



Technical innovation and quality control of wine production in China

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Abstract. Recent decades have witnessed an evolving trend of diverse product types, improved quality, and green, low-carbon, and sustainable development in Chinese wine market. A quality evaluation system, namely, with a dual orientation of "flavour compounds" and "sensory evaluation" is used as guidance for winemaking innovation in China. More diverse and personalized products catering for consumer market are produced by characterization of terroir of each wine region, exploitation of indigenous wine yeasts, and the application of modern analysis technology and artificial intelligent systems for wine blending. And such trends enable wine production to progress with precise technology, prominent product style, and diverse product types. The visual expression of product quality for consumers makes wine products more acceptable by general public. Meanwhile, a comprehensive quality evaluation system for products has been established, with indices including quality and safety, flavour profiles, sensory quality, labelling, consumer preferences, and green packaging, thereby effectively promoting the high-quality and sustainable development of wine industry in China.

1. China boasts a diverse range of climate types in its wine-producing regions, leading to a vast variety of wine products catering to the personalized needs of different consumers

China is characterized by a typical continental monsoon climate, with its wine-producing regions spanning vast territories from 24°N to 47°N latitude and 76°E to 132°E longitude. These regions encompass diverse climatic zones, including arid, semi-arid, semi-humid, cool, temperate, warm-temperate, and subtropical regions, with complex and varied sub-climatic types. This diverse range of climates offers significant potential for the production of various high-quality wines.

Over the past 130 years, China has developed 11 distinctive wine regions, each with unique characteristics. These include the Northeastern Region (semi-humid and cool zone), North China Region (semi-humid ecological zone), Shandong Jiaodong Peninsula Region (Yantai Region) (warm-temperate and semi-humid ecological zone), Yellow River Old Course Region (humid and semi-humid zone), Loess Plateau Region (semi-arid and semi-humid zone), Ningxia Helan Mountain Eastern Foothill Region (arid and semi-arid warm-temperate zone), Gansu Hexi Corridor Region (arid and semi-arid cool zone), Xinjiang Region (arid and semi-arid hot zone),

Southwestern Shangri-La Region (transverse dry-hot river valley ecological zone), Yunnan-Guizhou Plateau Region (Yunnan-Guizhou Plateau ecological zone), and Southern Region (southern humid ecological zone). Within each of these regions, several distinct sub-regions have emerged, each with its own unique characteristics.

The rich diversity of climates and soil types in China determines the variety of terroirs, enabling the production of diverse wines. China is capable of producing sparkling wines (in Ningxia), premium dry white wines (from Yantai, Gansu, Xinjiang, and Ningxia), as well as the mainstream categories of fresh and aged dry red wines, which account for a significant proportion. Additionally, there are alluring rosé wines, sweet and delightful ice wines (produced in Northeast China and Gansu), fortified wines with over 100 years of production history (e.g., Vermouth), and niche fortified wines (e.g., Port-style). This diverse array of wines greatly enriches the product range and satisfies the various preferences of Chinese consumers.

2. The quality of wine products has significantly improved, reaching international standards

In recent years, the quality of Chinese wines has experienced a substantial and sustained improvement, attaining international standards of excellence. At prestigious domestic and international competitions such as the Decanter World Wine Awards (DWWA), Concours Mondial de Bruxelles (CMB), Berlin Wine Trophy (BWT), Mundus Vini World Wine Awards, International Wine Challenge (IWC), Asian Wine Challenge (AWC), China Fine Wine Challenge (CFWC), and International Wine & Spirits Competition (IWGC), wines from China's major production regions including Yantai, Ningxia, and Xinjiang have repeatedly secured top honours, including Best in Show, Platinum Awards, Grand Gold Medals, Gold Medals, and Silver Medals, with the proportion of these awards increasing annually.

During the Concours Mondial de Bruxelles (CMB) in 2014, China's medal count (Silver and above) was a modest five. However, at the 2024 CMB held in Guanajuato, Mexico, an impressive achievement was made, with 339 red and white wines from 107 Chinese enterprises participating and claiming a total of 133 medals (6 Grand Gold, 83 Gold, and 44 Silver), representing 39% of all entries from China. This is a staggering 27-fold increase from the 2014 tally, showcasing remarkable progress.

Over the past five years, China's leading enterprise, Changyu, has garnered 1,147 awards at various domestic and international competitions, with multiple products winning the highest accolades in their respective categories. Its flagship brands, such as Longyu Estate, Koya Brandy, and Noble Dragon (Jiebaina), have been exported to over 80 countries and regions across Europe, North America, and Asia, reflecting the rapid internationalization of Chinese wines. With their superior quality and unwavering commitment, Chinese wines are making their mark on the global stage.

3. The concepts of green, natural, low-carbon, and sustainable development are increasingly becoming mainstream

As the socio-economic landscape evolves, the concepts of "green, natural, low-carbon, and sustainable development" in the wine industry are progressively emerging as the dominant paradigm. Notably, the eastern foothill of Helan Mountain in Ningxia has formulated three supportive systems, including the "Implementation Rules for the Management of Carbon Emission Trading in Ningxia Autonomous Region," and is currently constructing the "Yingu World Carbon Sink Vineyard," a multifunctional complex integrating grape growing, winemaking, and tourism, aimed at transforming abandoned gravel pits into prosperous purple treasures. Furthermore, Ningxia has initiated the "Carbon Asset Evaluation and Demonstration Application Project for the Vineyard Area at the Eastern Foothill of Helan Mountain," leveraging regional resource endowments to operate grape carbon sink assets with high value, thereby fostering the establishment of a typical vineyard carbon footprint and carbon sink assessment system.

More than 95% of China's wine products now utilize thin-walled and lightweight glass bottles, reducing material usage by over 20%, energy consumption and greenhouse gas emissions per bottle by 20%, and the weight of finished wine products in each container by approximately 1.3 tons, amounting to an annual reduction of approximately 20,000 tons in transportation weights. This significantly decreases fuel consumption and emissions from transportation vehicles, achieving a dual benefit of economic and environmental gains.

Through the implementation of projects such as heat recovery, water and electricity conservation, and "green packaging", indicators including comprehensive energy consumption, CO_2 emissions per unit of output value, major pollutant generation per unit of product, and wastewater generation per unit of product have reached international standards of excellence, marking beneficial explorations in green and low-carbon development.

Simultaneously, China has undertaken carbon footprint certification for wine products for the first time, quantifying direct and indirect CO2 emissions throughout the wine production process. This endeavour aims to gain a more precise understanding and evaluation of the environmental impact of wine production, enabling targeted adoption of more environmentally friendly and low-carbon measures to reduce carbon emissions and lay a solid foundation for the green, low-carbon, and highquality development of China's wine industry.

4. Dual-oriented quality evaluation, guided by flavour and sensory indicators, is applied to the quality control throughout the entire wine production process

Wine flavour represents a crucial characteristic in evaluating its quality, significantly influencing consumer acceptance and purchasing intention. It is a comprehensive sensation integrating taste, smell, and trigeminal nerve perceptions. Among these, odour and taste serve as the primary driving forces in flavour perception, independently influencing wine flavour while also enhancing or refining it through cross-modal interactions. Notably, wine aroma plays a pivotal role in determining the overall flavour quality. Scientific and precise analysis of its flavour contribution facilitates the interpretation of wine product characteristics and facilitates targeted production process regulation aimed at enhancing flavour quality.

In recent years, addressing the complexities of wine flavour, the diversity of analytical approaches, and the ambiguity in elucidating flavour traits, China's wine research community has delved deeply into the development of dual-oriented quality evaluation models centred on flavour and sensory aspects. By integrating artificial sensory evaluation with instrumental analysis, a more comprehensive flavour evaluation system is established, better elucidating the relationship between wine flavour, chemical composition, and sensory experience. Leveraging data processing methods such as statistical analysis and machine learning, precise quantitative correlations between wine flavour quality and underlying chemical substances are elucidated. The construction of such quality evaluation systems aids manufacturers in precisely identifying flavour quality control markers throughout the entire production process, thereby being of scientific guidance in making production strategies aiming at product flavour quality improvement.

5. Screening and industrial application are successfully carried out on indigenous wine yeasts

China boasts a diverse climate and widely distributed wine-producing regions, resulting in an abundant resource of indigenous wine yeasts. Through prolonged natural selection, these yeast strains have gradually adapted to the local terroir and grape characteristics. When utilized in wine fermentation, indigenous yeasts can fully embody the distinctiveness of grape varieties, potentially enhancing terroir expressions and crafting premium wines with pronounced individuality and style. Wines crafted with indigenous yeasts maximally preserve the regional characteristics of the product, showcasing remarkable terroir advantages.

Furthermore, amidst global warming, the issue of high sugar and low acidity in grapevine materials has become increasingly prominent. Chinese scientists have selected and bred several strains of indigenous yeasts, enabling China's local yeast market share to exceed 30% and facilitating bulk exports to traditional European wineproducing countries such as Italy, Germany, and Spain, adding a stunning Chinese touch to the global wine landscape. Indigenous yeasts have facilitated the expression of China's wine terroir diversity, significantly elevating the international competitiveness and reputation of China's wine industry.

Currently, the application of non-*Saccharomyces* yeasts in wine fermentation has emerged as a research hotspot, including aroma-enhancing, acidity-increasing, and flavour-specific yeast strains.

Wine fermentation is a complex microbial process where the physicochemical conditions of grape must interact with the microbial flora, thereby influencing wine quality. Non-Saccharomyces yeasts possess unique metabolic pathways and robust enzymatic activities, enabling them to reduce alcohol production while increasing glycerol, terpene, and ester contents. They also release mannoproteins or polysaccharides to improve mouthfeel and enhance colour stability. Notably, Torulaspora delbrueckii, a non-Saccharomyces yeast with a positive impact on wine sensory characteristics, is most widely used and commercialized. Co-fermentation with Saccharomyces cerevisiae can diminish vegetal aromas, enhance floral and fruity notes, and increase aroma complexity, sometimes even yielding dried fruit or pastrylike aromas.

With the advancements in modern biotechnology, including genomics, transcriptomics, proteomics, metabolomics, and high-throughput screening technologies combined with bioinformatics, the study of yeast interactions, metabolic mechanisms, and population dynamics holds immense promise. Specialized wine yeast strains with capabilities such as high sugar tolerance, acidity enhancement, aroma generation, and high alcohol tolerance continue to be developed and employed in production.

6. Modern analytical techniques and expert intelligent blending systems have been applied in the field of wine production

Modern analytical techniques, encompassing chromatography, mass spectrometry, spectroscopic technologies, and electronic nose technology, are employed in the analysis of wine aroma components and sensory attributes. These techniques can guide the improvement of raw materials, optimization of production processes, enhancement of quality expression, and innovation in consumption scenarios. Leveraging these techniques, a wine expert intelligent blending system has been developed. By entering the characteristics of the base wines from different vintages and varieties into the system, blending proposals are generated through artificial intelligence algorithms and big data analysis, enabling the formulation of diverse wine bodies that meet anticipated targets. This approach renders the blending of wines more quantitative, precise, intelligent, and efficient.

China's wine industry stands at the forefront of global production intelligence. Product blending and CIP (Clean In Place) have been fully automated. The post-processing procedures, including micro-oxygenation control, freezing control, and crossflow filtration, have also achieved intelligent production, all of which can be executed with a simple click of a mouse on the computer. The precise control throughout the entire production process ensures the efficiency of large-scale production and the stability and consistency of product batch quality.

7. A comprehensive product quality evaluation system for wine production has been established, encompassing six dimensions: product safety, flavour quality, sensory quality, labelling, consumer preference, and green packaging

Using the "Food Safety Law" and "Product Quality Law" as the foundation, China has formulated a series of product standards and regulations.

The quality and safety standards outline various indicator limits for product quality and safety, and are mandatory standards. These primarily encompass Food Additive Usage Standard (GB2760), Limits on Food Mycotoxin Contamination (GB 2761), Limits on Food contaminants (GB2762), Maximum Residue Limits of Pesticides (GB2763), among others.

Product quality standards define various aspects of products, including their definitions, classifications, requirements on raw materials and ingredients, physicochemical parameters, sensory parameters, production process control requirements, analytical methods, inspection rules, and requirements on labelling, packaging, transportation, and storage. These standards are typically recommendatory. Examples include Terms and Classification of Alcoholic Beverages (GB/T17204), Wine (GB/T15037), Brandy (GB/T11856.2), Ice wine (GB/T25504), and Characteristic Wines (*Vitis amurensis*) (GB/T27586).

Product labelling standards cover various mandatory and recommendatory requirements for product packaging, such as the General Rules for the Labelling of Prepackaged Foods (GB7718), General Rules for Nutrition Labeling of Pre-packaged Foods (GB28050), Requirements for Limiting the Excessive Packaging of Commodities (GB23350), and Logos for Packaging, Storage, and Transportation (GB/T191).

Green food standards encompass guidelines for Green Food (Wine) (NY/T274), Criteria for the Use of Food Additives in Green Food (NY/T392), Inspection Rules for Green Food Products (NY/T1055), and General Guidelines for Green Food Packaging (NY/T658).

Furthermore, guidelines such as Customer Satisfaction Monitoring and Measurement (GBT19014), Guidelines for Customer Satisfaction Organization Behaviour (GBT19010), and Guidelines for Customer Experience Management (GBT42509) are in place to evaluate consumer satisfaction with products. Enterprises also establish comprehensive quality management systems through certifications like ISO9001, ISO14001, and HACCP.

Based on these laws and regulations, national market supervision and administration departments at all levels conduct rigorous oversight throughout the production process, encompassing production access, process supervision, product sampling inspections, and penalty and accountability management.

8. References

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