Review Article

Research Progress on the Causes of Turbidity in Lujiu and the Treatment Measures

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Abstract
Lujiu is a traditional Chinese alcoholic beverage made by extracting animal and plant medicinal materials in Baijiu (Chinese liquor) or Huangjiu (Chinese rice wine). Due to the precipitation of various substances in the base liquor, Lujiu has a richer taste and higher nutritional value. However, it is also prone to turbidity. The turbidity that occurs after the preparation and storage of Lujiu seriously affects its appearance, quality and commercial value. Although there is a lot of discussion about turbidity and precipitation in wine and fruit wine, articles about the turbidity phenomenon of Lujiu are not common. This article reviews the main components in Lujiu, such as proteins, polysaccharides and phenolic substances, as well as the complex interactions between these components, and the commonly used methods for removing turbidity. This article aims to provide a basis for the future development of Lujiu products and the prevention and control of turbidity.

Keywords: Clarification, Lujiu, Removal, Treatment method, Turbidity

1 Introduction

Lujiu is a Chinese traditional alcoholic beverage made from herbal medicines or food homologous materials through extraction and blending processes [1]. It integrates multiple aspects of Chinese traditional cultures, such as diet and medicine, and is an alcoholic beverage variety that has attracted much attention from consumers under the new trend of health consumption. Lujiu has many similarities with liqueur. Both involve adding edible substances to a base liquor and then undergoing processes such as soaking, distillation, and blending. The differences between Lujiu and liqueur are shown in Table 1.

Based on the functional substances contained in herbs, soaking herbs in alcoholic beverages for days, weeks, or years is a tradition for people all over the world [2]. In China, there is also a thousand-year tradition of using plants to make wine. Through soaking, the functional components in the plants are precipitated in the wine, or secondary metabolites are generated, which can increase the nutritional and health care functions of the wine. The raw material for making this wine is plants with the same medicinal and edible origin, which are used for health care and can be drunk by most people. Medicinal wine can be considered one of the earliest types of Lujiu products in China. As people's consumption concepts have evolved and health awareness has increased, Lujiu products with health benefits, such as medicinal wine, have garnered increasing attention from consumers [3].

Table 1: The differences between Lujiu and liqueur.

Comparison Items	Liqueur	Lujiu	Ref.
Base liquor types	Distilled alcoholic drink.	Fermented alcoholic drink or distilled alcoholic drink.	[4]
Names of base liquor	Whisky, Vodka, rum, and distilled gin.	Baijiu, Huangjiu.	[5]–[8]
Additives	Fruits, spices, herbs, sugar.	Essential parts of plants and animals.	[2]
Flavor and texture	Fruit aroma, floral aroma, and spice flavor.	Medicinal fragrance	[9], [10]
Origin	Europe	Asian	[2]
Usage	Dessert wine aids digestion.	Health preservation and care.	[11]

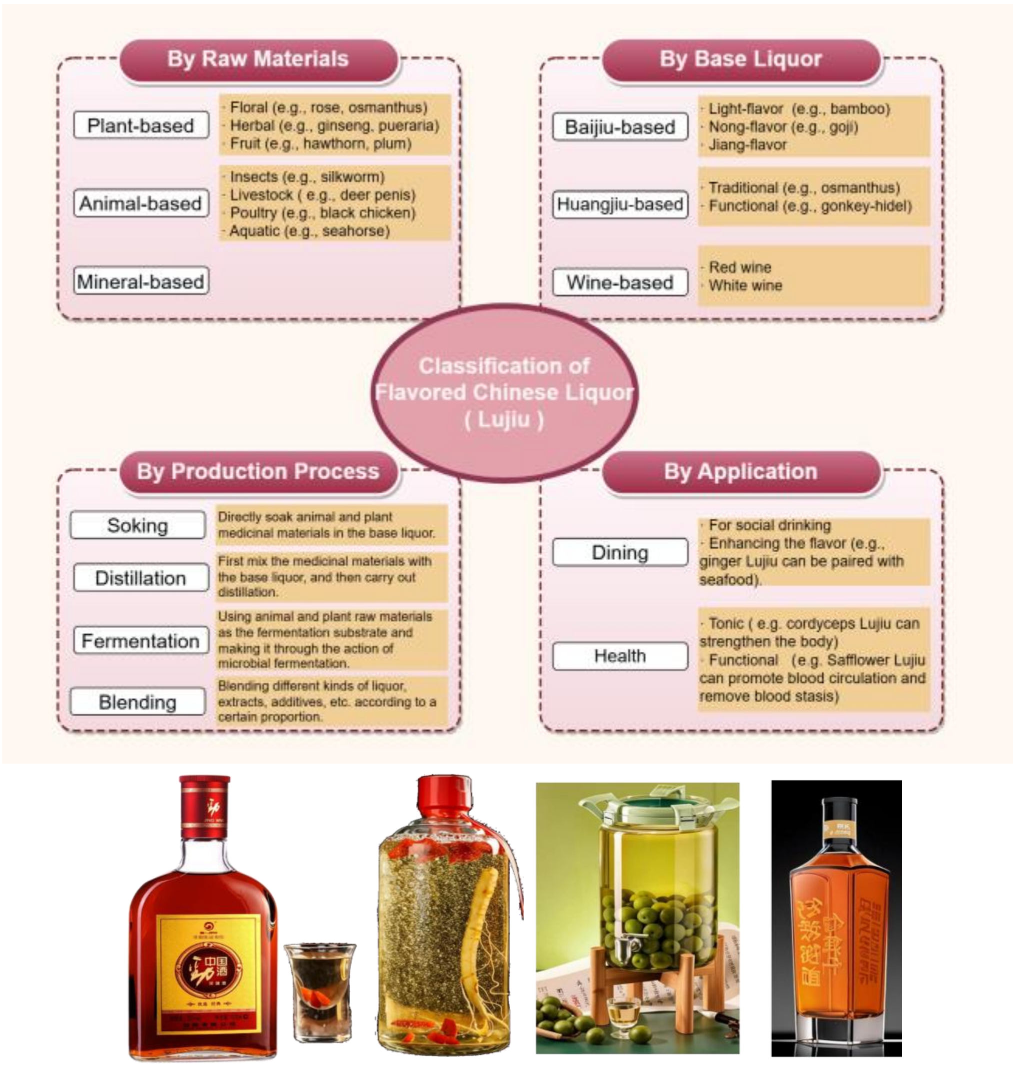

Figure 1: Classification of Lujiu.

As a kind of alcoholic beverage product with unique characteristics, Lujiu has its significant advantages. On the one hand, Lujiu contains a diverse array of health-promoting components. In China, most of the Lujiu are based on prescriptions and new results of pharmacological research on traditional Chinese medicinal materials as the basic formula. Mainly for health and fitness, it has the effect of strengthening the body. Lujiu generally contains various nutrients such as minerals, monosaccharides, polysaccharides, amino acids, peptides, proteins, organic acids, amino acids, flavonoids, phenolic acids, alkaloids and saponins [11]. Xu *et al.*, have used five kinds of Chinese herbs, such as Radix pseudostellariae, Astragalus and jujube to made Lujiu which has an anti-fatigue effect [12]. Yu *et al*., utilized *Dendrobium* (D.) officinale to develop Lujiu, which exhibits efficacy in reducing blood glucose levels and enhancing immune function [13]. On the other hand, Lujiu has a rich and diverse taste and flavor profile, because it is produced from a variety of raw materials, such as herbs, fruits, and aromatic plants. Lan *et al*., employed Head Space-Solid Phase Microextraction-Gas Chromatography-Mass Spectrometry (HS-SPME-GC-MS) to analyze the volatile compounds in six kinds of commercially available Lujiu. A total of 113 flavor compounds, including esters, alcohols, aldehydes, and olefins, were identified [14]. Mansi *et al*., identified 458 volatile compounds by HS-SPME-GC-MS, and according to the flavor characteristics of 34 kinds of Lujiu, the flavor types were divided into four types: herbal flavor, flower flavor, animal flavor and compound flavor [15]. The classification of Lujiu based on raw materials, base liquor, production process and application is shown in Figure 1.

As an alcoholic beverage, factors such as taste, color, and aroma play a crucial role in the product's sales performance. However, due to the complex sources of Lujiu, the different properties of their alcohol-soluble and water-soluble substances, turbidity and precipitation are prone to occur during production, storage and sales, which greatly affects the sensory quality and sales status of the product. It is also an enterprise's production frequently asked questions. The source of precipitation in wine is also related to the precipitation of substances added to the wine, such as proteins and polyphenols, through polymerization reactions. In actual production, turbidity can be effectively controlled through the improvement of equipment, optimization of processes, and strict control of raw materials. Additionally, methods such as adsorption, the addition of clarifying agents, and freezing can further reduce the occurrence of turbidity and precipitation during storage. This article reviews the nutritional value of herbal wine, analysis of the causes of turbidity, and methods of removing turbidity to support subsequent research.

2 Substance in Lujiu Associated with Turbidity

Lujiu is a complex mixture containing a variety of substances, mainly including polysaccharides, polyphenols, flavonoids, proteins, etc. These components work together to provide the basis for the health care effect of Lujiu. However, the interaction between the ingredients can also cause the Lujiu to be cloudy.

2.1 *Polyphenols*

Polyphenols are an important class of secondary metabolites synthesized by plants [16]. Phenolic compounds are natural substances consisting of one or more hydroxyl groups connected to one or more aromatic or benzene rings and are found in many herbs and fruits. Polyphenols are important functional components and flavor substances in various wines, such as Lujiu and wine [17]. The common polyphenols in Lujiu are resveratrol, catechin, quercetin, flavonoids and so on [18]. The addition of phenolic compounds in food has garnered growing interest due to their biological activities, such as free radical scavenging and antioxidant effects. These compounds can inhibit the oxidation of proteins and lipids in foodstuffs, thereby benefiting human health [19]. Therefore, people also add plants rich in polyphenols to alcoholic beverages to enhance the nutritional value of wine. However, the chemical properties of the phenolic hydroxyl group in the structure of polyphenols are relatively active, which makes it susceptible to environmental factors, so its application in food is limited. Xiaoling *et. al.*, found that high alcohol content and low feed liquid were more conducive to the leaching of polyphenols of Mulberry Lujiu [20]. The winemaking process and subsequent wine storage conditions will affect the content and properties of polyphenols. The types and contents of polyphenols in different Lujius are different, which are shown in Table 2.

Table 2: The types and contents of polyphenols in different Lujiu.

Categories	Polyphenol Species	Content (mg/L)	Main Effect	Ref.
Blueberry Lujiu	Anthocyanin, flavonoid	4–30	Antioxidant, improve vision, enhance memory, anti-inflammatory.	[21]
Mulberry Lujiu	Anthocyanin	10.14	Antioxidant, anti-inflammatory, reduce the blood-fat.	[22]
D. officinale Lujiu	Flavonoid	710	Enhance immunity, reduce the blood-fat.	[13]
Euryale ferox Lujiu	Flavonoids, phenolic acids	46.4	Stop diarrhea and remove dampness.	[23]
Lobed Kudzuvine Root Lujiu	Puerarin	0.898	Cure alcohol and protect liver, prevent cardiovascular and cerebrovascular diseases.	[24]

2.2 *Protein*

Although the protein content in Lujiu or other alcoholic beverages is at an extremely low level, its instability is still one of the most common non-microbiological causes to cause turbidity in the beverage. Studies on protein stability in alcoholic beverages are mostly concentrated in wine, Huangjiu, fruit wine, and beer. The protein in alcoholic beverages comes mainly from yeast and fruit. Wine is fermented from grape skins and seeds, and most of the protein can be removed during the brewing process [25]. As the storage time increases, the protein in fruit wine gradually aggregates, resulting in turbidity or even precipitation in bottled wine [26]. White wine is fermented only with clear fruit juice, the concentration of phenols is very low, and it may still contain a high protein content after bottling [27].

The protein characteristics of sake are significantly different from those of other fermented alcoholic beverages. The main feature is that the proteins in medicinal herbs and plants usually undergo denaturation, exposing their hydrophobic groups, which results in a certain solubility during the extraction process. However, during the blending stage in the later stage, due to the change in alcohol concentration, the solubility of these proteins decreases, leading to the occurrence of precipitation. One study used a reconstitution method to study the heat-induced aggregation behavior of purified wine proteins and showed that chitinase was the protein that aggregated most readily and was also the protein that formed the largest particles [28]. As macromolecular substances, proteins are easily cross-linked with other substances in solution. Temperature, pH and other factors can cause protein in alcohol development, self-aggregation, and flocculation [29]. Xie *et al*., used two-dimensional electrophoresis and matrix-assisted laser ionization time-of-flight tandem mass spectrometry (MALDI-TOF/TOF MS) to analyze the main components of Shaoxing rice wine colloidal mist proteins, showing that the amino acids in the colloidal mist are characterized by high hydrophobicity and low water solubility [30]. However, there is little research on protein of Lujiu, but in practical terms, there is a possibility of protein quality in the basic wine and additive materials.

2.3 *Polysaccharide*

Polysaccharides are the key components of the plant cell wall, such as glycans, cellulose, galactomannan, etc., that play a specific role in the regulation of human sugar metabolism [31]. The main sources of polysaccharides in alcoholic beverages include grapes, malt, grass, fruit and other raw materials, and microbial substitutes during the production process [32]. Polysaccharides are important functional substances in plants commonly used for brewing Lujiu, such as *Cistanche tubulosa* [33], *Lycium barharum L*. [34], *Panax ginseng C.A. Mey*. [35]. Wu *et al*., studied the structure of blackberry wine turbidity and found that the proportion of polyphenols and proteins in the turbidity was large and dominated, followed by total sugar [36]. Some information about the polysaccharide content of Lujiu and the measurement method is shown in Table 3. It has been observed that the polysaccharide content in Lujiu prepared from Chinese medicinal materials is consistently high, particularly which made from a mixture of different Chinese medicinal materials.

Table 3: The polysaccharide content of Lujiu and measurement method.

Categories	Polysaccharide Species	Content (mg/L)	Main Effect	Detection Method	Ref.
Lycium barbarum Lujiu	Lycium barbarum - polysaccharide	1457	Anti-tumor, anti-aging	phenol-vitriolic colorimetry, Ultraviolet-visible spectrophotometry	[37]
Ganoderma lucidum Lujiu	Ganoderma lucidum - polysaccharides	570.93	Improve blood sugar, adjust blood lipids, anti-inflammatory, anti-venom	Ultraviolet-visible spectrophotometry	[38]
Mulberry Lujiu	Mulberry -polysaccharide	127.58	Anti-aerobic, anti-fatigue	Phenol-vitriolic colorimetry	[39]
Silver apricot leaf dew wine	Lycium barbarum polysaccharide, jujube polysaccharide	2.79	Antitussive, antidiarrheal	Spectrophotometry	[40]
Shenrong Yuye Lujiu (Multi-drug combination)	Polygona-polysaccharose,Lycium barbarum - polysaccharide etc.	3880	Invigorate qi, improve eyesight	Phenol-vitriolic colorimetry	[41]

2.4 *Metal ion*

The identification of metals in Lujiu is a subject of increasing interest since complexation may reduce their toxicity and bioavailability. This issue is equally applicable to wine. Pesticides used in the planting process, environmental pollution, and the production and preservation of Lujiu may cause metal ions, such as iron, copper, manganese, etc., to be mixed into the wine [42]. Camelia *et al*., used an ion exchange molecular sieve to remove metal ions from white wine. The results showed that the method was effective and the materials used did not change the quality of the wine [43]. Iron and copper in wine will accelerate the oxidation of wine, thus affecting the stability of the wine [44]. Zhang *et al*., employed microwave digestion coupled with graphite furnace atomic absorption spectrometry to quantify the lead content in Lujiu [45]. Zhao used the Flame method - atomic absorption spectrophotometer the determination of ferric content of Lujiu [46].

2.5 *Higher fatty acid ethyl ester (HFAEE)*

Higher fatty acid ethyl esters (HFAEE) are widely present in raw wine in the form of colloidal nuclei [45]. There are three main types of HFAEE in alcohol: ethyl palmitate, ethyl oleate, and ethyl linoleate. Because it is in the form of gel in wine, it can give people a smooth taste and make the wine rich in flavor [46]. Under low temperature or low ethanol environment, the solubility of higher fatty acid esters decreases, and milky white floc suspension or precipitation appears. Some studies have found that at 10 °C, wine samples with a total content of ethyl palmitate, ethyl oleate and ethyl linoleate >250 mg/L are at risk of turbidity [47]. The solubility of higher fatty acid esters decreases under low temperature or low ethanol environment, and milky white floc suspension or precipitation appears [33]. In the production process of Lujiu, low-alcohol baijiu is often used, which will increase the precipitation of HFAEE.

3 Causes of Turbidity in Lujiu

Lujiu contains proteins, polysaccharides, amino acids, flavonoids, alkaloids, saponins and other nutrients, which makes it have health care function. But in the process of production and storage of Lujiu, the corresponding physical, chemical and biological reactions will slowly occur between these components and base wine components, thus changing the original equilibrium state of the Lujiu system and causing precipitation. The main substances causing the turbidity of dew wine are shown in Figure 2.

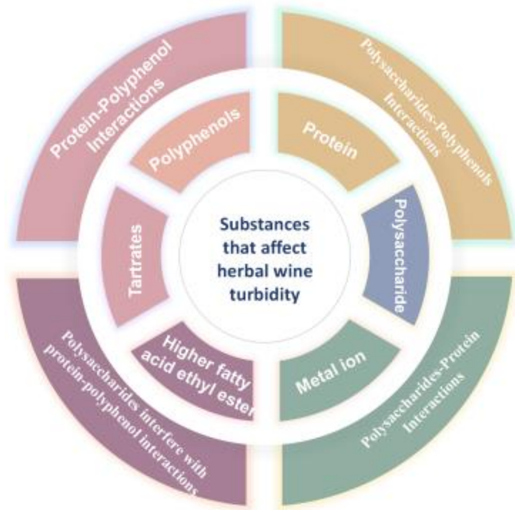

Figure 2: Substances that affect Lujiu turbidity.

3.1 *Protein-polyphenol interactions*

The current common view is that the interaction between phenolic and proteins is related to the formation of haze [48]. Haslam *et al*., first proposed the theory that protein-polyphenols are combined with each other through hydrophobic bonds and hydrogen bonds at multiple sites. Proteins have hydrophobic properties due to their aliphatic amino acid side chains, allowing them to form hydrophobic pockets that bind to polyphenols [49]. According to the former study, it showed that natural polyphenols have a peculiar affinity for "holes, pores or crevices" in polysaccharide structures. Gang Wu used high-performance liquid chromatography (HPLC), solid-state nuclear magnetic resonance (SS-NMR), Fourier transform infrared (FTIR) spectroscopy, and differential scanning calorimetry (DSC) to identify the main components of blackberry wine turbidity. The results show that the main substances in blackberry wine are polyphenols and proteins, in addition to polysaccharides, sulfur, phosphorus and iron [35]. The combination of hydrophobic bonds and hydrogen bonds is considered to be a model of protein-phenolic interactions. When protein hydrogen bonds are broken, more sites are exposed, which can combine with phenolic substances to form turbid substances [50].

3.2 *Polysaccharides-polyphenols interactions*

The interaction between polysaccharides and polyphenols can lead to the formation of diverse structures within the wine matrix, thereby modifying the physicochemical properties of the system and ultimately affecting the sensory quality, nutritional attributes, and functional activities of food products. These interactions primarily occur via non-covalent forces such as hydrogen bonding, ionic interactions, van der Waals forces, and hydrophobic effects. Additionally, covalent interactions, including enzymatic oxidation, carbodiimide-mediated cross-linking, and free radical-induced coupling, can also facilitate the formation of polysaccharide-polyphenol complexes [51]. This combination is reversible and highly specific [52]. Among them, hydrogen bonds mainly exist between the phenolic hydroxyl groups of polyphenols and the oxygen atoms of polysaccharide glycosidic bonds. The interaction between polysaccharides and polyphenols affects the digestion and absorption of polyphenols, because polysaccharides can embed polyphenols within the structure, thereby reducing the bioavailability of polyphenols.

3.3 *Polysaccharides-protein interactions*

There are two types of interactions between proteins and polysaccharides. One is that proteins and polysaccharides cause phase separation due to thermodynamic incompatibility between the two biological macromolecules, including binding phase separation and mutually exclusive phase separation [53]. The interactions arising from the attraction and repulsion between different biopolymers are influenced by internal factors such as pH, ionic strength, and charge density, as well as physical factors including temperature [54]. Second, the two generally form soluble and insoluble complexes through covalent bonds, electrostatic interactions, hydrogen bonds, hydrophobic bonds, van der Waals forces, ionic bonds, size exclusion effects, and molecular entanglement [55]. The combination of polysaccharide and protein reduces the degree of polymerization between unstable proteins and establishes a relatively stable system [56]. Luís *et. al*., found that the utilization of carboxymethylcellulose in red wines effectively enhances tartaric stability while preserving the integrity of phenolic composition, sensory properties, and color stability [57].

3.4 *Polysaccharides interfere with protein-polyphenol interactions*

The interaction between proteins, polysaccharides and polyphenols exists in many food systems. In particular, food systems, polysaccharides, can prevent the precipitation caused by the interaction between proteins and polyphenols. It is generally believed that polyphenols are physical cross-linking agents between protein molecules, forming insoluble aggregates through hydrophobic or hydrogen bonding interactions. The presence of polysaccharides interferes with this interaction and destroys the binding between proteins and polyphenols, or forms a protein-polyphenol-polysaccharide tertiary complex. The addition of polysaccharides forms a protective layer on the surface of the protein, which hinders protein aggregation to a certain extent. And the emergence of polyphenol active groups forms a kind of rigid, hydrogen-bonded protein and sugar micellar structures [58].

3.5 *Metal ion*

Currently, limited research has been conducted on the specific metal ions that negatively impact the clarity of Lujiu. However, it can be reasonably inferred that heavy metal ions such as lead and cadmium may adversely affect the clarity of Lujiu. This is because heavy metal ions have the potential to form insoluble complexes with organic acids, proteins, and other components in the liquor, leading to turbidity and precipitation [59]. Gang *et al*., investigated the effect of metal ions on turbidity in blackberry Lujiu and demonstrated that metal ions promote the interaction between proteins and polyphenols by binding to proteins and then chelating with multiple polyphenol molecules [60].

4 Measures to Reduce Turbidity and Sedimentation of Lujiu

Clarity is a critical sensory attribute of Lujiu, serving as the most perceptible characteristic of the product. It significantly influences both product quality and marketability. Consequently, turbidity removal is an essential step in Lujiu production. During production, physical, chemical, and biochemical interactions between the base wine and medicinal ingredients, water quality, the quality and alcohol content of the base wine, equipment sanitation, and environmental factors can easily lead to issues such as turbidity, loss of transparency, and precipitation in Lujiu.

4.1 *Clarification*

Adding a clarifying agent is a common clarifying method in Lujiu technology. Clarifying agents can be divided into two categories: organic matter and inorganic matter [61]. After organic clarifiers, such as gelatin, egg white, etc., are dissolved in hot water, they can easily form a transparent colloidal solution and be mixed with the wine to play a clarifying role. Inorganic clarifiers, such as diatomaceous earth, bentonite, kaolin, etc., are all viscose [62]. Since these substances have a large specific surface area, they have strong adsorption capacity and can absorb the colloidal substances in the wine. Generally, the clarifier used for processing Lujiu includes gelatin, diatomaceous earth, etc. [11]. Yuhang Liu *et al*., showed that the use of diatomite turbidizing agent for turbidity removal could improve the membrane filtration efficiency of purple-rice Lujiu and enhance its stability [63]. Zhihong *et al*., demonstrated that the light transmission rate of Kudzu Lujiu reached 97.8% following the addition of activated carbon and diatomite for deturbidity treatment. Furthermore, they evaluated the impact of four environmental conditions on stability, revealing the following hierarchy: low temperature < violent oscillation < 60 °C high temperature < open air exposure [24]. According to the study by Daniel *et al*., extensive removal of colloidal and macromolecular matter by the bentonites with potential to impact the characteristic properties of the wine [64]. Pettinelli *et al*., used legumin and chitin as clarifiers to improve the clarification effect of wine [65]. At present, some scholars are committed to researching some stabilizers that can replace bentonite, such as yeast mannoprotein, seaweed polysaccharide, chitin, protease, or to eliminate or reduce the turbidity after fruit wine through ultrafiltration and other methods [66]–[68].

The adsorption method uses the micropores on the surface of the adsorbent to form surface tension to adsorb precipitated substances in low-alcohol liquor [69]. The adsorption treatment of Lujiu with activated carbon can reduce the production of turbidity [70]. Some researchers also believe that the light absorption value of activated carbon adsorption treatment of wine has been greatly reduced, but the active ingredients have been lost. After membrane filtration, the sensory indexes of the wine samples were obviously improved, the light absorption value did not change significantly, and the turbidity removal effect was better [71]. Powdered activated carbon produced using high-quality fruit shells and charcoal as raw materials, using physical methods, is one of the common adsorbents. Wang *et al*., performed activated carbon adsorption treatment on the original wine for 36 h, which effectively reduced the content of higher fatty acid ethyl esters while ensuring the flavor of the wine, and basically maintained the original aroma [47]. Omoniyi studied the protein adsorption capacity of three adsorbents: titanium dioxide, alumina and activated carbon, and increased the suspension adsorption capacity of adsorbents treated with calcium or magnesium ions by 12% to 16%. At pH 7.0, pretreatment with calcium ions significantly increased TiO_2 adsorption capacity [72]. The research by Huang *et al*., found that the activated carbon adsorption method was not suitable for removing the turbidity of wine, and may affect the active ingredients in wine [71].

4.2 *Polysaccharide addition*

Adding polysaccharides is an effective method to enhance the stability of various alcoholic beverages, including wine, beer, rice wine, and fruit wine. Polysaccharides not only improve the taste and texture of these beverages but also prevent sedimentation and turbidity, thereby extending their shelf life. However, current research on the application of polysaccharides in Lujiu remains limited. Millarini *et al*., isolated and purified polysaccharides from *Saccharomyces cerevisiae* and added them to wine to reduce protein haze to about half of the initial value [73]. Yang *et al*., studied that polysaccharides such as pectin, xanthan gum, and guar gum can inhibit turbidity [74]. Some researchers have also reduced the production of turbidity by adding polysaccharides such as carrageenan, chitin, and chitosan to wine [75]. Canalejo *et al*., extracted six kinds of polysaccharides from wine pomace and must, adding them to white wine as clarifying agents, which could not only play a clarifying effect, but also increase the content of volatile substances in the wine body [76].

4.3 *Freezing clarification*

Freezing clarification means that the solution is stored at a low temperature for a certain time to denature the colloid, and then filtered to remove the suspended particles in the solution after thawing, so as to achieve the clarification effect [77]. There are few studies on the application of this method in Lujiu, and it is mainly used in the clarification of fruit juice and fruit wine. Some substances in the blended liquor will be precipitated as the temperature decreases, the solubility decreases, and the sedimentation and condensation increase. Freezing can make some colloidal substances deposit and clarify, including pigments, proteins, etc., so that the taste of the wine becomes soft [11]. Compared with other post-treatment purification and clarification methods, freezing treatment results in less loss of nutrients and improved quality. Second, the speed of clarification is fast, and the effect is good. Xiaohua *et al*., investigated the clarifying effects of frozen clarification and three clarifying agents (saponite, gelatin, pectinase) on mulberry fruit wine. They found that the light transmission rate of the wine gradually increased with prolonged low-temperature treatment. However, after 30 days, the change in light transmission became less significant. Compared to gelatin clarification, frozen clarification better preserved the original color and flavor of the mulberry fruit wine [78].

4.4 *Other methods*

In the production of Lujiu, various methods are employed based on the characteristics of raw materials and processing techniques. For instance, when fresh coconut water is used as the raw material for producing coconut Lujiu, chemical demulsification can be applied. Ethanol, acting as a demulsifier, can disrupt the emulsification system in the Lujiu, causing the finely dispersed particles to coalesce and precipitate, thereby achieving clarification [79]. In addition, various clarifying agents can be used in combination to achieve enhanced results. For instance, Qile *et al*., treated blueberry Lujiu with a combination of chitosan (0.2 g/L) and xanthan gum (0.4 g/L), resulting in a light transmission rate that was 31.4% higher compared to the untreated raw wine sample [80]. The comparison of the advantages and disadvantages of several turbidity removal methods commonly used in the production process of Lujiu is shown in Table 4

Table 4: Comparison of common methods for removing turbidity in Lujiu.

Clarification Method	Mechanism	Advantage	Disadvantage	Applicability	Ref.
Activated carbon	Activated carbon has a large specific surface area and abundant pore structure, which can effectively adsorb impurities, pigments and odors in Lujiu, and significantly improve its clarity and stability.	① It can effectively remove pigments, odors and some colloids. ②It can be widely used for the clarification of a variety of liquids. ③It can absorb bad odor and impurities, improve the purity of Lujiu.	It has great pollution on the environment and great loss to extract.	• Dark fruit liqueur such as blueberry liqueur and blackcurrant liqueur. • Herbal-flavored fortified liqueur containing herbal extracts.	[81]
Freezing method	Low-temperature freezing can change the properties of the colloids in Lujiu. When thawing, precipitates are formed, thus clarifying the liquor.	① It has little impact on the color, aroma and taste of the wine body. ② It reduces the loss of extracts. ③ It reduces contamination. ④ It has a relatively low cost.	The processing time is long, and the initial investment in equipment is large.	• Fruit liqueur with high tannin content, such as persimmon liqueur and pomegranate liqueur. • Liqueurs characterized by high sugar content, such as honey liqueur and jujube liqueur.	[82]
Bentonite	Bentonite swells after absorbing water and disperses in water to form a stable colloidal suspension. These colloids carry a negative charge and can attract the positively charged turbid substances in the liqueur, resulting in flocculent precipitates and clarifying the liqueur.	① It is suitable for removing protein turbidity. ② It can improve the long-term stability of liqueur. ③ It can cause rapid flocculation. ④ It has a low price.	It may adsorb some aroma components, resulting in the loss of flavor.	• Cloudy rice liqueur. • Herbal liqueur characterized by the presence of plant-derived protein components.	[83]

Table 4: *(Continued).*

Clarification Method	Mechanism	Advantage	Disadvantage	Applicability	Ref.
Diatomite	Diatomite is a naturally occurring inorganic substance with a porous structure and strong adsorption capacity. The metal ions in diatomite can interact with the acidic substances in the liqueur to form salts, accelerating the clarification of the liqueur.	① It has physical adsorption properties and is non-toxic and harmless. ② It has stable performance and a good clarifying effect. ③ It has a low price.	It has limited effectiveness in removing poorly soluble impurities and may cause residues.	• Various types of sake after clarification. • Fermented liqueur containing trace suspended particles.	[84]
Pectinase	Pectinase can hydrolyze the pectin substances in liqueur, causing other colloids in the liqueur to precipitate together due to the loss of the protective effect of pectin, so as to achieve the purpose of clarification.	① It can effectively remove pectin-like turbid substances and is suitable for fruit wine-based liqueurs. ② It is an enzyme preparation, which is non-toxic and harmless. ③ It has basically no impact on the aroma, color and taste.	It is only effective for pectin-like substances and ineffective for other turbid substances. It has relatively high requirements for conditions such as temperature and pH value, and the price of the enzyme preparation is relatively high.	• High pectin fruit liqueur. • Thickened type fermented mead after fermentation.	[85]
Egg white powder	Once the egg white powder is made into a solution, it exhibits a good flocculation effect and can cause macromolecular substances like proteins to settle quickly.	①It is suitable for clarifying the turbidity caused by polyphenolic substances. ②It is a natural substance extracted from eggs, which conforms to the trend of natural foods.	The egg white powder mainly targets the turbidity caused by polyphenolic substances, and has limited effectiveness in removing other turbid substances such as proteins and pectins.	• Oak barrel-aged liqueur with a tannin concentration exceeding 2 g/L. • Red fruit liqueur requiring taste softening, such as hawthorn and raspberry.	[86]
Gelatin	Gelatin is a fibrous protein. Tannins can connect with the protein chains of gelatin through hydrogen bonds, hydrophobic groups, etc., to form flocs, which then precipitate in the form of a contracted reticular structure.	① It is suitable for removing polyphenolic substances and colloidal turbidity. ② It is extracted from animal collagen and conforms to the trend of natural foods.	It has limited sources and is not suitable for vegetarian consumers. It has relatively poor stability and shows a poor effect on protein turbidity.	• Purple sweet potato liqueur and mulberry liqueur containing anthocyanins. • Sour and astringent plum liqueur with excessive tannic acid content.	[87]

5 Conclusions

There are multiple factors contributing to the turbid precipitation observed during the production of Lujiu, each requiring a specific analysis. While the methods for addressing turbidity and precipitation vary, they must be implemented without altering the product's functionality, taste, aroma, or color. Given that different Lujius have distinct production processes and formulas, as well as varying animal and plant-based medicinal ingredients, the materials and processes selected for treating turbidity will also differ. Consequently, targeted treatment methods are often necessary to enhance stability and prevent turbidity and precipitation. Future advancements in Lujiu stabilization technologies, such as the use of novel adsorbent materials, combined cold and heat treatments, or improved bentonite processing, could offer more environmentally friendly solutions. These innovations may also reduce the loss of active substances by utilizing regenerated adsorbents.

Moreover, maintaining stability during storage and transportation remains challenging due to the colloidal nature of Lujiu, which contains macromolecules like proteins, polysaccharides, and phenolic compounds. To address this, it is essential to identify the physical processes involved in instability, such as sedimentation, phase separation, flocculation, and solidification, as well as understand how changes in chemical composition influence these processes. Liqueur colloids can carry positive charges (e.g., phenolic substances, proteins, cellulose fibers) or negative charges (e.g., tannic acid, pectin, dextran, yeast cells), with their surface properties affecting both physical and chemical behaviors [88]. The surface properties of these components will affect the physical and chemical behavior of the Lujiu, but there is very little research on these areas.

The diversity and nutritional value of Lujiu components surpass those of wine and baijiu. However, there is currently a lack of in-depth microscopic research on the mechanisms underlying turbidity formation in this area. Future research could leverage the methodologies employed in wine haze studies to deepen the investigation into the turbidity mechanisms of Lujiu. This approach would enable the identification of the underlying causes of turbidity in it. By identifying the fundamental causes of turbidity, interventions can be implemented at the source, achieving both clarification of the wine body and preservation of its nutritional value. Additionally, further research could explore container materials and consumption methods, thereby comprehensively enhancing the promotion and application of mead. Lujiu is not only a traditional Chinese beverage, but similar beverages also exist in many countries across Southeast Asia and even worldwide. We should strengthen the research related to the stability of Lujiu, laying a foundation for the diversified research of products, the development of new food resources, and the expansion of the Lujiu market.

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Author Contributions

W.Y.: investigation, methodology, writing an original draft; C.P.: conceptualization, reviewing and editing; Z.W. reviewing and editing; A.T.: investigation, reviewing and editing; C.X.: reviewing, funding acquisition, project administration. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Y. Zhao, X. Chen, Z. Wang, L. Chen, J. Sun, B. Zhang, Y. Zhang, H. Li, N. Zhang, and B. Sun, “Sensomics-assisted flavor decoding and the sauce flavor enhancement strategy of tongrenyujiu–A novel lujiu product from Tong Ren Tang,” *Journal of Food Composition & Analysis*, vol. 139, Mar. 2025, Art. no. 106982.

[2] P. Yasurin, M. Sriariyanun, and T. Phusantisampan,“ Review: The bioavailability activity of *Centella asiatica*,” *Applied Science and Engineering Progress*, vol. 9, no. 1, pp. 1–9, Dec. 2015, doi: 10.14416/j.ijast.2015.11.001.

[3] L. Lu, J. Zhang, Y. Yin, L. Li, L. Li, M. Liu, and J. Hu, “Research progress in Chinese Lujiu,” *Liquor-Making Science & Technology*, vol. 1, pp. 107–111, Feb. 2025.

[4] G. H. Miller, “What Is Whisky?,” in *Whisky Science: A Condensed Distillation*, G. H. Miller, Ed. Cham: Springer International Publishing, 2024, pp. 1–89.

[5] V. L. Espitia-López, F. P. Malpica-Sánchez, H. B. Escalona-Buendía, and J. R. Verde-Calvo, “Innovation and development in whisky production around the world,” *Beverages*, vol. 10, no. 4, Art. no. 4, Dec. 2024.

[6] T. Mangwanda, J. B. Johnson, J. S. Mani, S. Jackso, and M. Naiker, “Processes, challenges and optimisation of rum production from molasses—A contemporary review,” *Fermentation*, vol. 7, no. 1, Mar. 2021, Art. no. 1, doi: 10.3390/fermentation7010021.

[7] D. Murray, “Chapter 24 - Vodka,” in *Whisky and Other Spirits (Third Edition)*, I. Russell, G. G. Stewart, and J. Kellershohn, Eds., Academic Press, 2022, pp. 441–455.

[8] E. Cillario, “Optimisation of a traditional gin distillation process,” M.S. thesis, Scuola di Ingegneria Industriale e dell'Informazione, Politecnico di Milano, Milan, Italy, Dec. 2023,

[9] W. Li, Z. Zhang, Y. Zhao, W. Li, L. Wang, Q. Shang, J. Du, and L. Jin, “Effect of protease combined with heat treatment on the volatile composition and aroma quality in liqueur wine,” *Molecules*, vol. 28, no. 13, Jan. 2023, Art. no. 13, doi: 10.3390/molecules28135129.

[10] G. S. do Nascimento, G. R. Borges, C. Scheid, and J. Garavaglia, “Article evaluation of chemical

and sensory composition of banana with cinnamon liqueur: Effect of storage process," *Food Science Technology*, vol. 43, Sep. 2023, doi: 10.5327/fst.2623.
[11] H. Liu, "Causes of turbidity in liqueur and its treatment methods," *Liquor-Making Science & Technology*, Feb. 2012, doi: 10.13746/j.njkj. 2012.01.035.
[12] Y. Xu, "Research and development of anti-fatigue health wine with radix psuedostellariae," M.S. thesis, Fujian University of Traditional Chinese Medicine, China, 2014.
[13] M. Yu, X. Ge, J. Song, Y. Dai, and L.Qian, "Preparation and Comprehensive quality analysis of dendrobium officinale flavor wine," *Liouor Making*, vol. 50, no. 5, pp. 37–41, 2023.
[14] L. Ding, K. Li, Y. Yang, M. Zeng, Y. Chen, and H. Song, "Determination and analysis of volatile compounds in 6 kinds of commercial lujiu," *Analysis and Testing*, vol. 29, no. 3, pp. 165–172, 2023, doi: 10.16736/j.cnki.cn41-1434/ts.2023. 03.042.
[15] M. Niu, H. Wang, L. Xiang, T. Tu, S. Li, J. Jia, Q. Ye, and S. Wang," Sensory characteristics and flavor components of Lujiu," *China Brewing*, vol. 42, no. 7, pp. 248–253, 2023.
[16] D. T. K. Trinh, N. T. T. Tinh, H. T. T. Hoa, N. T. An, P. N. Tuan, and P. H. Dai, "Optimization of parameters for the extraction of phenolic antioxidants from Boxberry Tree (Myrica esculenta) bark using response surface methodology," *Applied Science and Engineering Progress*, vol. 17, no. 1, Feb. 2024, Art. no. 6953.
[17] T. D. Shrestha, V. Kunathigan, K. Kitsawad, and S. Panprivech, "Impact of fermentation conditions on the extraction of phenolics and sensory characteristics of mangosteen wine," *Applied Science and Engineering Progress*, vol. 14, no. 3, pp. 406–416, Jul. 2021, doi: 10.14416/ j.asep.2023.09.001.
[18] A. James, T. Yao, H. Ke, and Y. Wang, "Microbiota for production of wine with enhanced functional components," *Food Science and Human Wellness*, vol. 12, no. 5, pp. 1481–1492, 2023, doi: 10.1016/j.fshw.2023.02.008.
[19] N. Rathod, N. Elabed, S. Punia, F. Ozogul, S. K. Kim, and J. Rocha, "Recent developments in polyphenol applications on human health: A review with current knowledge," *Plants*, vol. 12, 2023, doi: 10.3390/plants12061217.
[20] X. Zhou, C. Lu, W. Li, X. Xiao, K. Liu, X. Li, W. Xu, J. Wu, and G. Liang, "Study on the nutrient and active components in mulberry integrated alcoholic," *Bulletin of Sericulture*, vol. 2, pp. 10–13, 2022.
[21] K. Fang, S. Lu, Q. Xia, and Yi Yang, "Optimizing of main composition changes and extraction conditions of blueberry juice wine," *Journal of Food Safety and Quality*, vol. 4, no. 6, pp. 1769–1777, Dec. 2013, doi: 10.19812/j.cnki. jfsq11-5956/ts.2013.06.026.
[22] Y. Zhou, H. Qin, K. Tan, F. Liu, L. Su, G. Wu, J.Cai, S. Tang, and Q. Weri, "Effects of 4 kinds of different sterilization methods on the quality ofintegrated alcoholic beverages of mulberry," *Journal of Food Safety and Quality*, vol. 20, pp. 8105–8112, 2021.
[23] J. Wang, W. Hou, Y. Liu, S. Li, H. Li, and C. Pan, "Optimization of extraction process of Euryale ferox Lujiu by response surface methodology," *Cereals and Oils*, vol. 5, pp. 104–107, 2024.
[24] Z. Ye, S. Cai, Q. Li, Q. Xiong, and P. Lin, "Development on the alcoholic with extracts of pueraria and determination of puerarin," *Liquor Making*, vol. 2, pp. 121–124, 2021.
[25] L. N. ToledoI, F. N. SalazarI, and A. J. A. Aquino, "A theoretical approach for understanding the haze phenomenon in bottled white wines at molecular level," *South African Journal of Enology and Viticulture*, vol. 38, no. 1, pp. 64–71, Dec. 2016, doi: 10.21548/38-1-837.
[26] M. Marangon, S. C. Van Sluyter, K. A. Neilson, C. Chan, P. A. Haynes, E. J. Waters, and R. J. Falconer, "Roles of grape thaumatin-like protein and chitinase in white wine haze formation," *Journal of Agricultural and Food Chemistry*, vol. 59, no. 2, pp. 733–740, Jan. 2011, doi: 10.1021/jf1038234.
[27] P. Fronk and H. Decker, "Wine proteins," *Deutsche Lebensmittel-Rundschau*, vol. 103, no. 2, pp. 52–57, 2007.
[28] D. Gazzola, S. C. V. Sluyter, A. Curioni, E. J. Waters, and M. Marangon, "Roles of proteins, polysaccharides, and phenolics in haze formation in white wine via reconstitution experiments," *Journal of Agricultural and Food Chemistry*, vol. 60, no. 42, pp. 10666–10673, Oct. 2012, doi: 10.1021/jf302916n.
[29] L. Moreira, D. Porcellato, M. Marangon, C. Nadai, V. Duarte, T. Devold, A. Giacomini, and V. Corich, "Interactions between Starmerella bacillaris and Saccharomyces cerevisiae during sequential fermentations influence the release of yeast mannoproteins and impact the protein

stability of an unstable wine," *Food Chemistry*, vol. 440, 2024, Art. no. 138311.
[30] G. Xie, J. Han, X. Han, Q. Peng, J. Fu, C. Shen, J. Sun, J. Sun, J. Lu, Y. Lu, and G. Li, "Identification of colloidal haze protein in Chinese rice wine (Shaoxing Huangjiu) mainly by matrix-assisted laser ionization time-of-flight mass spectrometry," *Food Science & Nutrition*, vol. 8, no. 8, pp. 4027–4036, 2020, doi: 10.1002/fsn3.1655.
[31] J. Xu, Z. Weng, Q. Cui, W. Yu, Y. Lin, H. Song, L. Xiong, L. Wang, X. Shen, and F. Wang, "Current research on the regulation of glycolipid metabolism by plant-derived active polysaccharide," *Trends in Food Science & Technology*, vol. 159, 2025, Art. no. 104959, doi: 10.1016/j.tifs.2025.104959.
[32] H. R. Jones-Moore, R. E. Jelley, M. Marangon, and B. Fedrizzi, "The polysaccharides of winemaking: From grape to wine," *Trends in Food Science & Technology*, vol. 111, pp. 731–740, May 2021, doi: 10.1016/j.tifs.2021.03.019.
[33] Y. Wang, Z. P. Tian, J. J. Xie, Y. Luo, J. Yao, and J. Shen, "Rapid determination of polysaccharides in cistanche tubulosa using near-infrared spectroscopy combined with machine learning," *Journal Of Aoac International*, no. 4, p. 106, 2023, doi: 10.1093/jaoacint/qsac144.
[34] D. Li, J. Ma, and J. Yang, "Supplementation of lycium barbarum polysaccharide combined with aerobic exercise ameliorates high-fat-induced nonalcoholic steatohepatitis via AMPK/PPARα/PGC-1α pathway," *Nutrients*, vol. 14, no. 15, p. 3247, Aug. 2022, doi: 10.3390/nu14153247.
[35] J. Fang, Y. Li, H. Luo, W. Zhang, K. Chan, Y. Chan, H. Chen, Z. Zhao, S. Li, and C. Dong, "Impacts of sulfur fumigation on the chemistry and immunomodulatory activity of polysaccharides in ginseng," *International Journal of Biological Macromolecules*, vol. 247, 2023, Art. no. 125843, doi: 10.1016/j.ijbiomac.2023.125843.
[36] G. Wu, G. Fan, J. Zhou, X. Liu, C. Wu, and Y. Wang, "Structure and main polyphenols in the haze of blackberry wine," *LWT*, vol. 149, 2021, Art. no. 111821, doi: 10.1016/j.lwt.2021.111821.
[37] M. Liu, H. Wu, X, Xue, L. Wu, Q. Leng, Y. Wei, X. Zhang, Y. Shi, and Y. Zhang, "Optimize the detection conditions of lycium barbarum polysaccharide for integrated chinese spirits," *Liquor Making*, vol. 45, no. 1, pp. 39–41, Jan. 2018.
[38] L. Qin, J. Ma, R. Cao, H. He, A. Li, Z. Ding, Y. Wang, and T. Meng, " Development and research of ganoderma lucidum liquor and determination of active ingredients," *Liquor Making*, vol. 50, no. 3, pp. 33–36, May 2023.
[39] R. Zheng, X. Yi, X. Luo, X. Wu, and W. Wu, "Determination of polysaccharide in mulberry wine by ethanol precipitation - Phenol sulfuric acid method," *Analysis and Testing*, no. 9, pp. 154–158, 2021.
[40] T. Fan and R. Kuang, "Preparation and nutritional analysis of ginkgo leaf dew wine," *Journal of Shandong Agricultural Administrators' College*, vol. 23, no. 4, pp. 161–163, 2009, doi: 10.15948/j.cnki.37-1500/s.2009.04.047.
[41] S. Cai, D. Wu, and D. Wang, "Determination of polysaccharide in the alcoholic drink of shenrong yuye," *Food Research and Development*, vol. 35, no. 22, pp. 31–34, 2014, doi: 10.3969/j.issn.1005-6521.2014.22.009.
[42] B. Dragusha, M. Zogaj, X. Ramadani, and L. Susaj, "Determination of some heavy metals in some wines of Kosovo," *International Journal of Ecosystems & Ecology Sciences*, vol. 7, no. 3, pp. 635–638, 2017.
[43] E. Camelia, Luchian, V. V. Cotea, I. Sandu, and N. Bilba, "Removal of Mn(II), Ni(II) and Cu(II) ions from white wine through ion exchange in microporous mordenite and mesoporous Al-MCM-41," *Revista de Chimie Bucharest Original Edition*. vol. 62, no. 8, pp. 782–786, 2011, doi: 10.1016/j.procbio.2011.05.007.
[44] A. J. Mckinnon and G. R. Scollary, "Size fractionation of metals in wine using ultrafiltration," *Talanta*, vol. 44, no. 9, pp. 1649–1658, 1997, doi: 10.1016/s0039-9140(97)00070-2.
[45] R. Zhang, H. Li, J. Hu, T. Zhang, and H. Chen, "Determination of lead in alcoholie beverage by microwave digestion-graphite furnace atomic absorption spectrophotometry," *Chemical Analisis and Meterage*, vol. 22, no. 5, pp. 90–91, Sep. 2013, doi: 10.3969/i.issn.1008-6145.2013.05.026.
[46] G. Zhao, "Evaluation of uncertainty in measurement of manganese in fruit liqueur by flame atomic absorption spectrometry," *Metrology & Measurement Technique*, vol. 37, no. 2, pp. 71–72, 2010.
[47] J. M. Muñoz-Redondo, B. Puertas, M. J. Valcárcel-Muñoz, R. Rodríguez-Solana, and J. M. Moreno-Rojas, "Impact of stabilization method and filtration step on the ester profile of 'Brandy de Jerez'," *Applied Sciences*, vol. 13,

no. 6, Jan. 2023, Art. no. 6, doi: 10.3390/app 13063428.
[48] J. Wang, P. Cheng, L. Lu, L. Wei, and X. You, "Application of foreshot removal by turbidimeter combined with activated carbon adsorption in reducing turbidity of Baijiu," *China Brewing*, vol. 41, no. 8, pp. 163–168, 2022.
[49] J. Pino, M. P. Martí, M. Mestres, J. Pérez, O. Busto, and J. Guasch, "Headspace solid-phase microextraction of higher fatty acid ethyl esters in white rum aroma," *Journal of Chromatography A*, vol. 954, no. 1–2, pp. 51–57, Apr. 2002, doi: 10.1016/S0021-9673(02)00167-X.
[50] W. Albuquerque, L. Seidel, H. Zorn, F. Will, and M. Gand, "Haze formation and the challenges for peptidases in wine protein fining," *Journal of Agricultural and Food Chemistry*, vol. 69, no. 48, pp. 14402–14414, Dec. 2021, doi: 10.1021/ acs.jafc.1c05427.
[51] E. Haslam, T. Lilley, Y. Cai, R. Martin, and D. Mangnolato, "Traditional herbal medicines - the role of polyphenols," *Planta Medica*, vol. 55, no. 01, pp. 1–8, Feb. 1989, doi: 10.1055/s-2006-961764.
[52] B. Tian and R. Harrison, "Pathogenesis-related proteins in wine and white wine protein stabilization," *Chemistry and Biochemistry of Winemaking, Wine Stabilization and Aging*, Feb. 2020, doi: 10.5772/intechopen.92445.
[53] H. Xue, X. Du, S. Fang, H. Gao, K. Xie, Y. Wang, and J. Tan, "The interaction of polyphenols-polysaccharides and their applications: A review," *International Journal of Biological Macromolecules*, vol. 278, no. 1, 2024, Art. no. 134594, doi: 10.1016/j.ijbiomac. 2024.134594.
[54] W. Wijaya, A. R. Patel, A. D. Setiowati, and P. Meeren, "Functional colloids from proteins and polysaccharides for food applications," *Trends in Food Science & Technology*, vol. 68, pp. 56–69, 2017, doi: 10.1016/j.tifs.2017.08.003.
[55] J. Zheng, P. Van der Meeren, and W. Sun, "Newinsights into protein–polysaccharide complex coacervation: Dynamics, molecular parameters, and applications," *Aggregate*, vol. 5, no. 1, Feb. 2024, doi: 10.1002/agt2.449.
[56] F. Luís, M. Juliana, G. Raquel, V. Rafael, B. Joana, M. Carlos, M. Fernando, and C. Fernanda, "Efficiency of carboxymethylcellulose in red wine tartaric stability: Effect on wine phenolic composition, chromatic characteristics and colouring matter stability," *Food Chemistry*, vol. 360, 2021, doi: 10.1016/j.foodchem.2021.129996.
[57] Z. Liu, L. Xu, J. Wang, C. Duan, Y. Sun, Q. Kong, and F. He, "Research progress of protein haze in white wines," *Food Science and Human Wellness*, vol. 12, no. 5, pp. 1427–1438, 2023, doi: 10.1016/j.fshw.2023.02.004.
[58] M. Marroquin, A. Vu, T. Bruce, R. Powell, S. R. Wickramasinghe, and S. M. Husson, "Location and quantification of biological foulants in a wet membrane structure by cross-sectional confocal laser scanning microscopy," *Journal Of Membrane Science*, vol. 453, pp. 282–291, Mar. 2014, doi: 10.1016/j.memsci.2013.11.011.
[59] R. Rodríguez-Solana, J. D. Carlier, M. C. Costa, and A. Romano, "Multi-element characterisation of carob, fig and almond liqueurs by MP-AES," *Journal of the Institute of Brewing*, vol. 124, no. 3, pp. 300–309, 2018, doi: 10.1002/jib.495.
[60] G. Wu, X. Liu, S. Wu, J. Zhou, Y. Wang, and C. Wu, "Effect of metal ions on haze formation in blackberry wine," *LWT*, vol. 191, Jan. 2024, Art. no. 115628.
[61] G. J. Soleas and D. M. Goldberg, "Potential role of clarifying agents in the removal of pesticide residues during wine production and their effects upon wine quality," *Journal of Wine Research*, vol. 11, no. 1, pp. 19–34, 2000, doi: 10.1016/ j.lwt.2023.115628.
[62] Y. Zuo and G. Sun, "Application research progress of clarifiers in wine," *Journal of Anhui Agricultural Sciences*, vol. 40, no. 34, pp. 1680–16811, 2012.
[63] Y. Liu, L. Lin, J. Zheng, H. Li, F. Hu, J. Zheng, W. Liu, and W. Huang, "Effect of clarifier combined with membrane filtration on the stability of purple rice wine," *Science and Technology of Food Industry*, vol. 44, no. 14, pp. 237–245, Jul. 2023, doi: 10.13386/j.issn1002-0306.2022100091.
[64] D. E. Osorio-Macías, H. Bolinsson, J. A. Linares-Pastén, R. Ferrer-Gallego, J. Choi, J. M. Pearrieta, and B. Bergensthl, "Characterization on the impact of different clarifiers on the white wine colloids using asymmetrical flow field-flow fractionation," *Food Chemistry*, vol. 381, Jul. 2022, Art. no. 132123, doi: 10.1016/j. foodchem.2022.132123.
[65] S. Pettinelli, M. Pollon, L. Costantini, A. Bellincontro, S. R. Segade, L. Rolle, and F. Mencarelli, "Effect of flotation and vegetal fining agents on the aromatic characteristics of Malvasia del Lazio (*Vitis vinifera* L.) wine,"

Journal of the Science of Food and Agriculture, vol. 100, no. 14, pp. 5269–5275, 2020, doi: 10.1002/jsfa.10577.
[66] T. Ribeiro, C. Fernandes, F. M. Nunes, L. Filipe-Ribeiro, and F. Cosme, "Influence of the structural features of commercial mannoproteins in white wine protein stabilization and chemical and sensory properties," *Food Chemistry*, vol. 159, pp. 47–75, Sep. 2014, doi: 10.1016/ j.foodchem.2014.02.149.
[67] S. Ratnayake, V. Stockdale, S. Grafton, P. Munro, and A. Bacic, "Carrageenans as heat stabilisers of white wine," *Australian Journal of Grape and Wine Research*, vol. 25, no. 4, pp. 439–450, 2019, doi: 10.1002/jsfa.10577.
[68] I. Benucci, M. Esti, and K. Liburdi, "Effect of wine inhibitors on the proteolytic activity of papain from *Carica papaya* L. latex," *Biotechnology Progress*, vol. 31, no. 1, pp. 48–54, 2015, doi: 10.1002/btpr.2015.
[69] C. N. Rani and R. Talikoti, "Adsorption isotherm studies of the simultaneous removal of turbidity and hardness by natural coagulants," *Water Practice And Technology*, vol. 8, no. 3–4, pp. 495–502, 2013, doi: 10.2166/wpt.2013.053.
[70] K. L. Wilkinson, R. Ristic, C. Szeto, D. L. Capone, L. Yu, and D. Losic, "Novel use of activated carbon fabric to mitigate smoke taint in grapes and wine," *Australian Journal of Grape and Wine Research*, vol. 28, no. 3, pp. 500–507, Jul. 2022, doi: 10.1111/ajgw.12548.
[71] Z. Huang, C. Wei, and X. Huang, "Research on turbidity removal technology of health wine," *Journal of Sichuan University of Science and Engineering*, vol. 23. no. 6, pp. 689–691, Dec. 2010.
[72] O. K. Israel, "Adsorption of the proteins of white wine onto activated carbon, alumina and titanium dioxide," *African Journal of Pure and Applied Chemistry*, vol. 3, no. 1, pp. 006–010, Jan. 2009.
[73] V. Millarini, S. Ignesti, S. Cappelli, G. Ferraro, and P. Domizio, "Protection of wine from protein haze using schizosaccharomyces japonicus polysaccharides," *Foods*, vol. 9, no. 10, Oct. 2020, Art. no. 10, doi: 10.3390/foods 9101407.
[74] X. Yang, J. Dai, X. Wei, Y. Zhong, X. Liu, D. Guo, L. Wang, Y. Huang, C. Zhang, Y. Liu, X. Chen, and Q. Wang, "Characterization of recombinant GRIP32 as a novel haze protein for protein-polyphenol haze models and prevention of haze formation with polysaccharides in the models," *LWT*, vol. 136, Jan. 2021, Art. no. 110317, doi: 10.1016/j.lwt.2020.110317.
[75] D. Silva-Barbieri, F. N. Salazar, F. López, N. Brossard, N. Escalona, and J. R. Pérez-Correa, "Advances in white wine protein stabilization technologies," *Molecules*, vol. 27, no. 4, Art. no. 4, Jan. 2022, doi: 10.3390/molecules27041251.
[76] D. Canalejo, L. Martínez-Lapuente, B. Ayestarán, S. Pérez-Magariño, and Z. Guadalupe, "Potential use of grape and wine polysaccharide extracts as fining agents to modulate the volatile composition of *Viura* wines," *Food Chemistry*, vol. 430, Jan. 2024, Art. no. 137047, doi: 10.1016/j.foodchem.2023. 137047.
[77] Y. Zhong, J. Shu, Q. Gao, M. Yu, H. Dong, and J. Fan, "Research advances on processing and clarification methods of plant-based beverages," *Food and Fermentation Industries*, vol. 51, no. 4, pp. 409–416, 2025, doi: 10.13995/j.cnki.11-1802/ts.039904.
[78] X. Xie, J. Chen, X.An, and Y. Dai, "Effects of different processing methods on the clarifi cation of mulberry wine," *Journal of Wenshan University*, vol. 30, no. 3, pp. 28–30, Jun. 2017.
[79] C. Niu, S. Wang, L. Yi, Q. Wu, B. Tan, C. Zhang, X. Ma, X. Zhan, and Q. Pan, "Effect of chemical demulsification on the stability of coconut liqueur," *Journal of Anhui Agricultural Sciences*, vol. 47, no. 11, pp. 175–177, 2019.
[80] Q. Xia, Y. Cao, J. Chen, R. Liu, and Y. Han, "Studies on clarification of blueberry integrated alcoholic beverage," *The Food Industry*, vol. 39, no. 10, pp. 145–149, Oct. 2018.
[81] F. Cosme, A. Inês, D. Silva, L. Filipe-Ribeiro, L. Abrunhosa, and F. M. Nunes, "Elimination of ochratoxin A from white and red wines: Critical characteristics of activated carbons and impact on wine quality," *LWT*, vol. 140, Apr. 2021, Art. no. 110838, doi: 10.1016/j.lwt.2020.110838.
[82] S. Ni, Q. Yang, and G. Tong, "Comparative study of active carbon filtration and freeze filtration of tartary buckwheat liquor," *Liquor-Making Science & Technology*, no. 12, pp. 69–72, Dec. 2017, doi: 10.13746/j.njkj.2017232.
[83] E. Mladenova, I. Bakardzhiyski, and E. Dimitrova, "Investigation of elemental composition in white wine treated with varying doses of bentonite," *Beverages*, vol. 10, no. 4, Art. no. 4, Dec. 2024, doi: 10.3390/beverages 10040114.
[84] M. Behfar, A. Heshmati, F. Mehri, and A. M. Khaneghah, "Removal of ochratoxin a from

grape juice by clarification: A response surface methodology study," *Foods*, vol. 11, no. 10, May 2022, Art. no.1432.
[85] M. Gazaloğlu, C. Camarasa, and E. Nevoigt, "Exploring pectinolytic yeast diversity: Toward effective polygalacturonase producers for applications in wine-making," *Fems Yeast Research*, vol. 25, Jan. 2025, doi: 10.3390/foods 11101432.
[86] L. Martínez-Lapuente, Z. Guadalupe, and B. Ayestarán, "Effect of egg albumin fining, progressive clarification and cross-flow microfiltration on the polysaccharide and proanthocyanidin composition of red varietal wines," *Food Research International*, vol. 96, pp. 235–243, Jun. 2017, doi: 10.1016/j.foodres. 2017.03.022.
[87] R. Tenuja, N. Sobini, R. S. Dassanayake, and A. Kirushanthi, "Comparison of physico-chemical properties of wine fermented with palmyrah fruit pulp and cashew apple juice," *Sri Lankan Journal of Infectious Disesses*, vol. 14, Feb. 2025, doi: 10.4038/sljid.v14i5.8800.
[88] A. Mierczynska-Vasilev and P. A. Smith, "Current state of knowledge and challenges in wine clarification: Knowledge and challenges in wine clarification," *Australian Journal of Grape and Wine Research*, vol. 21, pp. 615–626, Dec. 2015, doi: 10.1111/ajgw.12198.