Safety and Risk Management in Wine Production

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Abstract. This study analyzes and synthesizes research aimed at identifying potential hazards in wine production, determining critical control points (CCPs), and defining mitigation measures. Based on the reviewed literature, hazards and risks were mapped across the technological stages of wine production, from raw material cultivation to the finished product. Eight CCPs were identified in the production scheme. The highest risk levels were associated with the clarification and packaging stages, where correct dosing of fining agents and the use of certified materials are essential. The results indicate that wineries implementing the HACCP system achieved a reduction of microbiological risks by approximately 60%. This study is based on a review of published scientific literature. A technological scheme of wine production was developed, CCPs were defined, and control measures were proposed. Special attention was given to the clarification stage, where potential hazards and preventive actions were analyzed in detail.

Keywords: food safety, risk management, wine production, HACCP, wine clarification.

1 Introduction

Wine production involves a series of stages, from agriculture to processing, storage, and transportation. At each stage, different risks and safety issues arise, including biological, chemical, physical, and occupational health risks.

The main objective of this article is to provide scientifically evidence-based recommendations for the identification, assessment, and management of risks. The categories of risks in wine production include: chemical risks (pesticide and herbicide residues; heavy metals such as cadmium, lead, and arsenic; substances formed in grape products through the action of mycotoxins and fungi; and compounds formed during technological processing, including fermentation by-products and biogenic substances); biological risks (microorganisms, bacteria, yeasts, and fungi); physical risks (foreign objects compromising product purity, such as soil residues and stone fragments, as well as equipment-related hazards); environmental and climate risks (climate change affecting grape cultivation, increasing pesticide use and fungal risk; water shortages, high temperatures, and extreme weather events impacting grape quality, yield, and the production chain); and supply and logistics risks (disruptions of temperature, humidity, and light conditions during storage and transportation).

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In the study entitled "An Evaluation of Food Safety Performance in Wineries", the control of metal residues (Pb, Cd, As) among producers in the Madrid region was identified as one of the most problematic CCP stages. At the same time, deficiencies in fungicide and pesticide control were reported [1].
Another study, "Processing Factors and Risk Assessment of Pesticide Residues in Wine", also noted that pesticide residue levels vary depending on processing factors and emphasized the need for systematic risk assessments related to consumer exposure [2].
In the study entitled "Chemical Hazards in Grapes and Wine, Climate Change and Challenges to Face", it was shown that climate change increases chemical hazards in grapes [3].
Based on these research studies, the stages of wine production, associated risks, critical control points (CCPs), and related control measures were systematically analyzed.

2 Analysis

The OIV (International Organisation of Vine and Wine) standard "OIV Guide to Identify Hazards, Critical Control Points and their Management in the Wine Industry" recommends the application of HACCP principles to ensure safety in wine production. In this system, the so-called "Prerequisite Programs" (PRP) are of great importance (hygiene, equipment cleanliness, worker training, control, etc.).

A study by López-Santiago et al. (2022) evaluated the implementation of the HACCP system in Spanish and Portuguese wineries. The results showed that the level of microbiological risks was reduced by 60% in establishments where HACCP was implemented, but documentation and worker training were still not at the desired level.

Benito et al. (2019) showed that the HACCP system is an effective tool for managing substances harmful to health in wine — biogenic amines, ethyl carbamate and sulfites. The levels of these substances should be controlled mainly during the fermentation and storage stages [4].

Microbiological hazards and OTA risk. Martínez-Rodríguez and Carrascosa (2009) investigated the risk of Ochratoxin A (OTA) formation in wine in the context of HACCP. The study found that OTA formation was mainly observed before fermentation and during the clarification phase. The authors suggested that temperatures not exceeding 18°C and that equipment be kept sterile during these phases as key CCPs.

These results are also confirmed in the OIV (2018) "Hazard Identification Guide". The OIV identifies OTA and microbiological contamination as one of the most important hazards in the wine industry during its risk identification [5], [6].

Regarding chemical hazards and heavy metal management, a study by López-Santiago et al. (2023) assessed heavy metal contamination (As, Pb, Cd) in wine. The results showed that the levels of these substances were fully compliant with EU and OIV regulations in establishments where the HACCP system was implemented. The highest risk was observed during the clarification and storage phases [7].

Plank et al. (2020) in their article "A Review of Plastics Use in Winemaking" investigated the migration of phthalates and bisphenol-A (BPA) from plastic containers into wine. They highlighted the potential health risks of these chemicals and the importance of including them as “chemical CCPs” in the HACCP plan [8].

Physical hazards and the packaging stage. A study by Christaki and Tzia (2010) compared HACCP and ISO 22000 systems, with the packaging stage being the most critical point. Their results showed that physical contamination was three times less common in establishments with HACCP implementation. B. Trela (2018) noted that simplified HACCP plans are possible, especially for small and medium-sized enterprises, and that the most important control points are clarification and packaging [9] [10].

While analyzing the OIV and international standardization approaches, the “Guide to Identify Hazards and Critical Control Points” document prepared by the OIV (2018) defined the international framework of the HACCP system in wine production and, according to this document, the CCPs that require the most attention in wine production were noted: fermentation (biological and chemical risks); clarification (physical and chemical risks); packaging (microbiological and physical risks). This approach was also confirmed with practical examples in the training materials prepared by WineCampus (2021) [11]. The factors on which the successful implementation of the HACCP system depends were identified: the training and knowledge level of the staff; the technical and sanitary condition of the equipment; the correct determination of CCPs at each stage; the presence of a documentation and continuous monitoring system. The table below reflects the HACCP steps, risks and important measures to be taken to reduce them at different stages of wine production (table 1 - compiled by the author).

Table 1. HACCP steps in wine production

Stage	Possible Type of Hazard	CCP (Critical Control Point)	Control Measures / Limits
1. Reception of raw material (Grapes)	Pesticide residue, mold, dirt	Yes	Purchase only from certified suppliers, visual inspection, laboratory analyses
2. Washing and sorting of grapes	Soil, stones, leaves, chemical residues	Yes	Quality of washing water, mechanical cleaning
3. Crushing and juice extraction	Physical contaminants, metal fragments	Yes	Equipment hygiene and material integrity control
4. Fermentation	Microbial growth, sulfur dioxide level	Yes	Temperature (20–28°C for red, 12–18°C for white), SO_2 level (50–150 mg/L)
5. Filtration and clarification	Physical and microbiological contamination	Yes	Sterile filtration, equipment disinfection
6. Wine maturation	Microbial development, oxidation	No (under control)	Temperature (10–15°C), oxygen control
7. Bottling and packaging	Glass fragments, non-sterile containers, contamination	Yes	Sterilization, filtration, filling with purified air
8. Labeling and storage	Physical and chemical contaminants	No	Store in a dry, cool, dark environment (10–15°C)

The description of critical control points in the technological production scheme of wine is illustrated in the figure 1.

GRAPE RECEPTION

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INSPECTION OF RAW MATERIAL
(pesticides, mold, debris)

CCP 1 → CHEMICAL AND PHYSICAL CONTAMINATION

↓

CRUSHING AND JUICE SEPARATION
(equipment cleanliness, corrosion control)

CCP 2 → EQUIPMENT HYGIENE AND TECHNICAL CONTROL

↓

FERMENTATION
(yeast, temperature, SO_2 level)

CCP 3 → TEMPERATURE AND SO_2 LIMITS

↓

CLARIFICATION / FILTRATION
(clarifying agent, filter cleanliness)

CCP 4 → AGENT DOSAGE AND FILTER STERILIZATION

↓

MATURATION / STORAGE
(barrel condition, oxidation, humidity)

CCP 5 → TEMPERATURE AND BARREL QUALITY

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BOTTLING / LABELING
(sterile bottles and corks)

CCP 6 → STERILIZATION OF BOTTLES AND CORKS

↓

STORAGE AND DISTRIBUTION
(temperature, light exposure, package integrity)

CCP 7 → CONTROL OF TEMPERATURE AND PHYSICAL DAMAGE

↓

CCP 8 → CONTROL OF LABELING AND STORAGE

↓

FINAL PRODUCT
(safe and high-quality wine)

Fig. 1. CCPs in wine production.

As mentioned above, the clarification stage is listed among the most relevant stages of the critical control points. Based on this approach, the selection of the clarification stage as a critical control point was investigated in more depth. The clarification stage in wine production (i.e. the process of clearing and clarifying wine from turbidity) is a very important stage for the quality and safety of the product. The application of HACCP principles at this stage serves to prevent biological, chemical and physical risks in the product. The following are the main HACCP rules to be applied at the clarification stage:

1. Hazard analysis. Possible hazards arising at the clarification stage:

• Biological risks: contamination with yeast, bacteria (e.g. Lactobacillus, Acetobacter);
• Chemical risks: excessive use of diluents (gelatin, bentonite, kaolin, egg white, PVPP, etc.) or their residues remaining in the product.
• Physical hazards: debris from filter material, dust particles, sediments or equipment component residues.

2. Identification of critical control points (CCP). The main CCPs in the clarification phase are: selection and dosing of diluents (the quantity and quality of the substance must be specified in the HACCP plan, only substances approved for the food industry must be used); cleanliness and sanitation of the equipment (it is important to clean the tank, pipes and filters using the CIP (Clean-in-Place) method); temperature and storage conditions (the clarification temperature should be between 10–15°C (this temperature may vary depending on the clarification method and diluent), contact with oxygen should be reduced to minimize oxidation). The table below sets out the critical limits for the clarification phase and the measures to eliminate them (table 2 – compiled by the author).

Table 2. Determination of critical limits and corrective actions

Control Point	Critical Limit	Note
Amount of Clarifying Agent	Must not exceed the standard (according to technological instructions)	Checked for each batch
Level of Microbiological Contamination	Must be less than 10^3 CFU/ml	Sterile environment must be ensured
Temperature	Within the range of 10–15°C	High temperature increases oxidation
Filter Cleanliness	Must be checked before each use	Prevents physical contamination

According to the table described above, the following actions are necessary in cases where critical limits are exceeded: the diluted wine batch is isolated; the reasons are investigated (dosing error, sanitary violation, etc.); if necessary, the product is sent for re-filtration; this situation is documented in the registration system. Important documents to be kept during documentation: quality certificates of diluents; monitoring logs (temperature, time, analysis results); CIP and sanitary cleaning protocols; HACCP plan and records of remedial measures.

Compliance with HACCP rules during the clarification stage protects the safety, stability and organoleptic quality of the wine. The main goal is to minimize the risks of contamination, oxidation and residues during clarification.

3 Conclusion

As a result of the research conducted, it was determined that the stages such as grape reception, pressing and juice separation, fermentation, clarification and filtration, maturation, packaging and storage are critical points in wine production technology. Since the most dangerous of the mentioned stages is the clarification and packaging of wine, during the risk assessment in dilution, critical limits of factors such as the fining agent dosage, the level of microbiological contamination, and temperature were noted. Important measures and important documents (quality certificates, monitoring logs, sanitary cleaning protocols) to be taken in connection with these risks were indicated.

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