Copper in Winemaking: From Vineyard Management to Analytical Control in the Winery

Dr. Francesca Bruni, researcher at the CDR Chemical Lab "Francesco Bonicolini"

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Introduction. Copper as a Critical Control Point in the Winemaking Process

In modern enology, the presence of copper (Cu) must be considered not only as a historical residue of vineyard treatments but also as a critical control point within the winery quality assurance protocol. Copper-based products remain one of the most effective solutions to **control downy mildew** (*Plasmopara viticola*). At the same time, their persistence can influence the chemical and microbiological stability of wine. Copper is an essential **micronutrient** for vine metabolism. However, when excessive residues reach the must and the wine, this metal becomes a technologically critical parameter capable of influencing fermentation kinetics, oxidative stability, and the final sensory profile.

Traditionally, vineyard treatments followed the so-called "**rule of three tens**". Ten millimeters of rain, ten centimeters of shoot growth, and temperatures around 10°C were considered favorable conditions for infection. Current agronomic knowledge has revised this rule. Research shows that infection can begin when leaves are only 2 to 3 cm in diameter, because stomata are already fully functional. As a consequence, treatments often start earlier and may be repeated more frequently during the season. This increases the probability that copper residues remain on the grapes and eventually reach the must. Regulatory limits establish **maximum** copper concentrations of **50 mg/kg** on grapes and **1 mg/L** in finished wine. From a technological perspective, however, many wineries consider **0.5 mg/L** as the **optimal threshold** to ensure stability and avoid quality defects.

Maintaining copper below this value significantly reduces the risk of oxidative reactions and colloidal instability.

Copper Toxicity and Yeast Metabolism

Once copper enters the winery, its removal becomes difficult. Standard clarification processes applied to musts generally do not significantly reduce copper concentration. Most of the metal remains bioavailable and can interact directly with yeast metabolism. The response of yeast to copper depends on the strain used during fermentation. Typical resistance levels are approximately:

• Indigenous or non-selected yeasts: tolerance up to 8 mg/L

• Traditional Saccharomyces cerevisiae strains: tolerance up to 12 mg/L

• S. cerevisiae / bayanus strains: tolerance up to 19 mg/L

• Non-H_2S producing strains: higher sensitivity, around 6 mg/L

Because of these differences, copper concentration must be evaluated together with the specific yeast strain employed in fermentation management.

Mechanisms of Oxidative Stress

Copper toxicity is primarily associated with the Cu^{2+} ionic form, which can participate in redox reactions that generate Reactive Oxygen Species (ROS). These reactive molecules damage cellular structures and interfere with key enzymatic systems involved in fermentation.

The main consequences include:

1. **Oxidative stress and slower fermentation kinetics**
   ROS damage cellular membranes and inhibit enzymes involved in glycolysis, slowing yeast activity.
2. **Increased acetaldehyde production**
   Yeast cells under oxidative stress tend to accumulate acetaldehyde as an intermediate metabolite.
3. **Impact on sulfur dioxide management**
   Acetaldehyde is the primary compound that binds sulfur dioxide (SO_2).
   Higher acetaldehyde concentrations therefore require higher SO_2 additions in order to maintain an adequate free SO_2 fraction, increasing the risk of exceeding legal limits for total SO_2.

Organoleptic Risks: Oxidation and Colloidal Instability

Copper is also a powerful redox catalyst in wine. Its presence accelerates oxygen consumption, increasing oxidative reactions by approximately 125 to 190%. These reactions can significantly affect both aroma stability and color evolution. White wines are particularly sensitive because they lack the polyphenolic redox buffer typically present in red wines.

The copper paradox

In bottled wines with low redox potential, **Cu^+ ions** can react with proteins and sulfhydryl groups, forming unstable colloidal complexes that may eventually precipitate as **reddish-brown deposits**, a phenomenon known as **copper casse**.

Wines most exposed to this instability are those that have accumulated copper during vineyard

treatments or cellar operations. **Light-bodied white wines are particularly vulnerable**, because they are often bottled early and have limited time to stabilize during bulk storage.
Copper casse typically develops **after bottling**, when the wine environment becomes more reducing due to limited oxygen and the presence of compounds such as **sulfur dioxide and ascorbic acid**. These conditions favor the formation of insoluble copper complexes that can precipitate during bottle storage.
External factors may increase the risk. **Light exposure**, especially UV radiation, can promote the phenomenon, which is one reason why white wines bottled in clear glass are more susceptible (Zoecklein et al., 1995). **High storage temperatures** can also accelerate the appearance of copper-related deposits when other instability conditions are present.
Proteins may participate in the formation of copper complexes, making wines with higher protein content more susceptible. In these cases, careful **bentonite fining** can help reduce protein levels and limit the risk of haze or deposits.
For this reason, **preventive monitoring of copper concentration** is more effective than corrective treatments such as potassium ferrocyanide or PVI-PVP copolymers, which may affect the sensory profile of the wine. Maintaining copper levels below **0.5 mg/L** remains the most reliable strategy to preserve colloidal stability and visual quality throughout the wine's shelf life.

Copper Monitoring with CDR WineLab®

Rapid analytical control is essential for managing **copper levels** during winemaking operations, because timely measurements allow winemakers to evaluate the impact of vineyard treatments, monitor clarification processes, and verify copper concentration before critical stages such as fermentation, stabilization, or bottling. The **CDR WineLab® system** enables wineries to perform copper analysis directly in the cellar, providing rapid results that support real-time quality control decisions without relying on external laboratories and their associated delays. The analytical method covers the concentration ranges typically encountered in both must and finished wine, allowing effective monitoring throughout the production process. Two measurement ranges are available: a **low range from 0.05 to 0.70 ppm**, with a resolution of **0.01 ppm**, and a **high range from 0.60 to 1.20 ppm**, also with a resolution of **0.01 ppm**. This dual range makes it possible to accurately detect copper concentrations close to the technological threshold associated with wine stability. To ensure reliable photometric measurements, simple sample preparation steps are recommended. Must samples should be centrifuged before analysis in order to remove suspended solids that could interfere with the measurement, while sparkling wines or fermenting samples should be degassed, typically using an ultrasonic bath, to eliminate dissolved carbon dioxide that may affect optical readings. These straightforward preparation procedures help guarantee **consistent analytical performance and reliable results during routine monitoring in the winery**.

Comparative Analysis: CDR Method vs Official OIV Method

In modern winemaking, it is important to distinguish between process monitoring and official certification analyses.

Criterion	CDR WineLab® Method	Official Method (OIV / Atomic Absorption)
Strategic purpose	Process control and quality assurance	Legal certification and export compliance
Response time	About 6 minutes	From several hours to days
Operational complexity	Minimal, usable directly in the winery	High, requires specialized laboratory staff
Sample preparation	Rapid centrifugation or degassing	Complex acid digestion
Precision	Excellent linearity across both ranges	Legal reference method
Operational cost	Low, ready-to-use reagents stable for 6 months	Higher cost due to external laboratory analysis

Conclusion. Copper Monitoring as a Key Element of Winery Quality Control

Copper management represents a critical element of modern winery quality assurance. Monitoring copper concentration throughout the winemaking process helps prevent fermentation difficulties, oxidative instability, and sensory defects that may appear after bottling. Analytical systems such as **CDR WineLab®** allow wineries to detect variations as small as 0.01 ppm, enabling timely interventions after vineyard treatments, flotation operations, or corrective cellar practices.
While official OIV methods remain essential for regulatory certification, rapid in-house analysis provides winemakers with a powerful tool to protect aromatic integrity, fermentation efficiency, and long-term wine stability.