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*Review*

# Advances in the Quality Improvement of Fruit Wines: A Review

**Lei He [1,*], Yifan Yan [2], Min Wu [1] and Leqin Ke [1]**

[1] Hangzhou Vocational & Technical College, Hangzhou 310018, China; wumin0912v@163.com (M.W.); keleqin691208@163.com (L.K.)
[2] Wine Research Centre, Faculty of Land and Food Systems, The University of British Columbia, Vancouver, BC V6T 1Z4, Canada; yyan8@mail.ubc.ca
* Correspondence: heleicaiq@163.com

**Abstract:** Fruit wines have gained great interest in recent years due to the increasingly diverse demands of consumers for different fruit wines with different colors, flavors, and nutritional values. Some fruits such as blueberry and strawberry are perishable and have a short shelf life. The production of fruit wine reduces fruit losses after harvest and enhances fruit utilization. The production of fruit wine with premium quality is determined by both intrinsic (i.e., genetic background) and extrinsic factors (e.g., yeast and fermentation protocol). This article provides an updated overview on the strategies and technologies aiming to improve the quality of fruit wines. Recent progress in improving fruit wine quality by variety selection, post-harvest treatments, yeast selection, fermentation protocols, fermentation conditions, and aging technologies has been comprehensively reviewed.

**Keywords:** yeast; inoculation protocol; fermentation condition; fruit variety; post-harvest treatment; aging technology

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**Citation:** He, L.; Yan, Y.; Wu, M.; Ke, L. Advances in the Quality Improvement of Fruit Wines: A Review. *Horticulturae* **2024**, *10*, 93. https://doi.org/10.3390/horticulturae10010093

Academic Editor: Anita Sønsteby

Received: 31 December 2023
Revised: 16 January 2024
Accepted: 17 January 2024
Published: 18 January 2024

## 1. Introduction

There has long been a focus on fruits due to their high levels of nutritive contents and bioactive compounds, as well as good taste and pleasant flavors [1,2]. However, some fruits such as blueberry, strawberry, plum, and peach are perishable and have a short shelf life, which leads to relatively large losses varying from 10 to 30% of the production volume [3]. In order to reduce the post-harvest loss of fruits and improve their availability in preserved form, fruit wines are made by the fermentation of a large variety of fruits other than grape, such as blueberry, bilberry, cherry, peach, apple, plum, and mango. In addition, the increasing demands of consumers for diverse alcoholic beverages or wines also contribute to the development of fruit wine.

The demand and consumption of fruit wines has increased rapidly in recent years, attracting attention to improve their quality. The overall quality of fruit wine (e.g., sensory characteristics and nutritional values) depends on a variety of factors, mainly including the quality of raw fruit material (i.e., freshly harvested fruits), post-harvest treatments, fermentation conditions, vinification procedures, and aging processes [4–8]. The quality of raw fruit material is subjected to the genetic background of the fruit, environmental conditions, and cultural practices during fruit growth and development [1].

Recent studies have provided enhancements in the improvement of fruit wine quality, especially by simultaneous inoculation (SIM) or sequential inoculation (SEQ) of mixed cultures of non-*Saccharomyces* yeast and *Saccharomyces* yeast [7,9–12], followed by yeast selection [13–15], fermentation condition optimization [6,16,17], raw fruit material selection [4,18], post-harvest treatment [5,18], and wine aging technology [8]. This article systematically summarized the recent advances in improving fruit wine quality and provided general guidelines for selecting high-quality raw fruit materials, proper post-harvest treatments and yeasts, optimal inoculation protocols and fermentation conditions, and appropriate wine aging technologies to improve fruit wine quality.

## 2. Selection of Raw Material and Post-Harvest Treatment to Improve Fruit Wine Quality

The quality of raw fruit material depends on various factors and their interactions [19]. Firstly, the genetic intrinsic factor implies that some varieties naturally produce higher volatile compounds, polyphenols, or other compounds than others. Additionally, extrinsic factors such as environmental conditions, cultivation management, and post-harvest treatments also have an impact on the quality of fresh fruits.

Fruit variety affects not only the physical properties and chemical compositions of fresh fruits but also plays an important role in the sensory perception of the resultant fruit wine. In grape wine, aroma compounds are traditionally divided into three types: varietal, fermentation, and aging aroma [20]. The varietal aroma compounds refer to the aroma compounds originating from the grape and are the major contributor to the overall aroma of wine [21]. Wines made by different varieties usually have a specific varietal aroma [22]. Additionally, red wines made from different varieties have different tastes. For instance, 'Merlot' red wine is very soft, while Cabernet Sauvignon red wine is powerful and sharp [23]. However, the impact of fruit varieties on fruit wine quality has not been extensively investigated. Recent studies mainly compared the compositions and content of targeted compounds among different varieties of raw fruit material [24–26], but only a few investigated the impact of fruit varieties on the quality of their corresponding fruit wines. Specifically, Yuan et al. identified the volatile markers for distinguishing 'O'Neal' and 'Misty' blueberry wines using a non-targeted volatile metabolomic approach [4] and tracked the changes in volatiles in the two blueberry wines during alcoholic fermentation [27]. Wang et al. further combined volatomic analysis and sensory assessment to illuminate the aroma characteristics of nine types of blueberry wines derived from different blueberry cultivars [18]. The content and composition of non-anthocyanin phenolics were investigated in white bilberry wine and blue bilberry wine, suggesting that non-pigmented bilberries could be potential candidates for white bilberry wine production [28]. In plum wine, Čačanska lepotica wine had the highest contents of total phenols, total anthocyanins, and total flavan-3-ols, as well as the highest color intensity, and the strongest antiradical activity compared to Čačanska rana and Požegača wines [29]. In mango wine, Reddy et al. suggested that mango varieties Banginapalli, Banglora, and Alphonso were the most suitable ones for fruit wine production among the selected six varieties in South India [30]. Based on organoleptic properties, the mango wines made from Banginapalli and Alphonso varieties had better sensory characteristics (e.g., flavor, taste, and mouth feel) [31]. Wang et al. found a lower degradation of bioactive melatonin in mulberry red wine made by 'Hongguo2' during fermentation than in mulberry white wine made by 'Baiyuwang', which may be attributed to the higher antioxidative phenolics in black mulberry cultivar compared to the white cultivar [32]. There are a wide variety of cultivated and wild fruit varieties available today [33], and future research should focus more on the selection of appropriate fruit varieties for fruit wine production.

Environmental conditions such as temperature, light, water, soil, and microbial populations originating from the native environment surrounding the vineyard significantly affect grape growth and development, and subsequently the quality of wine [34,35]. Cultivation management such as leaf removal, training systems, vine spacing, cluster thinning, and shoot density also affect the aroma compounds and phenolic compounds in wine [36–38]. However, to the best of our knowledge, there is little research investigating the effects of environmental conditions and cultivation management on the quality of fruit wine.

The effect of post-harvest treatments on fruit wine quality has rarely been investigated. Current knowledge suggests that berry sorting and partial dehydration after harvest affect the quality of blueberry wines. After berry sorting, 'Misty' berry wine made with smaller blueberries had a more intense fruity and floral aroma [18]. Moderate postharvest dehydration (20–30% weight loss) increased the contents of total terpenes, benzeneacetaldehyde and phenylethyl alcohol, ethyl butanoate, methyl salicylate, 1-hexanol, and $\gamma$-nonalactone in blueberries and corresponding wines, leading to the enhancement of floral, fruity, and sweet notes of blueberry wines [5].

## 3. Effects of Fermentation on Fruit Wine Quality

Fermentation is a crucial step in fruit wine production. Alcohol is converted from sugar during this process and diverse metabolites (e.g., esters and higher alcohols) determining fruit wine quality are also formed. A variety of factors including yeasts (i.e., *Saccharomyces* and non-*Saccharomyces*) [14,39,40], inoculation protocols of mixed culture fermentation (i.e., combination of mixed cultures, inoculation modality, and inoculum ratio) [7,9,10], and fermentation conditions (i.e., temperature and pH) [6,16] have been reported to affect the physico-chemical and sensory quality of fruit wines.

### *3.1. Yeasts*

The selection of yeasts is vital to obtaining grape wines and fruit wines with distinctive yet pleasant flavors [41,42]. Commercial *Saccharomyces cerevisiae* yeasts have been widely used in the production of blueberry [5,33], plum [6,43], pineapple [44], and strawberry [45] wines, achieving controllability and reproducibility during the fermentation process and predictability in the sensory quality of the fermented beverages. The *Saccharomyces cerevisiae* strain can also produce a mixed fruit wine from pawpaw, banana, and watermelon, which was acceptable by consumers [46]. Although *Saccharomyces cerevisiae* is the most common yeast species used in fruit wine fermentation, few studies investigated the impact of different *Saccharomyces cerevisiae* yeasts on the fruit wine quality. Lin et al. compared the influence of four commercial *Saccharomyces cerevisiae* on volatile profiles of pineapple wine and proposed that strains D254 and BV818 could be used for making intense pineapple wine and imparting characteristic aromas (e.g., 4-hydroxy-2,5-dimethylfuran-3-one, limonene, and ethyl 3-methylthiopropionate), respectively [44].

Despite the advantages of using *Saccharomyces cerevisiae*, grape wines produced by pure *Saccharomyces cerevisiae* lack the complexity of flavor when compared to those produced by spontaneous fermentation, during which non-*Saccharomyces* yeasts play an important role [41,47]. Non-*Saccharomyces* yeasts generally have low fermentability and weak alcohol tolerance [48]. Therefore, these yeasts were initially considered as undesired or spoilage strains during wine fermentation [41]. In recent years, non-*Saccharomyces* yeasts have gained attention due to their ability to enhance the flavor and improve the quality of wine [9,49]. Here, the effects of pure non-*Saccharomyces* yeasts inoculation on fruit wine have been reviewed, when compared to *Saccharomyces* yeasts (Table 1), mainly focusing on oenological characteristics (e.g., ethanol content, pH, titratable acidity) and volatile compounds. Generally, in contrast to *Saccharomyces* yeasts, pure inoculation of non-*Saccharomyces* yeasts leads to a lower content of ethanol in fruit wines such as blueberry [9], bilberry [50], peach [10], lychee [51], as well as apple, pear, and kiwifruit wines [40], compared to inoculation with *Saccharomyces* yeasts. The lower ethanol could be attributed to the different metabolic flux distribution during fermentation between non-*Saccharomyces* yeasts and *Saccharomyces* yeasts, and the lower tolerance of non-*Saccharomyces* yeasts to ethanol [52]. Lower ethanol levels were also observed in cherry wines made by *Torulaspora delbrueckii* and *Metschnikowia pulcherrima* when compared to the cherry wines made by *Saccharomyces* yeasts, but they were not statistically significant [53]. In addition to ethanol, the pH and titratable acidity also play a crucial role in the properties, quality, and microbiological stability of wine [54]. Sun et al. reported a lower pH in cherry wine inoculated with pure *T. delbrueckii* compared to that with *Saccharomyces* yeasts [53]. Likewise, lower pH was also observed in apple wine inoculated with *Pichia kluyveri* than that with *Saccharomyces* yeasts [40]. Fruit wine like blueberry wine fermented with industrial *Saccharomyces* yeasts usually has an excessively sour taste caused by high contents of residual organic acids, negatively affecting the flavor and quality of blueberry wine [55]. Fermentation with non-*Saccharomyces* yeasts could potentially solve this problem. Wang et al. found that titratable acidity was decreased in blueberry wine using pure *T. delbrueckii* when compared to *Saccharomyces* yeast inoculation [9], which could attribute to the decreased malic acid and citric acid contents [56]. A *Pichia fermentans* yeast also had a strong ability to degrade citric acid during blueberry wine fermentation [55]. Likewise, *Hanseniaspora uvarum* and *M. pulcherrima* reduced the titratable acidity in peach wine, mainly attributing to the reduced malic acid [10].

Regarding volatile compounds, increasing evidence demonstrated the positive contributions of non-*Saccharomyces* yeasts on the improvement of aroma complexity and sensory perception of fruit wines. Padilla et al. have concluded which non-*Saccharomyces* yeast species produced higher or lower volatile compounds in wine [41]. For instance, *M. pulcherrima*, *Candida zemplinina*, and *Lachancea thermotolerans* were described as higher producers of higher alcohols. *M. pulcherrima* still seems to be a strong producer of higher alcohols in peach wine [10] and bilberry wine [49], in accordance with its fermentation characteristics in wine [33]. Nevertheless, pure *M. pulcherrima* fermentation led to a decrease in higher alcohols in mango wine [57], indicating the impact of fruit matrices on higher alcohols during fermentation. A commercial strain of *T. delbrueckii* Zymaflore Alpha was found to increase total anthocyanins, total flavonoids, and total phenols in blueberry wine; however, three ethyl esters (ethyl 3-methylbutanoate, ethyl hexanoate, and ethyl octanoate) with fruity notes were simultaneously decreased [9], indicating pure *T. delbrueckii* fermentation in blueberry wine may not be the best choice. In contrast, four ethyl esters of ethyl L (−)-lactate, ethyl palmitate, ethyl 2-furoate, and ethyl caprate increased in peach wine inoculated with *T. delbrueckii* Zymaflore Alpha [10]. The different effects of the same commercial *T. delbrueckii* strain on ethyl esters in blueberry wine and peach wine might be attributed to the different chemical compositions of blueberry and peach fruits.

Additionally, some studies evaluated and compared the effects of different non-*Saccharomyces* yeasts on the quality of fruit wine, which improved the current understanding of the potential application of non-*Saccharomyces* yeasts in fruit wine production. Through comparing eight non-*Saccharomyces* yeasts, Liu et al. found that *H. uvarum* inoculation led to the highest levels of phenolic acids and flavan-3-ols in bilberry wine, and fermentations with *Saccharomycodes ludwigii*, *T. delbrueckii*, and *M. pulcherrima* resulted in higher levels of myricetin-3-O-glucoside and syringetin-3-O-glucoside but lower levels of most phenolic acids [15]. A recent study also compared ten non-*Saccharomyces* yeasts from Daqu in blueberry wine and found that *Wickerhamomyces anomalus* yeast showed good fermentation ability and the ability to convert anthocyanins and vinylphenols into more stable vinylphenol pyranoanthocyanins, and produced no H2S in the meantime. This might be a potential non-Saccharomyces yeast for the production of fruit wines with premium quality [13].

**Table 1.** Effects of pure *non-Saccharomyces* yeasts on fruit wine quality when compared to *Saccharomyces* yeasts.

| Fruit Wine | Yeast (s) | Impact on Fruit Wine Quality | Ref. |
|---|---|---|---|
| Blueberry wine | *T. delbrueckii* | Increased total anthocyanins, total flavonoids, and total phenols;<br>Decreased ethanol, titratable acidity, ethyl 3-methylbutanoate, ethyl hexanoate, and ethyl octanoate | [9] |
| Peach wine | *H. uvarum* | Increased pH, volatile acidity, ethyl acetate, methyl acetate, furfuryl acetate, 2-octanone, and pentanal;<br>Decreased ethanol and titratable acidity | [10] |
| | *M. pulcherrima* | Increased pH, (*E*, *E*)-farnesol, ethyl sorbate, 4-penten-1-ol, (Z)-3-hexenol, 2-methyl-1-butanol, and acetoin;<br>Decreased ethanol and titratable acidity | [10] |
| | *L. thermotolerans* | Increased pH, nerolidol, phenylethyl alcohol, 1-hexanol, ethyl butyrate, and ethyl hexanoate;<br>Decreased ethanol | [10] |
| | *T. delbrueckii* | Increased pH, ethyl L (−)-lactate, ethyl palmitate, ethyl 2-furoate, ethyl caprate, and nonanal;<br>Decreased ethanol | [10] |
| Apple wine | *M. pulcherrima* | Decreased acetic acid | [11] |
| | *M. sinensis* | Decreased ethanol | [11] |
| | *W. anomalus* | Increased ethyl acetate | [11] |
| | *P. kluyveri* | Decreased pH and ethanol | [40] |

**Table 1.** *Cont.*

| **Fruit Wine** | **Yeast (s)** | **Impact on Fruit Wine Quality** | **Ref.** |
|---|---|---|---|
| Plum wine | *H. thailandica* | Decreased total phenols and antioxidant activity | [14] |
| Pear wine | *L. thermotolerans* | Increased pH;<br>Decreased ethanol | [40] |
| Kiwifruit wine | *L. thermotolerans* | Decreased ethanol | [40] |
| | *C. zemplinina* | Decreased ethanol | [40] |
| Bilberry wine | *H. uvarum* and *I. orientalis* | Increased ethyl acetate | [49] |
| | *M. pulcherrima* | Increased higher alcohols | [49] |
| | *S. pombe* | Increased acetoin and pyruvic acid;<br>Decreased ethanol, 3-methyl-1-butanol, 4-methyl-1-pentanol, 3-methyl-1-pentanol, 2-ethyl-1-hexanol, ethyl acetate, diethyl succinate, and $\beta$-citronellol | [50,58] |
| | *T. delbrueckii* | Increased 2-phenylethanol and phenethyl acetate;<br>Decreased ethanol, total sugar, 4-methyl-1-pentanol, diethyl succinate, acetaldehyde, and 3-methylbutanal | [50] |
| Lychee wine | *T. delbrueckii* | Increased geraniol and *cis*-rose oxide;<br>Decreased ethanol, volatile acids, and esters | [51] |
| Cherry wine | *T. delbrueckii* | Decreased pH | [53] |
| Mango wine | *M. pulcherrima* | Decreased volatile acidity, ethyl acetate, and higher alcohols | [57] |
| | *T. delbrueckii* | Decreased volatile acidity and higher alcohols | [57] |

### *3.2. Inoculation Protocols of Mixed Culture Fermentation*

Although non-*Saccharomyces* yeasts have positive effects on fruit wine quality, such as increasing the complexity of aroma, reducing the anthocyanin adsorption, and benefiting the formation of some stable pigments like pyranoanthocyanins and proanthocyanins [9,13], these yeasts are usually characterized by a weaker fermentation ability when compared to *Saccharomyces cerevisiae*. Therefore, mixed fermentations of non-*Saccharomyces* yeast and *Saccharomyces* yeast have been proposed to retain the positive effects and reduce the negative impacts of non-*Saccharomyces* yeasts on wine quality. Previous studies found that the interaction between non-*Saccharomyces* yeast and *Saccharomyces* yeast during alcoholic fermentation is not only species-specific but also strain-specific [59]. In addition, the inoculation modality (i.e., SIM or SEQ) and inoculum ratio can significantly affect the quality of fruit wine [7,9,56]. On the basis of these findings, a suitable inoculation protocol with the optimal combination of mixed cultures, inoculation modality, and inoculum ratio of mixed cultures is necessary for mixed fermentation. Here, the effects of mixed fermentation of one non-*Saccharomyces* yeast and one *Saccharomyces* yeast on fruit wine quality have been reviewed, when compared to the *Saccharomyces* single yeast fermentation (Table 2). The improvement of ‘fruity’, ‘floral’, and ‘global aroma’ notes is of great interest in fruit wines. Terpenes and norisoprenoids with low olfactory perception thresholds are responsible for fruity and floral notes in wine [60,61]. Additionally, some ethyl esters of organic acids and straight-chain fatty acids, as well as acetates of higher alcohols, also contribute to the fruity aroma of wine [62].

Glycosidically bound terpenes and norisoprenoids typically exhibit remarkably higher concentrations than their free counterparts in fruits [61,63]. The addition of non-*Saccharomyces* yeasts with the ability to produce $\beta$-glucosidase plays a crucial role in releasing glycosidically bound terpenes and norisoprenoids during fermentation [64]. In fruit wines, the total terpene and individual terpene have been reported to be increased by mixed cultures of *M. pulcherrima/S. cerevisiae* [7,53], *Hanseniaspora opuntiae/S. cerevisiae* [65], *H. uvarum/S. cerevisiae* [10,65], and *T. delbrueckii/S. cerevisiae* [9,16,51,65], when compared to pure *S. cerevisiae* fermentation. Specifically, Zhang et al. found that 1:10SIM of *M. pulcherrima/S. cerevisiae* increased the levels of linalool and citronellol, and 10:1SIM, 1:1SIM, 10:1SEQ, 1:1SEQ, and 1:10SEQ increased the levels of linalool, citronellol, nerolidol, and total terpenes in plum wines, with 10:1SEQ producing the highest concentration of these compounds [7]. Likewise, higher $\alpha$-terpineol and linalool were observed in cherry wine inoculated with 10:1SEQ of *M. pulcherrima/S. cerevisiae* [53]. In blueberry wine, 1:1SIM of *T. delbrueckii/S. cerevisiae* resulted in higher levels of α-terpinene, 1,4-cineole, *o*-cymene, limonene, β-ocimene, terpinolene, and nerol oxide, while 1:1SEQ performed better than 1:1SIM, with higher levels of α-terpinene, 1,4-cineole, (+)-4-carene, *o*-cymene, limonene, trans-β-ocimene, β-ocimene, terpinolene, myrcenol, β-terpineol, nerol oxide, *cis*-geraniol, and (6*E*)-nerolidol [9]. In citrus wine, 10:1SEQ of *H. opuntiae/S. cerevisiae*, *H. uvarum/S. cerevisiae*, and *T. delbrueckii/S. cerevisiae* consistently led to an increase in total terpenes [65]. In addition, both 10:1SIM and 10:1SEQ of *T. delbrueckii/S. cerevisiae* increased linalool content in cherry wine [16,53]. A ratio of 10:1SEQ of *H. uvarum/S. cerevisiae* increased linalool content in peach wine [10], while 1:1SEQ of *T. delbrueckii/S. cerevisiae* increased geraniol content in lychee wine [51]. On the basis of the above-mentioned studies, an inoculation ratio of 10:1 coupled with SEQ of *M. pulcherrima/S. cerevisiae*, *H. opuntiae/S. cerevisiae*, *H. uvarum/S. cerevisiae*, and *T. delbrueckii/S. cerevisiae* could be good choices to produce more terpenes in fruit wines. In regard to norisoprenoids, SEQ of *T. delbrueckii/S. cerevisiae* and *M. pulcherrima/S. cerevisiae* were found to be beneficial for norisoprenoids accumulation. In previous studies, a higher concentration of β-damascenone was found in cherry wines fermented with 10:1SIM/SEQ of *T. delbrueckii/S. cerevisiae* and 10:1SEQ of *M. pulcherrima/S. cerevisiae* [53], while the lower level of β-damascenone was found in blueberry wine fermented with 1:1SIM of *T. delbrueckii/S. cerevisiae* [9]. The different inoculation ratios of *T. delbrueckii/S. cerevisiae* and the properties of different fruit matrices could be responsible for the opposite results of β-damascenone from the abovementioned studies. Moreover, 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN) and (*E*)-geranylacetone were increased in blueberry wine by 1:1SEQ of *T. delbrueckii/S. cerevisiae* [9].

The increase in desirable esters is another target of mixed fermentation of non-*Saccharomyces* yeast and *Saccharomyces* yeast. Generally, the combinations of *H. uvarum/S. cerevisiae*, *H. opuntiae/S. cerevisiae*, *M. pulcherrima/S. cerevisiae*, *Schizosaccharomyces pombe/S. cerevisiae,* and *T. delbrueckii/S. cerevisiae* with proper inoculation modality and ratio were found to increase the fruity esters in fruit wines. Specifically, higher total esters were observed after fermentation with both 10:1SIM and 10:1SEQ of *H. uvarum/S. cerevisiae* in plum wine [12]. Likewise, Hu et al. found that fermentation with 10:1SEQ of *H. opuntiae/S. cerevisiae* and *H. uvarum/S. cerevisiae* resulted in higher ethyl acetate, isoamyl acetate, and phenethyl acetate in citrus wine [65]. In peach wine, 10:1SEQ of *H. uvarum/S. cerevisiae*, *M. pulcherrima/S. cerevisiae*, *L. thermotolerans/S. cerevisiae*, and *T. delbrueckii/S. cerevisiae* increased the concentration of ethyl acetate, with the highest concentration of 51.16 mg/L by *H. uvarum/S. cerevisiae* [10]. Ethyl acetate shows favorable effects on wine aroma at concentrations below 80 mg/L [66], while it imparts spoilage characteristics to wine at levels of 150–200 mg/L [67]. Regarding *M. pulcherrima/S. cerevisiae*, a previous study in plum wine showed that 10:1/1:1/1:10SEQ of *M. pulcherrima/S. cerevisiae* increased the levels of total esters and several individual esters (i.e., hexyl acetate, isoamyl acetate, phenethyl acetate, and ethyl caproate), which contribute to the fruity odor [7]. The authors also found that 10:1/1:1SIM of the same mixed cultures increased the contents of hexyl acetate, isoamyl acetate, and ethyl caproate, while 1:10SIM increased the level of ethyl acetate in plum wine. In cherry wine, 10:1EQ of *M. pulcherrima/S. cerevisiae* was observed to increase the levels of ethyl butyrate, ethyl 3-methylbutanoate, ethyl hexanoate, ethyl hex-3-enoate, methyl octanoate, ethyl octanoate, ethyl decanoate [53]. In bilberry wine, 1:1SIM of *S. pombe/S. cerevisiae* led to higher ethyl hexanoate content, and 1:1SEQ of *S. pombe/S. cerevisiae* resulted in higher total ester, ethyl acetate, ethyl hexanoate, and ethyl heptanoate contents [50]. The effects of *T. delbrueckii/S. cerevisiae* on esters were inconsistent among different studies. A ratio of 10:1SEQ of *T. delbrueckii/S. cerevisiae* might be suitable for increasing ester contents, as it resulted in higher ethyl acetate, isoamyl acetate, and phenethyl acetate contents in citrus wine [65], higher ethyl acetate content in peach wine [10], and higher ethyl butyrate, ethyl 3-methylbutanoate, ethyl hexanoate, ethyl hex-3-enoate, and ethyl octanoate contents in cherry wine [16,53]. In bilberry wine, 1:1SEQ of *T. delbrueckii/S. cerevisiae* also led to higher levels of phenethyl acetate and ethyl dodecanoate [50], whereas blueberry wine fermented with 1:1SIM/SEQ of *T. delbrueckii/S. cerevisiae* had lower levels of two fruity esters ethyl hexanoate and ethyl octanoate [9]. These results suggested that the ester production by *T. delbrueckii/S. cerevisiae* could be good candidates of mixed cultures for improving ester production during fruit wine fermentation, but the effects of these mixed cultures are highly dependent on the inoculation ratio and fruit matrices.

In addition, the effects of mixed fermentations on oenological characteristics, phenolic compounds, and higher alcohols depend on fruit matrices, non-*Saccharomyces* species, inoculation modality, and inoculation ratio (Table 2). Decreased ethanol was observed in blueberry wines fermented with 1:1SIM of *T. delbrueckii/S. cerevisiae* and 10:1 SIM/SEQ of *H. uvarum/S. cerevisiae* [9], plum wines fermented with 10:1/1:1/1:10SEQ of *M. pulcherrima/S. cere-visiae* [7], citrus wines fermented with 10:1SEQ of *H. opuntiae/S. cerevisiae*, *H. uvarum/S. cerevisiae*, or *T. delbrueckii/S. cerevisiae* [65], and bilberry wines fermented with 1:1SIM/SEQ of *T. delbrueckii/S. cerevisiae* [50]. Fermentation with 1:1SIM/SEQ of *T. delbrueckii/S. cerevisiae* decreased titratable acidity in blueberry wine [9]. Decreased volatile acids were observed in lychee wine fermented with 1:1SEQ of *T. delbrueckii/S. cerevisiae* [51], and mango wine fermented with 10:1SIM *T. delbrueckii/S. cerevisiae*, and 10:1SIM of *M. pulcherrima/S. cerevisiae* [57]. In contrast, increased volatile acids were found in plum wines fermented with 10:1SIM/SEQ of *H. uvarum/S. cerevisiae* [12], cherry wine fermented with 10:1SEQ of *M. pulcher-rima/S. cere-visiae* [53], and peach wines fermented with *H. uvarum/S. cerevisiae* and *T. delbrueckii/S. cerevisiae* [10]. Fermentation with *H. opuntiae/S. cerevisiae*, *H. uvarum/S. cerevisiae*, and *L. thermotolerans/S. cerevisiae* resulted in increased higher alcohols in citrus wines or peach wines [10,65]. The impacts of *M. pulcherrima/S. cerevisiae* and *T. delbrueckii/S. cerevisiae* on higher alcohol contents seem to vary according to fruit matrices, inoculation modality, and inoculation ratio. For instance, 1:10SIM of *M. pulcherrima/S. cerevisiae* increased higher alcohols in plum wine, while 1:1/1:10SEQ decreased it [7]. Differently from plum wine, 10:1SEQ of *M. pulcherrima/S. cerevisiae* increased the higher alcohols in peach wine [10]. Fermentation with 1:1SIM/SEQ of *T. delbrueckii/S. cerevisiae* increased total anthocyanins in blueberry wines [9], which could be attributed to the lower anthocyanin absorption in *T. delbrueckii* cell walls [33].

Recent studies also suggested that inoculation of more than one non-*Saccharomyces* species in combination with *Saccharomyces cerevisiae* might be a new strategy to improve wine quality [41,68]. The concentrations of ethyl esters of fatty acids were higher in wine fermented by a combination of *C. zemplinina*, *H. uvarum*, and *S. cerevisiae* compared to that fermented by pure *S. cerevisiae*, *C. zemplinina / S. cerevisiae*, or *H. uvarum / S. Cerevisiae* [69]. Moreover, Zhang et al. suggested that the triple mixed cultures of *T. delbrueckii*, *H. vineae*, and *S. cerevisiae* could be an option for making up the species shortages and further improving the overall quality of 'Petit Manseng' wine [68]. However, knowledge on the effects of triple mixed cultures with more than one non-*Saccharomyces* species and one *Saccharomyces* species on fruit wine quality is still limited. Recently, the effects of triple mixed cultures of *S. cerevisiae*, *Dekkera bruxellensis*, and *W. anomalus*, and quadruple mixed cultures of *S. cerevisiae*, *D. bruxellensis*, *W. anomalus*, and *M. pulcherrima*, as well as quadruple mixed cultures of *S. cerevisiae*, *D. bruxellensis*, *W. anomalus*, and *Metschnikowia sinensis*, on the quality of apple wines were evaluated [11]. The highest contents of volatile compounds were found in apple wines fermented by mixed cultures of *M. pulcherrima / W. anomalus / D. bruxellensis / S. cerevisiae*.

**Table 2.** Mixed cultures of yeasts designed to improve the quality of fruit wines when compared to pure *Saccharomyces* yeast fermentation.

| **Fruit Wine** | **Mixed Cultures** | **Modality** | **Inoculation Ratio** | **Impact on Fruit Wine Quality** | **Ref.** |
|---|---|---|---|---|---|
| Plum wine | *M. pulcherrima/S. cerevisiae* | SIM | 10:1/1:1 | Increased linalool, citronellol, nerolidol, total terpenes, hexyl acetate, isoamyl acetate, and ethyl caproate | [7] |
| | | SIM | 1:10 | Increased higher alcohols, linalool, citronellol, and ethyl acetate | [7] |
| | | SEQ | 10:1 | Increased linalool, citronellol, nerolidol, total terpenes, total esters, hexyl acetate, isoamyl acetate, phenethyl acetate, and ethyl caproate;<br>Decreased ethanol | [7] |
| | | SEQ | 1:1/1:10 | Increased linalool, citronellol, nerolidol, total terpenes, total esters, hexyl acetate, isoamyl acetate, phenethyl acetate, and ethyl caproate;<br>Decreased ethanol and higher alcohols | [7] |
| | *H. uvarum/S. cerevisiae* | SIM | 10:1 | Increased total esters and volatile acids | [12] |
| | | SEQ | 10:1 | Increased total esters and volatile acids | [12] |
| Blueberry wine | *T. delbrueckii/S. cerevisiae* | SIM | 1:1 | Increased total anthocyanins, α-terpinene, 1,4-cineole, *o*-cymene, limonene, β-ocimene, terpinolene, and nerol oxide;<br>Decreased ethanol, titratable acidity, higher alcohols, β-damascenone, ethyl hexanoate, and ethyl octanoate | [9] |
| | | SEQ | 1:1 | Increased total anthocyanins, α-terpinene, 1,4-cineole, (+)-4-carene, *o*-cymene, limonene, trans-β-ocimene, β-ocimene, terpinolene, myrcenol, β-terpineol, nerol oxide, *cis*-geraniol, (6*E*)-nerolidol, TDN, and (*E*)-geranylacetone;<br>Decreased titratable acidity, ethyl hexanoate, and ethyl octanoate | [9] |
| | *H. uvarum/S. cerevisiae* | SIM | 10:1 | Decreased ethanol | [12] |
| | | SEQ | 10:1 | Decreased ethanol | [12] |
| Peach wine | *H. uvarum/S. cerevisiae* | SEQ | 10:1 | Increased pH, volatile acidity, higher alcohols, linalool, and ethyl acetate | [10] |
| | *M. pulcherrima/S. cerevisiae* | SEQ | 10:1 | Increased higher alcohols and ethyl acetate | [10] |
| | *L. thermotolerans/S. cerevisiae* | SEQ | 10:1 | Increased pH, higher alcohols, and ethyl acetate;<br>Decreased titratable acidity | [10] |
| | *T. delbrueckii/S. cerevisiae* | SEQ | 10:1 | Increased pH, volatile acidity, and ethyl acetate;<br>Decreased higher alcohols | [10] |
| Cherry wine | *T. delbrueckii/S. cerevisiae* | SIM/SEQ | 10:1 | Increased linalool, β-damascenone, ethyl butyrate, ethyl 3-methylbutanoate, ethyl hexanoate, ethyl hex-3-enoate, and ethyl octanoate | [16,53] |
| | *M. pulcherrima/S. cerevisiae* | SEQ | 10:1 | Increased volatile acids, α-terpineol, linalool, β-damascenone, ethyl butyrate, ethyl 3-methylbutanoate, ethyl hexanoate, ethyl hex-3-enoate, methyl octanoate, ethyl octanoate, and ethyl decanoate | [53] |
| Bilberry wine | *T. delbrueckii/S. cerevisiae* | SIM | 1:1 | Decreased ethanol | [50] |
| | | SEQ | 1:1 | Increased higher alcohols, phenethyl acetate, and ethyl dodecanoate;<br>Decreased ethanol | [50,56] |
| | *S. pombe/S. cerevisiae* | SIM | 1:1 | Increased pH and ethyl hexanoate | [50,56] |
| | | SEQ | 1:1 | Increased pH, total esters, ethyl acetate, ethyl hexanoate, and ethyl heptanoate | [50,56] |

**Table 2.** *Cont.*

| Fruit Wine | Mixed Cultures | Modality | Inoculation Ratio | Impact on Fruit Wine Quality | Ref. |
|---|---|---|---|---|---|
| Lychee wine | *T. delbrueckii/S. cerevisiae* | SIM | 1:1 | Increased pH | [51] |
| | | SEQ | 1:1 | Increased geraniol;<br>Decreased volatile acids | [51] |
| Mango wine | *T. delbrueckii/S. cerevisiae* | SIM | 10:1 | Decreased volatile acidity and higher alcohols | [57] |
| | *M. pulcherrima/S. cerevisiae* | SIM | 10:1 | Decreased volatile acidity and higher alcohols | [57] |
| Citrus wine | *H. opuntiae/S. cerevisiae* | SEQ | 10:1 | Increased higher alcohols, total terpenes, ethyl acetate, isoamyl acetate, and phenethyl acetate;<br>Decreased ethanol | [65] |
| | *H. uvarum/S. cerevisiae* | SEQ | 10:1 | Increased pH and higher alcohols, total terpenes, ethyl acetate, isoamyl acetate, and phenethyl acetate;<br>Decreased ethanol | [65] |
| | *T. delbrueckii/S. cerevisiae* | SEQ | 10:1 | Increased volatile acids, pH, higher alcohols, total terpenes, ethyl acetate, isoamyl acetate, and phenethyl acetate;<br>Decreased ethanol | [65] |

SIM, simultaneous inoculation; SEQ, sequential inoculation.

### 3.3. Fermentation Conditions

In addition to the yeasts and inoculation protocols, fermentation conditions such as temperature, pH, $SO_2$ level, and aeration are also important factors that affect yeast growth, duration, fermentation rate, and the subsequent quality of fruit wine [70,71].

Low-temperature fermentation inhibited yeast growth and sugar consumption but was able to maintain the varietal aroma from the fruit [72,73], while high-temperature fermentation can lead to the loss of key aroma compounds such as isobutyl acetate and isopentylacetate [74]. Therefore, fruit wines are commonly suggested to be fermented at a moderate temperature between 20 and 25 °C for optimal aromatic and sensory characteristics [6,16,74]. Specifically, apple wine fermented at 20 °C had the highest levels of the most key aroma compounds (e.g., isobutylalcohol and isopentylalcohol) and the highest consumer acceptance, in comparison to those fermented at 17 °C, 23 °C, and 26 °C [74]. Likewise, in plum wine, the highest sensory evaluation score was obtained during fermentation at 20 °C when compared to those at 16 °C, 18 °C, 22 °C, and 24 °C [6]. Sun et al. found that sequential fermentation of *T. delbrueckii*/*S. cerevisiae* at 25 °C rather than 20 °C and 30 °C can result in the best sensory quality of cherry wine, which was partially attributed to the altered yeast–yeast interactions by temperature [16]. Furthermore, two cultivars of mulberry wines fermented at 25 °C showed higher levels of bioactive melatonin than those fermented at 16 °C [32]. To obtain a mango wine with a satisfactory production of ethanol, increased glycerol, and minimized volatile acidity, the fermentation conditions of temperature 22.5 °C, pH 3.8, and inoculum size 11.9% were recommended as optimal conditions [71]. A further study evaluated the effects of temperature, pH, $SO_2$, and aeration on the microorganisms and sensory quality of mango wine, and suggested that temperature 25 °C, pH 5, 100 ppm of $SO_2$, and must with initial oxygen were optimum for a better quality of mango wine [70]. Sun et al. unraveled that the amount of added $SO_2$ was related to the contents of reducing sugars, soluble solids, ethanol, and volatile aroma compounds in strawberry wine, and suggested that the addition of 60–80 mg/L of $SO_2$ at the beginning of fermentation was able to improve strawberry wine quality [17].

## 4. Effects of Wine Aging Technologies on Fruit Wine Quality

The main drawback for some fruit (e.g., blueberry and plum) wine making is destitute anthocyanin contents and/or unstable anthocyanins in the corresponding fruit wines.

The degradation and absorption of these anthocyanins during aging directly threaten the organoleptic quality and dramatically shorten the shelf life of fruit wine. In the wine aging process, physical methods, such as ultrasonic waves, gamma rays, electric fields, nanogold photocatalysis, and high pressure have been proven to greatly reduce the aging time and improve the wine quality [75]. In blueberry wine, low-frequency power ultrasound treatment with specific treatment time and cycles (i.e., 180 W, 20 min, and 2 cycles) has been reported to improve color characteristics and reduce chromatic aberration of blueberry wine, which were attributed to unattenuated anthocyanins protected from the ultrasound treatment [76]. The improved color characteristic of the L* value in blueberry wine was also obtained by high-power pulsed microwave with low frequencies (50 and 100 Hz), and an increased maturity of blueberry wine body along with a shortened aging time were achieved at the same time [77]. Ultrasound treatments at 28 and 40 kHz improved the color performance (i.e., a*, b*, and C* values) and intensity of aged plum wine [8]. In addition, Cao et al. found that high hydrostatic pressure greatly affected alcohol and ester contents, as well as increased phenolic compounds in red raspberry wine [78]. The ultrasonicated mulberry wine was found to possess more antiradical properties than manosonicated and pressurized mulberry wines, as the different effects of these non-thermal processing methods on antioxidant compounds such as flavonols and anthocyanins [79].

## 5. Prospects

Fermentation plays an important role in determining the quality of fruit wine due to the complex biochemical reactions and formation of quality-related compounds during the process. Increasing evidence showed the benefits of mixed culture fermentation of non-*Saccharomyces* and *Saccharomyces* to improve the quality of fruit wine; however, the combination of mixed cultures, inoculation modality, and inoculum ratio still need further optimization according to the chemical composition and nutritional characteristics of raw fruit material, as well as the preference of winemakers and consumers. The actual performance of mixed inoculation strategies must be evaluated in fermenters at both pilot scale and industrial scale before they are applicable for commercial use. It is worth noting that mixed fermentation is characterized by complex and largely unknown interactions between non-*Saccharomyces* and *Saccharomyces* yeasts [80], which might result in unpredictable, uncontrollable, and unreproducible fruit wine quality. Omics approaches (e.g., genomic, proteomic, and metabolomic) and molecular tools could be promising tools to solve this problem [81].

Additionally, knowledge on the effects of the genetic background of raw fruit material, growing environmental conditions, cultivation management, post-harvest treatments, and wine aging technologies on fruit wine quality is rather limited at this stage, which also restricts the strategies for the quality improvement of fruit wines and processing of perishable fruits. It remains necessary to investigate the effects of these factors on the chemical components and sensory quality of fruit wines, and this will provide the winemakers with fundamental knowledge on fruit wine quality and therefore allow winemakers to manipulate and improve fruit wine quality through various strategies and technologies.

**Author Contributions:** Conceptualization, L.H. and Y.Y.; methodology, L.H., Y.Y. and M.W.; formal analysis, L.H., Y.Y., M.W. and L.K.; investigation, L.H., Y.Y., M.W. and L.K.; writing—original draft preparation, L.H. and Y.Y.; writing—review and editing, L.H. and Y.Y.; supervision, L.H.; project administration, L.H.; funding acquisition, L.H. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Hangzhou Vocational & Technical College Foundation for High-level Talent Research Initiation (Grant No. RCXY202319).

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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