in the industries, however, it was found that only one of the 50 wineries surveyed used statistical analysis in interpreting experimental results, and only eight had a special room for sensory testing.

Application of difference tests, such as the pair and triangle tests, was introduced in 1948. These tests have been used to show whether winery or field treatments, such as mechanical harvesting of grapes, have a significant effect on wine sensory properties.

Basic information on many topics, such as sourness, has been accumulated as well. Threshold levels (the minimum detectable amount of a substance) were determined for acids and other components in water and wine. Investigating the sourness of different acids and concentrations of acids, researchers concluded that sourness is best correlated with the log of titratable acidity. In studies of the interrelationship of sourness, sweetness, and bitterness in wine, it was found that increasing concentrations of either acid or caffeine depressed sweetness, but that adding sugar had no effect on detection of acid. Interestingly, in a study of salivary response to tasting of wine and its separate components, salivary flow rates were higher in response to aqueous tartaric acid solutions than to wines containing the same acid concentration. Addition of ethanol to the aqueous acid solution reduced the flow rate of saliva, which was consistent with a previous observation that addition of ethanol to acid systems results in decreased sourness. With the recent information on the relationship of organic acid anions, pH, and titratable acidity, our on-going research promises to contribute further to our understanding of the theory of sourness.

Much of the research done at the University has facilitated the use of sensory evaluation by trained tasters as an analytical, objective, and reliable method of analysis. However, because of the time and expense involved in sensory testing, attempts are continually being made to develop procedures to replace the sensory test with chemical or instrumental analyses.

In 1953, U.C. researchers sought to predict overall wine scores for Cabernet Sauvignon wines using alcohol, total acid, hydrogen ion concentration, tannin, and volatile acid. When any one of the indicators was used, predictability was low, but as is statistically inevitable, using all five parameters increased the ability to predict the wine scores. In a series of experiments studying the effect of cropping level on Zinfandel aroma, various wine analyses and gas chromatographic peaks (collected from wine aroma) were correlated with both cropping level and sensory rating scores. Several peaks and various must or wine data correlated linearly with crop levels. Gas chromatographic peaks were correlated with the intensity of specific attributes (vegetative, fruity, woody, and the like) rated in a series of Cabernet Sauvignon wines. Because of the nature of the statistical tests used and the variability of the systems studied, further research is necessary before conclusions can be reached about the importance of specific components to wine flavor.

Recently, with the technique of principal component analysis, we were able to "cluster" wines by variety using data from gas chromatography of wine aroma components. Although no formal sensory testing was involved, perhaps the most successful correlation of sensory and instrumental analysis has been the identification of the component producing an intense geranium odor in wine. Researchers isolated 2-ethoxyhexa-3,5-diene and outlined the mechanism for its formation from sorbic acid in wines undergoing malo-lactic fermentation.

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Wine— a multibillion-dollar industry

Kirby S. Moulton

The current problems of the California wine industry all have parallels in the industry's earlier days. Its history is a fabric of high and low profits, overplanting and underplanting, surplus and shortage, and ascending and descending preferences. The industry has become robust and exceedingly complex but has never really resolved the problem of the profitable coordination of grape production and wine sales.

Nearly every observer of the California wine scene is aware of the great grape planting spree of the 1970s when "...nearly every land owner caught the wine fever...and vineyards sprang up as if by magic all over California." But those words were written in 1878 by Charles Kohler in his University of California master's thesis about planting excesses which happened in the 1850s.

The evolving structure

California's vineyards expanded enormously between 1880 and 1980, and much of this growth occurred relatively early. The 56,000 acres reported in 1880 doubled by 1885 and reached almost 350,000 acres 25 years later. The initial expansion was almost entirely in grapes for winemaking, which represented three-quarters of the 1885 acreage.

The increase placed great stress on wine marketing just as it has more recently. Grower prices tumbled from over $20 per ton in the early 1880s to less than $10 per ton by the end of the decade. Imports posed serious market threats, and dishonest selling practices diminished grower and winery profits.

Some marketing problems were described by Professor E. W. Hilgard in 1880. They included the practice of selling California wines under foreign labels "after two trips across the Atlantic, or even perhaps only across the bay." Blending was left chiefly to the wine merchants of San Francisco with somewhat uncertain quality results. Professor Hilgard noted, however, that neutral spirits, logwood, glycerine, and sulphuric acid played relatively small roles in blending practices of these merchants. The Mission variety grape common in California's early vineyards was believed by Hilgard and others to contribute to marketing problems: the low-quality wines made from Mission encouraged the production of sweet wines to mask the grape's defects.

Reduced yields were necessary to produce quality wines, but quality-based price differentials rarely compensated for the loss of sellable grape tonnage. The dilemma was painfully evident in the severe depression of the 1870s. The choice for growers was to plant other crops or turn the hogs into the vineyards at harvest time. Wineries fared little better. Economic disasters squeezed their number from 139 in 1870 to only 45 registered in California in 1880.

Wine drinkers in the United States consumed about 28 million gallons of wine annually during the 1880s, a level stimulated by improved marketing and augmented production. Even with increased demand, U.S. producers successfully thwarted foreign competition, and imports were cut in half between the 1870s and 1880s to less than 20 percent of the expanding market. Nevertheless, the volume of imports was always significant in the pre-Prohibition U.S. wine market, and dropped to an unimportant 3 percent

only in the immediate post-repeal period.

Overall wine consumption averaged over 50 million gallons annually by 1913. Even during Prohibition, per capita wine consumption was sustained as thousands of consumers became home wine makers. This desire to consume wine partly explains the expansion of California's vineyards to 650,000 acres by 1928, a level not again reached during the succeeding 50 years.

Wine consumption surged after repeal. California production in 1935-39 was 50 percent higher than its pre-Prohibition average but was dominated by sweet wines, a distinct shift from the 1880s, when dry wines were preferred.

It is difficult to place a reliable value on the total shipments of California wine, because they include a large number of different wines with different prices. Based on estimated average wholesaler prices of 65¢ for dry wine and $1.00 for sweet wine, the value of California wine shipments in 1880 was $7 million or an average of about 70¢ per gallon. A corresponding estimate for 1980 (based on trends through 1979) is $1.6 billion, or an average value of $5 per gallon.

Economic relationships

Production costs and sales revenues changed significantly between 1880 and 1980 in response to improved technology and vastly different price levels. The scope of these changes can be appreciated by using a common dollar for comparisons between the two time periods. The following comparisons are made by using the Consumer Price Index to measure 1880 prices in 1980 dollars. Changes in the index suggest that 1880 prices should be multiplied by eight to obtain their comparable 1980 value.

Land values have changed most notably during the past century. Lands suitable for vineyards sold for $10 to $125 per acre in 1880 and probably averaged $50. Now these lands sell for $3,000 to $10,000 per acre and probably average $5,000 for better vineyard sites. The equivalent 1980 value of 1880 land prices is $400 per acre, and even the most expensive would have sold for the equivalent of $1,200.

This radical escalation in land prices helped convert grape growing to the highly capital-intensive activity that it is today. It also reduced growers' flexibility in meeting grape price fluctuations and motivated a search for more stable pricing arrangements.

This change is also apparent in vineyard establishment and production costs. Complete development costs currently are about $6,000 per acre, depending on location and characteristics. Even discounting potential differences in cost accounting, today's costs far exceed the current value of 1880 costs, estimated to be $600 to $1,000 per acre.

Cultural and harvest costs also show relatively large increases over the last century. Today's costs, excluding depreciation, interest, and overhead, average $730 per acre as compared with $100 per acre, the current value of 1880 costs.

Production costs rose more rapidly than grape prices, although higher yields per acre helped mitigate losses in income. Prices for wine grapes fluctuated between $10 and $21 per ton during most of the 1880s and rarely exceeded this range during the following decades. Expressed in 1980 dollars, these prices were equivalent to $80 to $170 per ton, not far from the average 1979 price of $211 per ton for wine grapes.

Wine grape yields estimated in some early references (2 to 6 tons per acre) would have resulted in 1880 revenues of $80 per acre, or about $650 in current dollars. This is one-half of the estimated $1,270 per acre received by wine grape growers in 1979, based on a 6-ton-per-acre yield. After deducting cash cultural and harvesting costs, the net amount remaining to cover other costs, including depreciation and return on the owner's labor and investment, was $550 per acre in 1880 and $540 in 1979, measured in current dollars.

In spite of difficulties in evaluating the accuracy of 1880 statistics, it is clear that growers have had to run very fast just to keep up. The remarkable stability in grower numbers and the substantial increase in grape acreage suggest they have been successful.

Bulk wine prices actually declined in real terms between 1880 and 1980. The earlier price was 25¢ per gallon, or the equivalent of $2.00 in 1980 dollars. Bulk table wine prices in early 1980 were almost one-third lower than this at $1.30 per gallon. Increased winemaking efficiency accounts for an important part of this price restraint.

Prices at the wholesale level, approximately $4 to $5 per gallon, appear relatively unchanged over the past century when expressed in 1980 dollars. Restaurant prices are difficult to compare because of the wide range of pricing practices, but a half carafe costing about 13¢ in 1880 is probably two-thirds of current prices when converted to 1980 dollars.

TABLE 1: Structure of California's Wine and Wine Grape Industry: Comparison between 1880 and 1980

	1880	1980 (preliminary)
Total grape acreage	56,000	669,000
Wine shipments (1,000 gallons)	10,000	320,000
Value of winery shipments ($1,000)	$ 7,000	$1,600,000
U.S. wine consumption (1,000 gallons)	28,000	460,000
U.S. wine imports (1,000 gallons)	5,000	90,000
Number of registered wineries	45	406

SOURCE: Data for 1880 calculated from unpublished working papers of S.W. Shear, Giannini Foundation of Agricultural Economics and from the Annual Report of the State Viticultural Commissioners, 1881. Data for 1980 projected from Wine Institute, Annual Statistical Report, 1978, and Monthly Statistical Bulletins.

TABLE 2. Economic Relationships in California's Wine and Grape Industry, 1880 and 1980

	1880*	1980 (preliminary)
Land prices ($ per acre)	$50.00	$5,000
Vineyard development cost ($ per acre)	$75.00	$6,000
Vineyard cultivation cost ($ per acre)	$10.00	$ 450
Grape harvest cost ($ per acre)	$ 2.00	$ 280
Wine grape prices ($ per ton)	$20.00	$ 211
Bulk wine price ($ per gallon)	$ 0.25	$ 1.30
Retail wine price (restaurant, $ per gallon equivalent)	$ 1.25	$ 10.00
Trade price to restaurant ($ per gallon)	$ 0.50	$ 4.00
Consumer Price Index (1967 = 100)	29	240

SOURCES: Data for 1880 from the Annual Report of the State Viticultural Commissioners, 1881. Data for 1980 derived from University of California Cooperative Extension Cost Data publications, and from reports of the Federal-State Market News Service (weekly reports). Restaurant prices estimated by author.

*Values for 1880 are the midpoints of ranges estimated by Viticultural Commissioners as being relevant for the California wine and grape industries.

Conclusion

The figures presented here, admittedly sketchy and subject to uncertainty, suggest that California's wine and grape industry has grown enormously over the past century, but, surprisingly, the growth rate was more rapid a century ago than during the spree of

the 1970s. The acreage planted to grapes has fluctuated as markets have changed. Grower prices have fluctuated in response to climatic variations and cyclic shortages and surpluses. The magnitude and duration of these shortages and surpluses suggest that grape supply and wine demand have never been effectively coordinated.

Wine and grape prices have changed reasonably with changes in the Consumer Price Index. Production costs, on the other hand, appear to have grown at a substantially higher rate. The wine and grape industry has remained a vigorous part of California's agricultural economy, presumably in large part because improved efficiency has offset significant cost changes. A major part of this gain was from University research directed toward improved varieties, better cultural practices, and superior winemaking technology.

Many research challenges remain if California's industry is to meet future wine demands. Among these are economic studies directed toward more complete wine demand forecasts and their implication for grape variety requirements; analysis of trade policies that will facilitate market development for California wines; and more complete analysis of wine production and marketing strategies and costs in order to improve efficiency.

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100 years of wine microbiology

Ralph E. Kunkee ☐ George M. Cooke

It can be said that wine microbiology began about 100 years ago, if we think of it as being concerned mainly with alcoholic fermentation and selection of yeasts, malo-lactic fermentation and the bacteria involved, and problems with microbiological spoilage. Louis Pasteur's first edition of *Etudes sur le Vin* was published in 1866, and in 1889 Kulisch presented the first evidence that malolactic fermentation was microbiological. However, the major contributions by the University of California in wine microbiology did not begin until early in this century.

As new vineyards were planted at the turn of the century, the University wine microbiologists were able to look at the ecology of the recently established microflora (the yeast and the bacteria on the grapes) and to compare these studies with those from the well-established vineyards of the European wine regions.

Yeast culture collection

Athough no enological research was done, as such, at the University during Prohibition, apparently some attention was paid to establishing a wine yeast culture collection and, later, a bacteriological culture collection. Because information was not published, however, it is difficult to pinpoint the actual origins of the various strains in the present University of California enology collection at Davis. Professor William Cruess had a collection of yeast originally obtained by Dean Eugene Hilgard. We presume that some of our present culture collection came from these strains. We know that a "Burgundy" and a "Champagne" strain arrived in the collection from an institute in France.

Professor Cruess also studied flor sherry production. Because the yeast strains needed were not available in California, he obtained them from Spain and added them to the collection. This research on flor sherry was continued later and led to the utilization of the submerged flor process, now widely practiced in California.

Apparently the present system of numbering the yeast strains did not begin until after 1938, when Professor John Castor systematized the yeast collection. It seems to have been Castor who introduced the strain "Montrachet."

The use of pure yeasts as starter cultures, as recommended by University enologists, became common practice in California after Prohibition. One strain of choice was Montrachet because of its fast fermentation rate, consistency in fermentation, and pleasant end-products. A few other strains also have been considered exceptionally good.

The use of a limited number of wine yeast strains, some of which came from the University's collection, led to commercialization of yeast starter culture preparation, first in the pressed cake form and then as active dry preparations. Early research in the preparation of frozen and frozen dried yeast was the basis for the later development of these active dry yeast cultures.

Another important development by the University was the isolation, cultivation, and description of a wine spoilage bacterium known as hair bacillus or cottony mold, *Lactobacillus trichodes* (that is, "hairlike"). The organism is resistant to ethanol and thrives in dessert wines—its most common natural habitat. Fortunately, it is also extremely sensitive to sulfur dioxide and thus has not been an important spoilage problem in California wine since publication of the research results in 1943.

Fermentation studies

Castor began the studies at the University on controlled fermentations with various wine yeast strains, and studied rates of yeast growth and fermentation. These latter studies led recently to formulations of computerized fermentation equations. The fermentation control research was continued; a lengthy series of papers was published following Castor's work, which described on a practical basis the factors that influence the alcoholic fermentation.

Research in the late 1950s on formation of the higher alcohols (fusel oil) showed that they do not arise exclusively from amino acids in the grape juice itself, as had been thought previously. The higher alcohols can also come directly from the sugars in the grape juice during alcoholic fermentation by yeast. Information obtained from bacteriological research at that time led to the proof, with the use of mutant yeast strains, of the metabolic pathways of the formation of the higher alcohols and suggested the kinds of metabolic control that should be applicable.

Continuing some of this earlier work, we have recently obtained a mutant of Montrachet that is deficient in the pathway for the production of a higher alcohol. This mutant yeast strain ferments as rapidly as the control strain and produces low levels of fusel oil.