AATCC Review

25 January 2023: Received
28 May 2023: Revised
03 August 2023: Accepted
06 October 2023: Available Online

www.aatcc.peerjournals.net

Review Article Open Access

Fermentation Characteristics and Metabolomics Profiling for Quality Wine

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ABSTRACT

The consumer acceptability of wines depends upon theira specific aroma and sensory characteristics which depend largely on metabolites contributed by grapes as well as fermenting yeast. Such metabolites can be encouraged in wines through fermentation management which is one of the key steps in wine quality control by supplementation of UFAs, microoxygenation etc. and quantifying the wine quality through metabolomics. Hence, enologists as well as wine industries have been increasingly working on the most efficient practices to produce high-quality wine that caters to both the aroma and taste of wine. Studies have been conducted to improve wine quality by mining the quality traits of fermentation yeast (S. cerevisiae). Different strains of yeast produce varying quality and quantity of metabolites like amino acids, nitrogen and unsaturated fatty acids during fermentation which provides wine its distinctive characteristics. In the present study, ethanol production was significantly increased with supplementation of oleic acid. Further, a micro-oxygenation process has been developed that revealedan increased production of various metabolites such as total phenols (24.28%) as well as improvement in colour intensity (4.67%) over three months when an oxygen dosage of 0.025 LPM is supplied in an incremental manner. Metabolomics is utilized to quantitatively measure the small number of known metabolites in wine thus providing a better understanding of the fine volatile metabolites and the basis for wine flavor profile.

Keywords: *Fermentation, Flavor profile, Metabolomics, Microoxygenation, S.cerevisiae, Unsaturated fatty acids, wine quality.*

INTRODUCTION

Worldwide, the wine business has been expanding quickly, with vineyards constituting a key component of many nations' agricultural systems [1]. The global wine industry is projected to touch $ 456.76 billion in 2030 with a CAGR of 4.30% [2]. Italy, France, Spain, the United States, Australia, and Chile are major nations that produce wine. Due to various cultural and religious customs, there has been an increase in wine consumption worldwide, particularly red wine. For example, in France, it has become a dietary supplement called the "French paradox". In India, the changed lifestyle of people has increased the net consumption of wine, most of which focuses on the upper and upper-middle class covering approximately 2% of the total population [3].

The wine business has realized that the market now controls the stage, and consumers today support wine producers who provide a satisfying and recognizable "sensory experience" by purchasing their products [4]. Based on these criteria, the American Wine Society (AWS) rates wines using a 20-point scale 'Davis scorecard'. The number of categories has been whittled down to five by AWS: Appearance, Aroma & Bouquet, Taste & Texture, Aftertaste, and Overall Impression. Each category of wine is scored, and the sum determines the wine's rating based on the standards. Before we even reach for the glass, colour intensity, and clarity all set our expectations for the wine's flavour. Additional expectations are created by the aromas, namely correlations between ethanol content, volatiles, citrus notes, and vivacious acidity or between dried fruit and spice oak aromas and a warm, rounded palate [5]. Therefore, understanding the biology of human perception, preferences for aroma and flavour, the relationship between wine composition and sensory quality, and the production of wine to changing market demands are necessary to meet quality needs in the future [6]. Research in the field of wine has historically, and rightly, tended to concentrate on enology, viticulture, and wine sensory analysis

This manuscript provides existing knowledge on the oenological practices responsible for enhancing wine favour such as synergizing grape varieties and yeast cultures, incorporating unsaturated fatty acids (UFAs) for texture, amino acids for complex aromas, and controlled microoxygenation for smoother tannins, phenolic compounds and colour intensity and harmonious flavours. Further quantifying the flavor profile of the wine novel 'Omics' tool 'Metabolomics' has been discussed through which analyzing and measuring the diverse range of small metabolites present in wine can be performed. This comprehensive approach helps to identify and understand the compounds responsible for the wine's unique flavours, aromas, and overall sensory characteristics.

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DOI: https://doi.org/10.58321/AATCCReview.2023.11.04.138

1. FLAVOR PROFILE OF WINE

The intricate relation between yeast metabolites and grape components determines the flavor character and quality of the wine. The particular chemicals and interactions that contribute to the various flavors and sensory qualities of wines have been the subject of recent investigations. With a focus on the significance of yeast and grape metabolites in influencing wine flavor and quality, this comparative analysis tries to present an overview of the important findings from these investigations. Ethanol and other alcohols that smell like ripe fruit, like isoamyl alcohol (banana) and fusel alcohols (n-propanol, isobutanol) are the main constituents of wines.

In a study on Chardonnay wines, researchers discovered a link between the descriptors floral and fruity and the presence of 2-phenylethyl acetate, which gives off a rose-like and honey aroma. Many esters in red wines that considerably add to the fruity flavor of the beverage, were found to be ethylbutyrate, ethyl 2-methylbutyrate, isoamyl acetate, ethyl 3-methylbutyrate, ethyl hexanoate, and ethyl octanoate [7]. A variety of volatile compounds are produced by yeast during the fermentation of sugars which defines the sensory profile of a wine (Fig 1) [8].

In a study on the overexpression of *S. cerevisiae* alcohol acetyltransferases, researchers discovered that ATF1p and ATF2p expression levels significantly influence the formation of isoamyl acetate and ethyl acetate, two essential esters in wine flavor where these molecules are involved in producing fruity scents like isoamyl acetate (apple), ethyl acetate (pear), and isoamyl hexanoate (banana) [9]. In one of of the study, it has been reported that the flavonol quercetin was more prevalent in Sangiovese grapes, which contributes to their distinctive flavor profile as it is a phenolic substance that is found in grape skins, seeds, and stems that give the wine its astringency, bitterness, and structure [10]. The antioxidant qualities of anthocyanins, the pigments that give red wine its colour, have received substantial research [11]. Substances that add floral and herbal scents, such as linalool and geraniol are also found in wines whereas Sulfides and Mercaptans are both naturally occurring compounds that, when present in large quantities, can cause unpleasant scents. The significance of yeast selection and fermentation conditions in determining wine flavor profiles has also been highlighted by recent studies. In contrast to wines fermented with a single "wild" strain, it has been reported that domesticated *S. cerevisiae* strains generate wines with distinctive tasting qualities [12]. Furthermore, various yeast inoculation techniques, such as single or multi-strain co-inoculation, can produce observable flavor changes in wines [13]. These studies have shed light on the complex interplay between yeast and grape metabolites that affect wine flavor and quality. These findings draw attention to particular substances, including alcohols, esters, and phenolic compounds as well as the impact of yeast type and fermentation environment on wine characteristics. Understanding these interactions can help winemakers develop wines with the flavor profiles and sensory qualities they are looking for

1.1 AMINO ACIDS AND FLAVOR PROFILE

By regulating the synthesis of esters, volatile compounds, and other odor-active substances, amino acids play a critical role in enriching the flavor profile of wine. For higher alcohols, volatile acids, and esters, which add to the aroma and sensory qualities of wine, amino acids function as metabolic precursors. Wine aroma is greatly influenced by higher alcohols, a class of alcohols having more than two carbon atoms per molecule. A major stage in their creation involves the transformation of α-ketoacids generated from amino acids or sugars into higher alcohols like 1-butanol and 1-pentanol. Up to a certain point, their concentration in wine is regarded favorable, but at higher concentrations, their strong odour becomes overpowering.

The amino acid metabolism during wine fermentation depends heavily on the Gap1 permease, an amino acid sensor, and transporter in *S. cerevisiae* [14]. The Ehrlich route, which is involved in the production of fuel alcohols from amino acids, has also been the subject of recent research. According to one of the studies, adding more of a particular amino acid, such as valine or leucine, can promote the synthesis of a particular fusel alcohol [15]. The amino acid is transaminated in the Ehrlich pathway, and the resultant α-ketoacid is then decarboxylated to produce a fuel aldehyde. The final stage entails either oxidizing the fusel aldehyde to the matching fusel acid or reducing it to fusel alcohol. The growing environment has an impact on the process; aerobic conditions favor the formation of fuel acids, whereas anaerobic conditions favor the development of fusel alcohols. In a recent research, threonine, proline, and arginine were examined in comparison to volatile substances such as methanol, acetic acid, and furfural [16]. The regression analysis of this study showed that the sensory properties of wines are predominantly governed by volatile compounds and amino acids. In comparison to other wine ingredients, amino acids were discovered to play a prominent impact in taste and olfactory perception. Together, these elements made up more than 82% of the sensory features, whereas the other elements made up less than 18%. Investigations have also been done on how oenological procedures affect the amino acid content in wine. The impact of pectinase treatment on the levels of amino acids in wine was investigated in one of the studies in which it was discovered that pectinase preparations produced sizable amounts of crucial amino acids such as tryptophan, histidine, isoleucine, and phenylalanine [17]. Pectinase administration resulted in more positive sensory qualities, even though the intensity of some unfavorable descriptors was decreased when compared to the use of pectinases and α-glycosides in Sauvignon blanc and Feteascăregală wines.

1.2 ROLE OF NITROGEN IN FLAVOR PROFILE

Nitrogen is an essential component in the growth and quality of wines, which is important for the production of grapes and wine. For a successful fermentation and the desired sensory characteristics of wine, berries must have sufficient levels of yeast assimilable nitrogen (YAN) at harvest. The effects of foliar application of urea-based fertilizers supplemented with amino acids on 'Greco' grapevines discovered that whereas applications made before or after complete veraison were unsuccessful, applications made during full veraison raised berry YAN levels at harvest. This work lends credence to the idea that foliar application of urea fertilizers enriched with amino acids is a successful strategy for raising the concentration of assimilable nitrogen in grapevine berries [18]. In our laboratory, nitrogen, and phosphorus supplementation was found to improve ethyl alcohols and volatiles in guava wine [19]. Additionally, it has been established that the absorption of nitrogen by yeast during fermentation results in the production of volatile compounds, which support the overall aromatic qualities of wine. It has been demonstrated that different yeast strains create diverse fragrance profiles, as those with higher nitrogen affinities create a fuller aroma [20]. As a result of their interaction with volatile molecules, amino acids have a considerable impact on the flavor and aroma of wines.

1.3 ROLE OF UNSATURATED FATTY ACIDS (UFAs) IN FLAVOR PROFILE OF WINE

a) EFFECT ON YEAST METABOLISM

Unsaturated fatty acids are present in the plasma membrane of yeast and are responsible mainly for the formation of aroma and flavor producing metabolites in wine. The UFAs composition and quantity determines the aromatic functions of UFAs. Berries of grapes contain about 0.15-0.24 percent lipids (i.e. wet weight), with UFAs accounting for the majority of the total lipid content [21]. Linoleic acid (C18:2n6) is the most abundant lipid, followed by oleic (C18:1n9) and α-linolenic acids (C18:3n3). The first lipidomic analysis of SB grape juice was reported revealing that its lipid content is highly variable and can reach 2.80 g/L [22].

During fermentation, *S. cerevisiae* cells have easy access to these free fatty acids, which may alter their metabolic activity and eventually determine the quality of the finished wine. Linoleic acid, which is naturally found in grape juice, is needed for yeast development and metabolism during fermentation. Wine fermentation is an anaerobic process, and *S. cerevisiae* cannot synthesize unsaturated fatty acids under such conditions. Hence, *S. cerevisiae* should have unsaturated fatty acids (UFAs) in order to flourish in anaerobic environments by adjusting to fermentation conditions like ethanol toxicity and high sugar levels thus preserving membrane function and integrity. Several studies have shown how UFAs influence volatile compound development via controlling the generation of precursor acyl-CoA and the regulation of associated genes [23]. Therefore, it is necessary to define the yeast metabolic activities to counter the changes in UFA levels.

b) EFFECT ON METABOLITES FORMATION

The addition of UFAs prior to fermentation has a considerable impact on yeast metabolism, influencing the chemical and volatile composition of wines. The particular effects vary depending on the type of UFAs used, their combinations, grape varietals, and fermentation procedures, making this an exciting field of research for improving wine production and flavor characteristics.

In one of the studies, when a mixture of UFAs (linoleic, oleic, and -linolenic acids) was added to wines, the wine composition changed significantly as compared to the control. Wines with additional UFAs had increased glycerol as well as higher alcohol levels, but reduced acetic acid, acetate esters along with medium-chain fatty acids [24]. Pre-fermentative addition of Tween 80, which contains 70% oleic acid and 30% each of stearic and palmitic acid, increased the higher alcohols, esters, and volatile fatty acids in Chardonnay wine in the study of synergistic effect. It was reported in one of the studies that the addition of oleic acid and ergosterol to wine boosted the synthesis of higher alcohols along with certain acetate esters, highlighting the function of certain UFAs in altering taste components [25]. Another study showed that increased linoleic acid concentration increased the synthesis of C6 compounds along with higher alcohols while decreasing acetate esters and certain ethyl esters [26]. This highlights the uniqueness of UFA presence on various taste components. According to researchers, logically increasing the concentration of UFAs mixture (linoleic, oleic, and linolenic acids) can enhance yeast development and the majority of volatile wine compounds, such as greater alcohol levels, acetate esters (isoamyl acetate and 2-phenyl ethyl acetate), and ethyl esters [27]. In one of the study it was revealed that adding OA (12 and 60 mg/L) increased the production of acetate esters in wine, particularly isoamyl acetate, but adding LA (12 mg/L) increased the production of fatty acids (octanoic acid and decanoic acid) [28].

In our laboratory 'grape must' was supplemented with Unsaturated Fatty Acids (UFAs) with the range from 25 mg/L –lower conc. and 125 mg/L higher conc., 10 mg/L lower conc. and 100 mg/L higher conc., for Linoleic acid (LA) and Oleic acid (OA) respectively. Additionally, the 'grape must' supplemented with yeast cultures with no UFAs was used as a control. The results revealed that *S. cerevisiae* strain SB when supplemented with lower amounts of UFAs (Oleic acid- OA and Linoleic acid) had a preferred flavor profile in comparison to higher amounts of UFAs supplementation. Yeast strain also produced maximum ethanol with lower concentrations of UFAs and a better sensory profile as well (Table 1). GC-MS profiles of L-OA have shown the presence of esters such as hexadecanoic acid methyl ester, and penta decanoic acid methyl ester which are absent in other treatments (unpublished data).

c) EFFECT OF TEMPERATURE ON MCFAs PRODUCTION

Low amounts of medium-chain fatty acids (MCFA) and their ethyl esters can be found in wine aroma profiles. MCFA ethyl esters help give wines their fruity scent. High MCFA concentrations can prevent yeast development and lower product quality [29]. These acids are produced within the cells and are influenced by yeast species, strains, and temperature, but little is known about how they accumulate in wine. The fermentation process, growth of *S. cerevisiae,* and its metabolic activities depend highly on the temperature. Temperature affects the performance of yeast during the process of wine fermentation. Low-temperature wine fermentation produces lipids that contain medium-chain fatty acids [30]. Most strains were observed to have a much more efficient metabolism at lower temperatures producing metabolites like ethyl ester that provides a distinctive flavor, as compared those working at high temperatures which produces acetate esters [31]. It was revealed in one of the research that even minor changes in the proportion of unsaturated fatty acids have a significant impact on wine aromatic components [32].

Furthermore, the effect of an MCFA mixture added at the end of the fermentation process on the number of carbonyl compounds in wine was investigated [33]. It was observed that the amount of unsaturated fatty acids (UFAs) and medium chain fatty acids (MCFs) produced were highest at 28º C as compared to other temperatures which was suspected to be related to specific strains or correlation with availability of oxygen. Since the absence of oxygen produced higher MCFA at this temperature, it was suggested keeping the temperature below 28º C to get faster results even with comparatively lower MCFAs and Unsaturated fatty acids [34].

1.4 MICROOXYGENATION

Most of the aging process for red wine involves oxidation aiding in the development of the characteristics of color, flavor, and astringency. The deliberate addition of minute, regulated amounts of oxygen to wine in order to achieve desirable colour, smell, and texture changes is known as micro-oxygenation (MOX). The later is the process of adding small amounts of oxygen to wine so as to generate desired color, texture changes, and aroma. The main claims about how micro-oxygenation affects wines include improved yeast health during alcoholic fermentation, improved wine color and stability, more complex organoleptic characteristics, a reduction in sulphur off-odors, and the ability to mimic the reactions that occur during wine oak-aging [35]. Overdose of oxygenation has been linked to the formation of aldehydes in wine related to oxygen, which diminishes its sensory qualities, and an accumulation of oxygen in headspaces of storage containers' promotes the growth of aerobic bacteria, which leads to spoiling. Moreover, it has been established that micro-oxygenation affects the amount of various secondary metabolites present in wine [36].

How long wine is oxygenated depends on a number of factors, including volume of wine, temperature, chemical reaction rates, oxygen dosage amount, flux rates, and composition of wine. Watching for considerable increases in the flux of the acetaldehyde reaction-intermediate is considered the major MOX process indicator [37]. The general patterns of the sensory results imply that MOX outcomes vary depending on the characteristics of the wine's composition prior to starting the oxygen addition. The majority of researchers note an increase in the fruitiness of wines, a decrease in the herbaceousness and reductive characteristics, as well as a fuller and rounder palate structure that is thought to be preferable over control wines [38]. MOX can increase the polymerization of phenolic compounds in wine, it follows that MOX will alter the tannic structure of the wine and consequently the mouthfeel. With large doses typically between 5- and 90-mL L^{-1} per month for 10 to 25 days duration between alcoholic fermentation and Malolactic Fermentation (MLF), oxygen application rates vary significantly depending on the timing of oxygen addition [39]. A study showed that the vast range of oxygen additions i.e from 4.9 mg L^{-1}at the lowest to 124 mg L^{-1} at the highest affects the production of phenols that affect the sensory characteristics of wine including its flavor providing it a more fruity flavor and reducing the herbaceous and vegetal notes [40]. MOX has been found to enhance the concentration of phenolic compounds such as anthocyanins, tannins, and colour intensity of red wines as this could be easily interpreted from the above-cited studies. Increase in phenolic compounds and colour intensity of wine leads to the stabilization of vibrant hues, wine structure, and mouthfeel. In our laboratory (Table 2) when a specific amount of oxygen dose (0.025 LPM -Incremental) was applied to red wines prepared from *S. cerevisiae* strain SB in an incremental manner for three months, there was a significant increase in total phenolic compounds (24.28%) and colour intensity (4.67%) of wines as compared to oxygen amount which was given in single dose and control where no MOX treatment was given.

Some studies reported better stabilization of wine colour when MOX is completed with wine roasting (addition of wood fragments) [41]. Similarly, it has been reported that better wine colour intensities and anthocyanin content in red wine are obtained when it subjected to MOX -post-fermentation [42]. Studies have also reported that MOX results in significantly greater low molecular weight phenolic compounds [43][44]. Similarly, the impact of MOX on acetaldehyde production, yeast metabolism and color of Pinot noir wine has been observed in one of the study, results of depicted that in light-colored wine MOX has a substantial effect on colour development and pigmented phenolic compounds [45].

2. METABOLOMICS

Targeted metabolomics focuses on quantifying a predefined set of known metabolites using established analytical methods, while nontargeted metabolomic profiling aims to comprehensively analyze a wide range of metabolites to uncover novel insights. Contrarily, metabolite profiling/fingerprinting is based on the broad, untargeted analysis of a wide number of analytes, necessitating little sample preparation and generic analytical processes, enabling the investigation of various chemicals [46].

Several analytical techniques are used to analyze metabolic profiles, including gas chromatography (GC), liquid chromatography coupled to mass spectroscopy (LCMS), capillary electrophoresis (CE) [47], infrared and Raman spectroscopy [48], nuclear magnetic resonance (NMR) spectroscopy, and direct injection MS (DIMS) [49]. The most often used method for studying wine metabolomes is GC-MS analysis, which has various advantages such as sensitivity, robustness, ease of use, and minimal investment. The integration of other "omic" platforms was used to comprehensively evaluate the aromatic variability present in *S. cerevisiae* strains and to evolve a suitable starter culture for micro-brewers to improve product quality in terms of aroma, flavor, and texture at the commercial level [50].

These data-rich analytical techniques, in combination with appropriate chemometric methods, have demonstrated great utility in metabolomic studies with the goal of evaluating the relationships between the grape and wine metabolome and their geographical origin, variety or vintage, environmental factors, and viticulture practices in the vineyard, the winemaking process, as well as nutraceutical quality from a more holistic perspective. Researchers compared the metabolomes of commercial wine yeast strains (*S. cerevisiae, S. bayanus* var. *uvarum*, and *S. kudriavzevii*) at 12°C and 28°C on a synthetic grape'must' medium. Their findings revealed that cryotolerant yeast species (*S. bayanus var. uvarum* and *S. kudriavzevii*) behaved differently to temperature differences than the S. cerevisiae strain, with glucose metabolism being the most notable variation [51].

A study performed the analysis of a variety of wine components using capillary electrophoresis and demonstrated it to be a strong and reliable method. It revealed that wine contains a wide range of organic compounds with ethanol as the primary and second most prevalent compound after water [52]. NMR is frequently used to determine the wine's geographic origin. Because the high added value of wines is due to obeying state regulations on the protected denomination of origin (PDO) and protected geographical indication (PGI) for wine appellation administration, research on the NMR metabolic effects of geographical origin is critical [53]. The metabolites of wines are easily studied using NMR techniques. These metabolites include sugars including glucose, galactose, fructose, ribose, and alcohols like mannitol, both enhancing the sweetness of wine. On the other hand, HPLC, and GC are commonly employed instead of NMR because they have somewhat higher reproducibility. However, the use of NMR in wine analysis has been expanding in other areas. In order to determine the level of maturity before harvesting) and to evaluate the impact of terroir and cultivation methods [54] on grape berry composition, NMR was employed to characterize the metabolome of intact grape berries or berry extracts. Nontargeted 1H NMR was used to identify Czech wine types, however, the prediction accuracy varied greatly amongst cultivars, ranging from 45% to 96% [55]. NMR wine analysis can be nontargeted, similar to fingerprinting, which does not employ particular metabolite recognition, involves recording many spectra under identical conditions, and heavily relies on multivariate data analysis to uncover patterns that may be used for sample discrimination. Targeted analysis is a different strategy that makes it possible to identify particular essential wine components. Researchers used a targeted strategy to group wines by grape types and production techniques, using caftaric acid as a marker for wine oxidation and shikimic acid as a marker for grape variety [56]. A nontargeted technique was utilized in the same investigation to identify patterns throughout the entire spectral region and separate 600 samples of German wines with a good prediction of over 95%.

Analytical platforms such as gas chromatography coupled to mass spectrometry (GC-MS), ultrahigh-performance liquid chromatography-quadrupole time-of-flight high-resolution mass spectrometry (UHPLC/Q-ToF-MS), Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR-MS), and 1H NMR have all been used to characterize wine groups, monitor storage and aging processes, and discover novel compounds. The UHPLC/Q-ToF-MS system has been demonstrated to be particularly successful in wine characterization and distinguishing between varietal and regional origin. A study presented a detailed investigation of the metabolome of eleven monovarietal Italian red wines using an untargeted UHPLC/QToF-MS method [57]. However, one of the biggest issues with this untargeted strategy is the vast number of unreported compounds in LC databases, which usually complicates the identification procedure. In another study, researchers used a targeted metabolomics technique based on the calculation of secondary metabolite indices in a separate experiment to detect the unlawful use of Primitivo and Negro Amaro grapes in the production of Valpolicella wines [58].

Two strains of yeast (commercial and isolated from grapes) were studied for their effectiveness in white wine production. A metabolomic study using NMR technique revealed different metabolite components in wine with different yeasts. The study showed that during wine production, the choice of a better yeast strain equals to the production of better-quality wine. Therefore, the quality of the wine was impacted because of different yeast varieties depending upon their geographical location [59]. To perform a quick analysis of lactic acid and malic acid fermentation, NMR was used to compare the concentration of malic acid and lactic acid during fermentation. For more precise results, enzymatic analysis was carried out [60]. In one of the studies, two *Saccharomyces cerevisiae* strains, EC1118 and BDX, were used to ferment red wine, and the effects of adding a combination of UFAs (containing linoleic, oleic, and α-linolenic acids) were examined, respectively [61]. By using a high-performance liquid chromatogram (HPLC), the amounts of glycerol, ethanol, citric acid, acetic acid, malic acid, and succinic acid in the finished wines were identified. The flavor profiles produced by the strains of EC1118 and BDX were comparable, with the exception of MCFA ethyl esters, which exhibit strain-specific features because of the differential expression of EEB1. These findings demonstrate how UFA modulation can control both volatile and non-volatile syntheses.

CONCLUSION

Numerous studies have been conducted on wine production, especially concerning its flavor, aroma, and colour. The sector focuses on enhancing sensory experiences and wine production while assuring security and environmental sustainability. Several substances, including yeast metabolites like fusel alcohols, esters, carbonyls, and volatile fatty acids, affect the flavor of wine. These substances help explain why wine has fruity and flowery flavors. Specific scents, such as those of banana, strawberry, and apple, are produced by substances like isoamyl acetate, ethyl 3-methylbutyrate, and ethyl hexanoate, respectively. Flavanols and tannins, which are present in grape skins and seeds, contribute bitterness, astringency, and structure to flavors. Wine's flavor and taste profiles are affected by the various yeast strains used in the fermenting process. The scent is influenced by the amount of unsaturated fatty acids present, and membrane fluidity and yeast fermentation depend on the balance of these acids. Wine flavor is enhanced by fermenting at lower temperatures. Yeast membranes are given varied quantities of unsaturated fatty acids to ensure membrane fluidity. Overall, these elements help produce high-quality wine with appealing sensory characteristics.

In wine production, microoxygenation, amino acids, and nitrogen supplementation all play significant roles in determining the end product's quality and sensory attributes. Wine is subjected to regulated microoxygenation, which improves aroma complexity, colour stability, and tannin softening. In addition to being necessary for yeast metabolism, amino acids act as building blocks for the volatile chemicals that give the wine its fruity, flowery, and spicy flavors. Fermentation effectiveness and yeast viability depend on proper nitrogen levels. The addition of nitrogen guarantees the health of the yeast, avoids stalled fermentation, and maintains the desirable wine characteristics. Winemakers can optimize fermentation, improve flavor and aroma profiles, and boost overall wine quality by controlling these variables. Amino acids enhance the sensory experience, microoxygenation adds complexity and balance, and nitrogen supplementation helps yeast function. Winemakers can produce wines that adhere to quality standards and give consumers a satisfying taste experience with the implementation of these techniques. Metabolomics offers the subtle distinction to dissect and quantify the intricate interplay of compounds shaping wine flavor, enabling a deeper understanding and precise manipulation of sensory experiences. This advanced analysis boosts the art and science of winemaking, encouraging innovation and refining flavor expertise.

FUTURE PRESPECTIVES

Improving wine quality is an interplay of grape election, fermentation management including a dedicated yeast that produces wines with a variety of sensory metabolites, improved post fermentative practices like storage, bottling etc. There are enhanced methodologies employed to improve the quality and aroma of wine and cater to needs of a wider consumer base. Various studies that have contributed to several aspects can be experimented upon in future including the use of currently available data to select the most appropriate yeast strain to enhance the metabolites creating the flavor profile and produce high quality and quantity of wine. Along with the *Saccharomyces* strains, more and more focus has been shifted towards other strains that may enhance the overall production without negatively impacting flavor. Cellular and genomic advances will further provide a detailed study on yeast metabolism and its impact.

CONFLICT OF INTEREST

No potential conflict of interest was reported by authors.

ACKNOWLEDGEMENT

The authors acknowledge the analyses help received in the DST-FIST laboratory of the Department of Microbiology, Punjab Agricultural University (PAU), Ludhiana, Punjab, India.

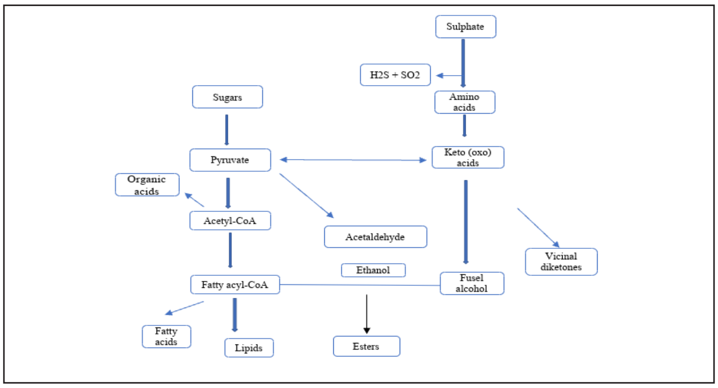

Figure 1. Major metabolic routes through which brewer's yeasts synthesize sensory metabolites (Adapted from Russell and Stewart (1998).

Table 1: Effect of UFAs on ethanol fermentation of grape must by S.cerevisiae SB. [L-OA represents the lower concentration of linoleic acid (25mg/L); L-OA represents the lower concentration of oleic acid (10mg/L)].

Fatty acids	pH	Acidity	Total Sugars(g/100ml)	Alcohol (v/v%)	Fermentation Efficiency (%)	Mean score of Hedonic Scale
L-LA	3.43±0.03	0.43±0.15	1.198±0.08	9.38 ±0.14	75.48 ±0.10	7.00
L-OA	3.38±0.03	0.440±0.01	1.342±0.06	9.86±0.08	77.03±0.08	8.62
Control	3.48±0.01	0.419±0.05	1.316 ±0.02	9.21 ±0.12	72.18 ±0.10	7.60
	NS	0.126	0.147	0.120		0.137

Table 2. Effect of post fermentative MOX of red wine on quality parameter.

Microoxygenation Dose (LPM)	Months								CD at 5%	
	0		1		2		3			
	Total Phenols (µg/ml)	Intensity (n)	Total Phenols (µg/ml)	Intensity (n)	Total Phenols (µg/ml)	Intensity (n)	Total Phenols (µg/ml)	Intensity (n)	Total Phenols (µg/ml)	Intensity (n)
Control	2160 ±0.12	11.87±0.06	2425±0.08	12.37±0.03	2575±0.05	12.63±0.16	2745±0.09	12.64±0.08	3.26190	.0441389
0.025 (Incremental)	2211±0.08	12.63±0.10	2450±0.14	12.70±0.06	2720±0.19	13.15±0.05	2920±0.15	13.25±0.13	4.98264	.0487974
0.050 (Incremental)	2185±0.22	12.18±0.16	2370±0.26	12.38±0.02	2650±0.16	12.77±0.18	2820±0.29	13.01±0.16	5.95539	.0841988
0.025 (Single)	2210±0.10	12.62±0.07	2440±0.11	12.99±0.18	2670±0.24	13.10±0.14	2740±0.18	13.19±0.09	5.64978	.0666158
0.050 (Single)	2174±0.15	12.21±0.16	2390±0.23	12.47±0.12	2640±0.10	12.73±0.08	2710±0.21	12.80±0.16	6.24607	.0565062
CD at 5%	4.60029	.0531556	4.60029	.0508265	2.81709	.0508265	3.98397	.0391645		

REFERENCES

1. Maicas S, Mateo JJ (2020) Sustainability of wine production. Sustainability (2):559.

2. Fortune Business Insights. The global wine market is projected to grow from $340.23 billion in 2021 to $456.76 billion in 2028 at a CAGR of 4.30% in forecast period, 2021-2028 https://www.fortune business insights.com/wine-market-102836 (2022).

3. Gupta V, Sajnani M (2019) Risk and benefit perceptions related to wine consumption and how it influences consumers' attitude and behavioural intentions in India. Br Food J 122(8):2569-2585.

4. Woldarsky V (2019) Tapping into the emotions of the wine consumer through storytelling: A case study. J Appl Leadership Manag 3:47-72.

5. Spence C (2020) Wine psychology: basic & applied cognitive research. Cogn Res Princ Implic 5:22.

6. Woldarsky V (2019) Tapping into the emotions of the wine consumer through storytelling: A case study. J Appl Leadership Manag 3:47-72.

7. Cordente AG, EspinaseNandorfy D, Solomon M, Schulkin A, Kolouchova R, Francis IL, Schmidt SA (2021) Aromatic Higher Alcohols in Wine: Implication on Aroma and Palate Attributes during Chardonnay Aging. Molecules 26(16):4979

8. Russell I, Stewart GG. An Introduction to Brewing Science & Technology - Brewer's Yeast. The Institute of Brewing, 1998

9. Verstrepen KJ, Van Laere SD, Vanderhaegen BM, Derdelinckx G, Dufour JP, Pretorius IS, Winderickx J, Thevelein JM, Delvaux FR (2003) Expression levels of the yeast alcohol acetyltransferase genes ATF1, Lg-ATF1, and ATF2 control the formation of a broad range of volatile esters. Appl Environ Microbiol 69(9):5228-37.

10. Romboli Y, Mangani S, Buscioni G, Granchi L, Vincenzini M (2015) Effect of Saccharomyces cerevisiae and Candida zemplinina on quercetin, vitisin A and hydroxytyrosol contents in Sangiovese wines. World J MicrobiolBiotechnol 31(7):1137-1145.

11. López-Miranda S, Serrano-Martínez A, Hernández-Sánchez P (2016) Use of cyclodextrins to recover catechin and epicatechin from red grape pomace. Food Chem 203:379-385.

12. Hyma KE, Saerens SM, Verstrepen KJ, Fay JC (2011) Divergence in wine characteristics produced by wild and domesticated strains of Saccharomyces cerevisiae. FEMS Yeast Res 11(7):540-51.

13. King ES, Kievit RL, Curtin C, Swiegers JH, Pretorius IS, Bastian SEP, Francis IL (2012) The effect of multiple yeasts co-inoculations on Sauvignon Blanc wine aroma composition, sensory properties, and consumer preference. Food Chem 122:618-626.

14. Chiva R, Baiges I, Mas A, Guillamon JM (2009)The role of GAP1 gene in the nitrogen metabolism of Saccharomyces cerevisiae during wine fermentation. J Appl Microbiol 107(1):235-244.

15. JirasinKoonthongkaew, NontawatPloysongsri, Yoichi Toyokawa, VithayaRuangpornvisuti, Hiroshi Takagia (2022) Improvement of Fusel Alcohol Production by Engineering of the Yeast Branched-Chain Amino Acid Aminotransaminase. Appl environ microbio 88 (13).

16. Temerdashev ZA, Khalafyan AA, Yakuba YF (2019) Comparative assessment of amino acids and volatile compounds role in the formation of wines sensor properties by means of covariation analysis. Heliyon. 5(10):e02626.

17. Scutaras EC, Luchian CE, Cioroiu IB, Trincă LC, Cotea VV (2022) Increasing amino acids content of white wines with enzymes treatments. Agronomy 12:1406.

18. Mataffo A, Scognamiglio P, Dente A, Strollo D, Colla G, Rouphael Y, Basile B (2020) Foliar application of an amino acid-enriched urea fertilizer on 'Greco' grapevines at full veraison increases berry yeast-assimilable nitrogen content. Plants 9(5):619.

19. Kocher GS, Pooja (2011) Status of wine production from guava (Psidium guajava L.): A traditional fruit of India. African J Food Sci 5 (16): 851-860, 23.

20. Torrea D, Fraile P, Garde T, Ancín C (2003) Production of volatile compounds in the fermentation of chardonnay musts inoculated with two strains of Saccharomyces cerevisiae with different nitrogen demands. Food Control 14(8):565-571.

21. Gallander JF, Peng AC (1980) Lipid and fatty acid compositions of different grape types. Am J Enol Vitic 31:24-27.

22. Tumanov, S, Zubenko, Y, Greven, M, Greenwood DR, Shmanai V, Villas-Boas SG (2015) Comprehensive lipidome profiling of Sauvignon blanc grape juice. *Food Chem 180*: 249–256.

23. Duan LL, Shi Y, Jiang R, Yang Q, Wang YQ, Liu PT, Duan CQ, Yan GL (2015) Effects of Adding Unsaturated Fatty Acids on Fatty Acid Composition of Saccharomyces cerevisiae and Major Volatile Compounds in Wine. S Afr J Enol Vitic 2015:36(2).

24. Liu P, Ivanova-Petropulos V, Duan C, Yan G (2021) Effect of Unsaturated Fatty Acids on Intra-Metabolites and Aroma Compounds of Saccharomyces cerevisiae in Wine Ferment 10(2):277.

25. Fairbairn S, Silva Ferreira AC, Baue FF (2019) Modulation of yeast-derived volatile aromas by oleic acid and sterols. S Afr J Enol Vitic 42(2):32-64.

26. Pinu FR, Edwards PJ, Jouanneau S (2014) Sauvignon blanc metabolomics: grape juice metabolites affecting the development of varietal thiols and other aroma compounds in wines. Metabolomics 10:556-573.

27. Duan LL, Shi Y, Jiang R, Yang Q, Wang YQ, Liu PT, Duan CQ, Yan GL (2015) Effects of Adding Unsaturated Fatty Acids on Fatty Acid Composition of Saccharomyces cerevisiae and Major Volatile Compounds in Wine. S Afr J Enol Vitic 2015:36(2).

28. Liu PT, Duan CQ, Yan GL (2019) Comparing the effects of different unsaturated fatty acids on fermentation performance of Saccharomyces cerevisiae and aroma compounds during red wine fermentation. Molecules 24(3):538.

29. Han L, Han D, Li L, Huang S, He P, Wang Q (2020) Discovery and identification of medium-chain fatty acid-responsive promoters in Saccharomyces cerevisiae. Eng Life Sci 20(5-6):186-196.

30. Tronchoni J, Rozes N, Querol A, Guillamon JM (2012) Lipid composition of wine strains of Saccharomyces kudriavzevii and Saccharomyces cerevisiae grown at low temperature. Int J Food Microbiol 155(3):191-198.

31. Zhao Y, Liu S, Han X, Zhou Z, Mao J (2022) Combined effects of fermentation temperature and Saccharomyces cerevisiae strains on free amino acids, flavor substances, and undesirable secondary metabolites in huangjiu fermentation. Food Microbiol 108.

32. Liu P, Ivanova-Petropulos V, Duan C, Yan G (2021) Effect of Unsaturated Fatty Acids on Intra-Metabolites and Aroma Compounds of Saccharomyces cerevisiae in Wine Ferment 10(2):277.

33. Licek J, Baron M, Sochor J (2020) Comparison of MCFA and other methods of terminating alcohol fermentation and their influence on the content of carbonyl compounds in wine. Molecules 25(23):5737.

34. Restrepo S, Espinoza L, Ceballos A, Urtubia A (2019) Production of Fatty Acid Content during Alcoholic Wine Fermentation under Selected Temperature and Aeration Conditions. Am J Enol Vitic 70(1):63-70.

35. Tao Y, García JF, Sun DW (2013) Advances in Wine Aging Technologies for Enhancing Wine Quality and Accelerating Wine Aging Process. Crit Rev Food Sci Nutr 54(6):817-835.

36. Bastante, Pérez-Coello M, Hermosín-Gutiérrez M S, Isidro (2011) Effect of wine micro-oxygenation treatment and storage period on colour-related phenolics, volatile composition and sensory characteristics. Lwt - Food Sci Technol 44:866-74.

37. Ancín-Azpilicueta C, Jiménez-Moreno N, Sola-Larrañaga C. Wine. In: Galanakis CM, editor. Innovations in Traditional Foods. Woodhead Publishing; 2019. p. 221-256. doi:10.1016/B978-0-12-814887-7.00009-5.

38. de Beer D, Joubert E, Marais J, Manley M (2008) Effect of oxygenation during maturation on phenolic composition, total antioxidant capacity, color and sensory quality of Pinotage wine. S Afr J Enol Vitic 29:13–25.

39. Cano-López M, Pardo-Minguez F, López-Roca JM, Gómez-Plaza E (2006) Effect of microoxygenation on anthocyanin and derived pigment content and chromatic characteristics of red wines. Am J Enol Vitic 57(3):325–331.

40. González-Sanjosé ML, Ortega-Heras M, Pérez-Magariño S (2008) Microoxygenation treatment and sensory properties of young red wines. Food Sci Technol Int 14:123-130.

41. Nevares I, Del Alamo M, Cárcel LM, Crespo R, Martin C, Gallego L (2008) Measure the Dissolved Oxygen Consumed by Red Wines in Aging Tanks. Food Bioprocess Technol 2(3):328-336.

42. Cano-López M, Pardo-Minguez F, López-Roca JM, Gómez-Plaza E (2006) Effect of microoxygenation on anthocyanin and derived pigment content and chromatic characteristics of red wines. Am J Enol Vitic 57(3):325–331.

43. Canas S, Caldeira I, Anjos O, Belchior AP (2019) Phenolic profile and colour acquired by the wine spirit in the beginning of ageing: Alternative technology using micro-oxygenation vs traditional technology. Lwt 111:260–269.

44. Oberholster A, Elmendorf BL, Lerno LA, King ES, Heymann H, Brenneman CE, Boulton RB (2015) Barrel maturation, oak alternatives and micro-oxygenation: Influence on red wine aging and quality. Food Chem 173:1250-1258.

45. Yang Y, Deed RC, Araujo LD, Waterhouse AL, Kilmartin PA (2022) Effect of microoxygenation on acetaldehyde, yeast and colour before and after malolactic fermentation on Pinot Noir wine. Aust J Grape Wine Res 28(1):50-60.

46. Casto-Puyana M, Perez Miguez R, Montreo L, Herrero Miguel (2017)Application of mass spectrometry-based metabolomics approaches for food safety, quality and traceability. TrAC Trends Anal Chem 96. doi: 10.1016/j.trac.2017.08.007.

47. Coelho C, Bagala F, Gougeon RD, Schmitt-Kopplin P (2016) Capillary Electrophoresis in Wine Science. Methods Mol Biol 1483:509-523

48. Martin C, Bruneel JL, Guyon F, Guillaume F (2015) Raman spectroscopy of white wines. Food Chem 181:235-42.

49. Viskić M, Bandić LM, Korenika AMJ, Jeromel A (2021) NMR in the Service of Wine Differentiation. Foods 10(1):120.

50. Wen LY , Lixin C, Cong L, Jun Fu, Liu J, Kan G, Ho O, Huang C, Lan O, Cao Y, Yong (2023) Applications of multi-omics techniques to unravel the fermentation process and the flavor formation mechanism in fermented foods. Critical reviews in food sci nutri 1-17.

51. López-Miranda S, Serrano-Martínez A, Hernández-Sánchez P (2016) Use of cyclodextrins to recover catechin and epicatechin from red grape pomace. Food Chem 203:379-385.

52. Coelho C, Bagala F, Gougeon RD, Schmitt-Kopplin P (2016) Capillary Electrophoresis in Wine Science. Methods Mol Biol 1483:509-523

53. Viskić M, Bandić LM, Korenika AMJ, Jeromel A (2021) NMR in the Service of Wine Differentiation. Foods 10(1):120.

54. Mazzei P, Celano G, Palese AM, Lardo E, Drosos M, Piccolo A (2019) HRMAS-NMR metabolomics of Aglianicone grapes pulp to evaluate terroir and vintage effects, and, as assessed by the Electromagnetic Induction (EMI) technique, spatial variability of vineyard soils. Food Chem 283:215-223.

55. Mascellani A, Hoca G, Babisz M, Krska P, Kloucek P, Havlik J (2021) 1H NMR chemometric models for classification of Czech wine type and variety. Food Chem 339:127852.

56. Godelmann R, Fang F, Humpfer E (2013) Targeted and nontargeted wine analysis by 1H NMR spectroscopy combined with multivariate statistical analysis. Differentiation of important parameters: grape variety, geographical origin, year of vintage. J Agric Food Chem 61:5610-5619.

57. Lacalle-Bergeron L, Izquierdo-Sandoval D, Sancho JV, López FJ, Hernández F, Portolés T (2020) Chromatography hyphenated to high-resolution mass spectrometry in untargeted metabolomics for investigation of food (BIO) markers. TrAC Trends Anal Chem 135:116161.

58. De Rosso M, Mayr CM, Girardi G, Vedova AD, Flamini R (2018) High-resolution mass spectrometry metabolomics of grape chemical markers to reveal use of not-allowed varieties in the production of Amarone and Recioto wines. Metabolomics 14:1-10.

59. Mazzei P, Spaccini R, Francesca N, Moschetti G, Piccolo A (2013) Metabolomic by 1H NMR spectroscopy differentiates "Fiano Di Avellino" white wines obtained with different yeast strains. J Agric Food Chem 61(45):10816-10822.

60. Avenoza A, Busto JH, Canal N, Peregrina JM (2006) Time course of the evolution of malic and lactic acids in the alcoholic and malolactic fermentation of grape must by quantitative 1H NMR (qHNMR) spectroscopy. J Agric Food Chem 54(13):4715-20.

61. Liu P, Ivanova-Petropulos V, Duan C, Yan G (2021) Effect of Unsaturated Fatty Acids on Intra-Metabolites and Aroma Compounds of Saccharomyces cerevisiae in Wine Ferment 10(2):277.

