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Spanish Scientists Use Artificial Intelligence to Revolutionize Wine Fermentation Modeling

Hybrid models combining AI and scientific knowledge promise greater accuracy for winemakers facing climate-driven changes in grape composition.

Monday, February 9, 2026



Researchers at the Spanish National Research Council (CSIC) are using artificial intelligence to model wine fermentation, aiming to help winemakers better control this complex process. The project, called Tailored-Wine, is funded by Spain’s State Research Agency and led by the Institute of Marine Research (IIM-CSIC) in Vigo. The team has

been developing computational tools for years to help wineries predict and manage fermentation, a stage that involves live microorganisms and many variables that are difficult to monitor.

The new initiative adds artificial intelligence to existing models based on physics, chemistry, and biology. According to Eva Balsa, the lead researcher, the goal is to create hybrid models that combine scientific knowledge with AI techniques. These models are expected to be more accurate and adaptable, especially as climate change increases variability in grape composition.

The research group previously developed digital twins for the wine sector—virtual replicas of fermentation processes that allow for simulation and prediction. Now, they are focusing on understanding yeast metabolism in greater detail, particularly how yeasts manage carbon and nitrogen during fermentation. This is important because the levels of these nutrients in grapes can vary depending on grape variety, vintage, and increasingly due to climate change.

To gather experimental data for their models, the Vigo team is collaborating with the Institute of Agrochemistry and Food Technology (IATA-CSIC) in Valencia. The IATA's pilot winery will provide real-world data under the coordination of Amparo Queral and Eladio Barrio. A bioinformatics expert from IATA is also involved to incorporate genetic information about yeast strains into the models.

Once developed, the computational models will be validated at the Valencia experimental plant before being transferred to industry use. Balsa notes that accounting for changes in nitrogen and carbon content is now a priority because these shifts can significantly affect fermentation outcomes.

The researchers have already started using AI in their previous project's final phase. They recently published a scientific article comparing knowledge-based models with those relying solely on AI. Their findings show that pure AI models require much more laboratory work, while hybrid models are useful when detailed knowledge is lacking. Training AI with existing scientific models can achieve similar accuracy quickly, making this approach promising for industrial applications.

In parallel with Tailored-Wine, Balsa’s team has launched another public-private partnership project involving wineries Ramón Bilbao and Bodegas Roda from Haro, a University of Zaragoza group specializing in aromas, engineering firm Inconef, and multinational Lallemand, which produces yeast and nutrients for fermentation. This consortium aims to implement more detailed digital twins in wineries and combine them with smart sensors and hardware technologies not yet widely used in the industry. The system will support real-time decision-making for winemakers.

These digital tools could also be applied beyond wine production. Yeasts play a key role in many biotechnological processes, such as yogurt fermentation. While wine presents unique challenges—like aroma production—the modeling strategies developed by CSIC researchers could benefit other sectors where yeast-driven fermentation is essential.