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Bordeaux mixture and copper: changing practices and future challenges

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European viticulture at the end of the 19th century was hit by disastrous introductions of American pathogens: powdery mildew in 1845, phylloxera in the 1860s, downy mildew in 1878, and black rot in 1885. Certain historical facts allow us to trace the discovery of Bordeaux mixture and its impact on controlling downy mildew in the Médoc region before 1921. Ultimately, a national-level analysis of copper sales in agriculture shows that copper remains an indispensable plant protection product, despite its classification as a candidate for substitution for ecotoxicological reasons.

Materials and methods

This study was conducted using data published on the centennial of Bordeaux mixture in 1885 by Robert Lafon, with the support of historians[1]. Data was also obtained from the national sales database of plant protection product distributors in France, available on the BNVD traçabilité-eaufrance website: https://ventes-produits-phytopharmaceutiques.eaufrance.fr/about, and were analyzed for sales of copper-based products between 2009 and 2023.

Historical origins of Bordeaux mixture

Following the replanting of vineyards devastated by phylloxera—using American *Vitis* species to address the phylloxera crisis, downy mildew was introduced from North America in 1878. Downy mildew, *Plasmopara viticola*, is an oomycete, an obligate endemic parasite, first observed in France near Coutras on an American grape variety (Jacquez) in August 1878, near Libourne. Millardet also observed it on *V. aestivalis* in nurseries in the Gironde region that same year. Described by Planchon (stunted growth caused by *Peronospora viticola*)[2], and Millardet in 1878, it was reported and detected in other regions[1]. As early as 1882, downy mildew caused significant losses, and those observed in 1897, 1910, and 1915 were the result of devastating downy mildew outbreaks in the Médoc (Figure 1). This particularly damaging disease was controlled using "Bordeaux mixture," a copper-based fungicide. Nevertheless, due to a shortage of labor and inadequate monitoring, the 1915 downy mildew outbreak reduced the harvest by more than half nationwide.

In October 1882, P. M. Alexis Millardet and C. Ernest David discovered the effectiveness of Bordeaux mixture in combating downy mildew in grapevines. This entirely fortuitous discovery stemmed from concurrent observations that demonstrated its efficacy. In Burgundy, the effectiveness of sulfur-treated stakes was quickly noted by Pulliat as early as 1883 and confirmed in 1884 by Perray as a means of protecting against downy mildew near the trellises[1]. At the same time, in 1882 in the Médoc, estate manager E. David of Château Beaucaillou in Dauzac discovered that the edges of vineyard plots whitewashed with a mixture of lime and copper sulfate to deter grape theft also limited downy mildew. A. Millardet (Figure 2) witnessed this effect and conducted trials (1883–1884). The copper salts deposited on the leaves prevented the germination of downy mildew spores and, consequently, the infection of the vines. Following a discovery in the water from his well, he knew that copper possessed this anti-germinative property. Professor U. Gayon demonstrated that water from an old copper pump became enriched with soluble copper and contained a concentration 20 times higher (5 mg/L) than that required to kill downy mildew spores[1]. As early as 1884, E. David proposed an initial "recipe" for the copper-lime mixture, in which 8 kg of copper sulfate dissolved in 100 L of water is mixed with a lime slurry made from 15 kg of fatty stone lime in 30 liters of water[1] (Figure 2). In 1887, Professor Gayon arrived at the universally used formula containing 2 % copper sulfate. Two types of mixtures emerged: "Bordeaux mixture" and "Burgundy mixture," invented in 1887 by Masson, in which lime is replaced by sodium carbonate (Na_2CO_3)[3].

As early as 1885, the effectiveness of Bordeaux mixture ($Ca(OH)_2$+ CuSO4) against downy mildew was demonstrated empirically, and its use became widespread following the severe outbreak of 1886. The mixture, which is more or less bioavailable, is currently prepared by mixing slaked lime (1.3 kg) with a copper sulfate solution (2 kg per hectoliter of water). Since then, numerous copper-based formulations have emerged, helping to resolve this bioavailability issue[3]. Alongside the original Bordeaux mixture, there are currently copper oxides, copper oxychlorides, cuprous oxide, and copper sulfates (tetracupric, tricalcium, or tribasic).

Evolution of copper formulations and application rates

Approved copper application rates were long above 5 kg/ha, and in some cases much higher (up to 80 kg/ha per year), leading to its accumulation in the soils of many vineyards at levels ranging from 1 to 400 mg Cu/kg of dry soil weight[4], frequently observed in older vineyards. Furthermore,

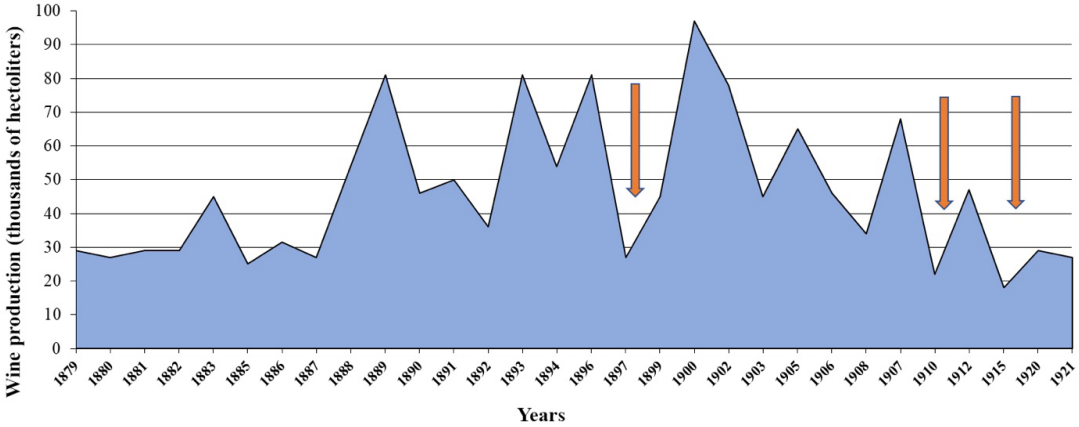


FIGURE 1. Total annual wine production in the Médoc in thousands of hectoliters following the onset of downy mildew (based on Pijassou R, 1978, *Un grand vignoble de qualité : le Médoc*, vol. 2. Doctoral dissertation, Bordeaux; sources: Tastet-Lawton archives: statistics). The arrows indicate very severe outbreaks of downy mildew.

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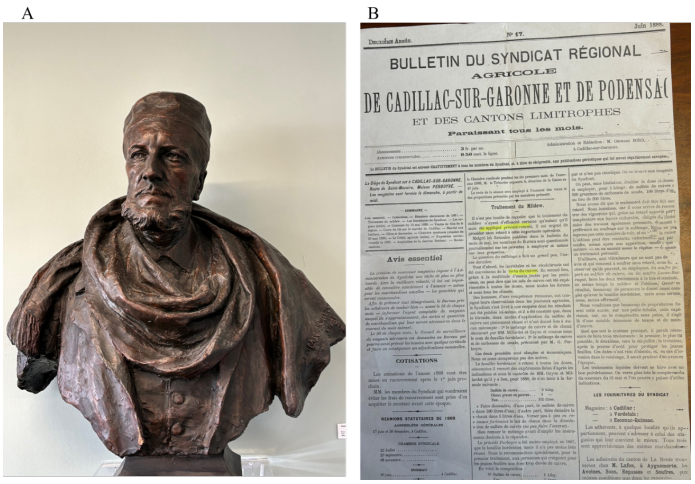


FIGURE 2. (A) Photograph of the bust of Alexis Millardet (photo, M. F. Corio-Costet), (B) recipe for Bordeaux mixture published in 1888 in the bulletin of the regional union of Cadillac-sur-Garonne and Podensac.

copper exhibits some toxicity to aquatic and terrestrial organisms[4]. Today, in response to demands from the European Union and policymakers, these application rates are being drastically reduced (limited to 4 kg/ha/year, averaged over 7 years to 28 kg/ha, EEC Directive No. 2092/91, ANSES reevaluation in 2025)[5] [6], but with more effective copper forms and formulations (e.g., copper hydroxide at 0.75 kg/ha). Consequently, copper is included on the list of active ingredients identified by ANSES and the European Union as candidates for substitution[6]. However, copper is believed to boost the vine's defenses by promoting cell wall thickening, soluble peroxidase activity, and polyphenol production.

Current uses and regulatory restrictions

Copper remains the only effective pesticide in organic farming (AB) against downy mildew, although it is not included on the list of biocontrol products in France (https://agriculture.gouv.fr/quels-sont-les-produits-de-biocontrole). From 2013 to 2016, organic farming used three times more copper than so-called conventional agriculture[5]. The latest review by ANSES in 2025 led to the removal of 17 out of 34 copper-based products approved for use in French viticulture.

An analysis of copper product sales at the national level reveals that the quantities of copper metal sold annually range from 1,500 to 2,500 metric tons (Figure 3), with copper sulfate accounting for 700 to 1,500 metric tons, peaking at over 2,500 metric tons in 2018 due to severe outbreaks of downy mildew. This translates to significant sales in Gironde and along the Atlantic coast, as well as in the Mediterranean region[5]. However, since 2010, a decline in copper sales has been observed (approximately -5 %, varying by vintage). Between 2013 and 2018, the wine industry purchased approximately 1,000 metric tons of copper per year[5].

Conclusion

Copper sprays, more than 140 years after their discovery, are still widely used and remain indispensable in organic viticulture. In the short term, reducing copper doses and optimizing treatments remain a challenge, which is being addressed by a strategic action plan aimed at developing alternative techniques for controlling downy mildew in viticulture (the PARSADA project). In the medium term, the use of natural products, microorganisms, biostimulants, immune stimulators, natural extracts, or varietal improvement[7], in combination with reduced copper doses or even optimized formulations (nanoparticles)—would help limit copper use and optimize treatment strategies[7] [8]. A paradigm shift—focusing on controlling the production of primary inoculum (oospores) in year N-1, rather than preventing or reacting to the epidemic in year N+1—represents a promising approach to reducing dependence on copper. ■

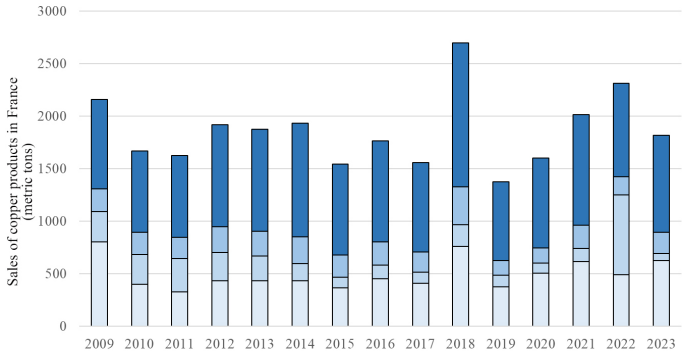


FIGURE 3. National distribution of copper product sales between 2009 and 2023. Shown in shades of blue from lightest to darkest: copper hydroxides, copper oxychloride, cuprous oxide, and copper sulfate-based products.

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