Hampshire, and Harold C. Hodge and Marion N. Gleason, School of Medicine and Dentistry, University of Rochester, New York.[23] Cited over 230 times from 1957 through 1986, it provides exhaustive information on the toxicity of virtually every poisonous compound found in commercially produced substances.

**Figure 3:** Chemical structure of an anthocyanin, one of the natural pigments found in wine.




The other core document is a quarterly index of poisonous substances and common items in which they are found, such as cleaning products.[24] Since wines contain ethanol—which, of course, is toxic in unusually large amounts—they are listed alphabetically by brand name and manufacturer. The index is edited by Barry H. Rumack, Rocky Mountain Poison Center, Denver, Colorado.

In a highly competitive industry where everyone wants to know what components make for better-tasting wine, analytical methods are important. Thus it is not surprising that a research front on "HPLC and spectral methods for separation of phenolic compounds" (#86-8351) turned up. HPLC refers to high-pressure liquid chromatography. It involves the use of tiny, high-pressure tubes to separate the constituents of a solution for analysis.[25] Phenols include anthocyanins, the pigments that produce most red, purple, and blue colors in multicellular plants; they are the only significant pigments in red grapes.[5] (p. 48) Other phenols found in grapes are the light yellow anthoxanthin pigments in the skins and seeds of white-wine grapes. Figure 3 shows the chemical structure of an anthocyanin pigment.

Phenols are the subject of a 1969 book by Vernon L. Singleton and Paul Esau, Department of Viticulture and Enology, University of California, Davis. It provides qualitative and quantitative descriptions of the phenolic composition of grapes and wines and discusses the impact of these compounds on the flavor of wine.[26] Phenols originate in grape skins and seeds and in the oak from the barrels used to age some wines. They are responsible for the color, bitterness, astringency, some odors and flavors, and antioxidant characteristics of wine. This book and a paper by Larry W. Wulf and Charles W. Nagel, Department of Food Science and Technology, Washington State University, Pullman, on the use of HPLC to isolate and quantify the various anthocyanin pigments in two types of *V. vinifera* grapes[27] helped to identify research front #86-8351. Through co-citation analysis, just a pair of well-cited works can pinpoint complex subject matter. There were 15 papers published on this topic in 1986.

The largest 1986 research front explicitly connected to wine making is entitled "Current trends in wine technology" (#86-2020) and turned up 131 citing publications. A sampling of the 16 core documents cited by these publications shows how basic some of the research on wine is these days. In 1980 David E. Cane, Department of Chemistry, Brown University, Providence, Rhode Island, wrote a review of the role of allylic pyrophosphates in the synthesis of isoprenoid metabolites.[28] Pyrophosphates are water-soluble compounds, some of which serve as the precursors of various terpenes,[28] a class of about 5,000 structurally related compounds that are made up of various numbers of isoprene units ($C_5H_8$).[29,30]

Terpenes and isoprenes—including monoterpenes, which are made up of two isoprene units (10 carbon atoms)—were the subject of a 1953 paper by L. Ruzicka, Laboratory of Organic Chemistry, Swiss Federal Institute of Technology,[31] and a book chapter by Rodney Croteau, Institute of Biological Chemistry and Biochemistry/Biophysics Program, Washington State.[32] Ruzicka's paper detailed the chemical structures of numerous terpenic compounds and described the reactions that produce them and the compounds for which they, in turn, are precursors.[31] Croteau's quite recent article (1984) discussed the origins, production, and breakdown of monoterpenes, which constitute the "characteristic components of the essential oils" of higher plants.[32]

Another article that is core to this front involves gas chromatography.[33] This method traps the components of the mixture being analyzed in a stream of an inert, inorganic gas. The constituents are then briefly absorbed in a liquid or solid through which the gas is passed. The various components are absorbed at different rates, according to their chemical composition; this results in differences in the retention times in the column of the instrument, allowing the constituents to be isolated.[25]

It is interesting to note that another core document for front #86-2020 is George W. Snedecor's *Statistical Methods Applied to Experiments in Agriculture and Biology*,[34] now 50 years old. We published a commentary on this *Citation Classic*®, written by his coauthor, statistician William G. Cochran, Harvard University, Cambridge, Massachusetts, in 1977.[35] (Snedecor died in 1974; Cochran authored a chapter analyzing sample surveys for the fifth edition of Snedecor's book, which appeared in 1956.) It and many other similar works are cited by nonmathematicians who apply statistical analysis to their raw data. It is easy to understand why such books continue to be cited. However, it also illustrates how co-cited documents that are in fact themselves unrelated in subject matter can together define a precise subject area.

This concludes our discussion of current research in wine making; in Part 2 we will describe the leading institutions for wine research today, some of the highly cited papers from these institutions, and the journals that publish enological research.

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