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Fermentation and Wine Production: A Biotechnological Perspective

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Abstract

Wine production is an ancient and intricate process that combines agricultural, biochemical, and technological practices to transform grapes into one of the world's most celebrated beverages. The production process begins in the vineyard, where grape variety, soil composition, climate, and viticultural practices influence the quality of the fruit. Harvesting is carefully timed to ensure optimal sugar and acid levels. Once harvested, grapes undergo crushing and pressing to extract juice, followed by fermentation, a critical stage where yeast converts sugars into alcohol. The fermentation process may vary depending on the type of wine; red, white, rosé, or sparkling; and can be influenced by temperature control, yeast selection, and fermentation vessels. After fermentation, wine is clarified and aged, either in stainless steel tanks, oak barrels, or bottles, to develop complexity and character. Aging duration and techniques significantly impact the wine's aroma, flavor, and mouthfeel. Modern wine production also incorporates advanced technologies for quality control, filtration, and bottling, ensuring consistency and safety. Additionally, sustainability and environmental considerations are increasingly important, with many producers adopting organic and biodynamic methods. Understanding wine production offers insights into both the science and artistry involved in creating a beverage that is deeply rooted in history and cultural tradition, yet continually evolving with innovation and global demand.

Keywords: Fermentation, Wine Production, Biotechnology, Fruits, Wines

Introduction

The global challenge of excessive food wastage, particularly in developing nations, has become a significant concern in recent years. According to the Food and Agriculture Organization (FAO), approximately one-third of food produced for human consumption is lost or wasted globally each year, with fruits being a major contributor [1]. This widespread waste presents not only environmental and economic challenges but also hinders efforts to address food insecurity in resource-limited settings. One potential solution to mitigate fruit wastage is the transformation of excess fruits into value-added products, which can offer both economic and nutritional benefits [2, 3]. Wine production from non-traditional fruits offers a novel and sustainable approach to utilizing these underutilized resources while enhancing food security.

In conventional winemaking, grapes are the primary raw material due to their favourable sugar content and fermentation properties. However, the increasing availability of alternative fruits, such as tiger nut, palm fruit, and watermelon, has sparked interest in exploring their potential for fermentation and wine production. These fruits are rich in sugars, vitamins, and minerals, making them ideal candidates for fermentation processes that can yield high-quality wines with distinct flavors and nutritional properties. Palm fruit, in particular, is widely consumed across various regions in Africa and Asia but is often discarded in large

quantities due to limited utilization [4]. Similarly, watermelon and tiger nut have demonstrated potential as raw materials for fermentation, contributing to both the reduction of food waste and the production of a novel alcoholic beverage [5, 6].

Fermentation is a biotechnological process by which microorganisms such as yeast convert sugars into alcohol and other byproducts [7]. The efficiency of fermentation is influenced by factors such as fruit composition, yeast strain selection, fermentation conditions, and the presence of various sugars and organic acids. As a method for producing alcoholic beverages and other foods, fermentation is widely regarded as safe when properly managed, offering unique advantages over other food processing techniques like thermal processing, chemical preservation, or irradiation. According to [8], fermentation enhances food safety by creating an acidic environment that inhibits pathogenic bacteria, while also improving nutritional value and flavor, making it a critical and reliable technique in biotechnology.

While alternative wine production methods are gaining attention, the use of blended juices for wine production is an emerging area of research. The potential benefits of such a process include the reduction of food waste, the creation of new flavors, and the development of economically viable products for both local consumption and export [9]. However, questions remain about the fermentation dynamics, the interplay of sugars and acids, and how different fruit blends may influence the final wine's physicochemical properties. Thus, this study will explore the fermentation process, the effect of blending on wine characteristics, and the potential for large-scale adoption of these fruit-based wines. This study aims to contribute to the broader field of sustainable winemaking practices and highlights the role of biotechnology in transforming underutilized fruits into valuable, marketable products.

Concept of Wine

Wine is any alcoholic beverage produced from juices of variety of fruits by fermentative action of microorganisms either spontaneously or seeding with a particular strain mainly of yeast species to adopt a particular quality of wine [10]. Wine is one of the most recognizable high value added products from fruits. Most commercially produced wines are usually made from fermented grapes; this fermentation process is not done by introducing any chemicals or sugar but by adding different species of yeast to the crushed grapes.

Classification of Wine

The most famous types of wines are red and white wines, followed by rosé and sparkling wines. There are other wine specialties around the world, such as the Portuguese Port Wine, a very rich flavor, often used by chefs in their signature dishes. Many types of wines can be divided into several groups, which are easy to remember. Depending upon product manufacturing all wines can be classified as grape wine, fruit wine, berry wine, vegetable wine, plant wine, raisin wine etc. Grape wine is made exclusively from grapes and during the production process prohibited from using any other materials (exception is made only for sugar and oak barrels).

Fruit wines are fermented alcoholic beverages made from a variety of base ingredients other than grapes; they may also have additional flavors taken from fruits, flowers, and herbs. These types of wines are made from pear, apple, banana, papaya, mango, jackfruit juice etc. Cherry wine is produced from cherries, usually those cherries that provide sufficient acidity to wine. Plant wine is produced from juice of trees like maple, birch, melons, watermelons, and other garden plants such as rhubarb, parsnips and rose petals. Raisin wine is made from dried grapes (raisins). Multisort wine is produced by mixing different kinds of grapes and wine materials.

According to the standard definition, wine is fermented beverage only produced from grapes. Otherwise, fruit wine is given the prefix of the fruit from which it originates [11]. Today, a wide variety of fruits which differ in shape, color, taste and nutritive value, are available at the market and many are widely utilized for production of fermented beverages [12]. Fruits used for the production of fruit wines in different parts of the world include: apples, berries, cherries, wild apricots, pears, kiwifruit, plums, peaches, strawberries, currants, bananas, pineapples, cashew nuts, pomegranates, lemons, tangerines, oranges, dates, and figs [13]. Most fruit wines belong to still wines group, as they retain no carbon dioxide produced during the fermentation. Sparkling wines, on the other hand, contain a considerable amount of carbon dioxide. Apple and pear ciders are the most common representatives of sparkling fruit wines. When alcohol level of wine is considered, wines can be categorized as either table or fortified wines. Table wines usually contain 11–16% alcohol but can be as low as 7%. Fortified or dessert wines are generally very sweet, they include added brandy, with alcoholic content ranging from 16% to 23%. Regardless of designation, fruit wines are typically consumed in small amounts and are rarely wholly consumed shortly after opening [38].

Red wine

Red wine is made from red grapes, which are actually closer to black in color. There are many different types of red wines. This is considered to be the most classic in the kingdom of wines, even mint hints. The juice from most black grapes is greenish-white; the red colour comes from anthocyan pigments present in the skin of the grape.

White Wine

White wine is not exactly white; it is often yellow, gold or straw coloured, depending on whether it includes the skin of the grape or just the juice. White wine can be made by the alcoholic fermentation of the non-coloured pulp of green or gold coloured grapes or from selected juice of red grapes, produced in Europe, and numerous other places such as Australia, California, New Zealand and South Africa and so on. It is treated so as to maintain a yellow transparent colour in the final product. White wines often taste lighter, crisper and more refreshing than a red wine and so they often gain popularity during warmer months of the year. White wines are typically served alongside white meats and fish.

Pink wine

Pink wine having a light pink color, grape skin removed immediately after the start of the fermentation process. These wines are made from a mixture of "black" and "white" grapes, using the technology of producing white wines. Classification of wines by the sugar and alcohol implies their division in dining rooms and fixtures.

Production of fruit wines

The techniques used for the fruit wines production are analogous to those applied for production of grape wines [13]. However, differences arise from the fact that it is often difficult to extract the sugars and other soluble compounds from a pulp of some fruit varieties (in comparison to grapes),

as well as from the fact that the juices obtained from most fruits are lower in sugar content and higher in acids than grapes [14]. The production of wines made from different fruit varieties is the same and includes alcoholic fermentation of the pulp or fruit. The main differences lie in the physicochemical characteristics of fruit varieties and the modifications undertaken prior to alcoholic fermentation [14]. The main steps of fruit wine production are the following: fruits (fresh or frozen) reception and preliminary preparation; fruits musts preparation by crushing, squeezing (pressing), clarifying, and amending; spontaneous or inoculated (using selected wine yeasts) fermentation of fruit musts; fruit wines maturation and conservation; and, finally, aging of fruit wines. The preparation of musts for fruit wine production depends on the fruit used. Sometimes it is enough to crush the fruits and in some cases the peeling, pulping and other operations need to be performed. When soft fruits like plums, apricots, cherries and citrus fruits are used for wine production, seeds or pits must be removed, since they contain bitter resins that can have a detrimental effect on fruit wine taste. To solve the problem of excess acid and sugar deficiency of some fruit musts, the addition of water to dilute the excess acid and the addition of sugar to balance the sugar deficiency is advisable. Ortiz *et al*. described the preparation of blackberry, blueberry and apple musts [15]. Fruits were crushed, mixed with water to diminish the viscosity and acidity of the juices (and for economic reasons) and sulphited. The total soluble solids content of all musts was adjusted to 21° Brix by the addition of sugar. Furthermore, maceration enzymes were also added.

Duarte *et al*. successfully used Brazilian exotical tropical fruits cacao, cupuassu, gairoba, jaboticaba and umbu for the production of fruit wines [16]. All the fruits were mechanically depulped, following the total soluble solids content adjustment to 16 °Brix and pH adjustment to 4.5. Reddy and Reddy described the preparation of the mango must. Mangoes were washed with 1% HCl and then peeled and pulped manually [17]. The resulting musts were sulphited and treated with pectinase enzyme to achieve the better extraction of the pulp and higher juice yield. Kiwifruit was used as a raw material for the production of fruit wine by Soufleros *et al*. The kiwifruits were washed, peeled and pulped to accelerate the action of added pectolytic enzymes [18]. The pulp was also sulphited and pressed in a hydraulic press to increase the juice yield. The saccharose syrup was added to the resulting juices in order to increase the total sugar content.

The preparation of pineapple must was described by Pino *et al*. Fresh, healthy and ripe pineapples were peeled, cut into pieces and then pressed through a colloid mill [19]. The milled fruit was added to wort containing sugar, dibasic ammonium phosphate and citric acid, thus achieving the total soluble solids content of 14 °Brix, pH 3.7 and total acidity of 6.0 g/L. Potassium or sodium metabisulfite should be added before fermentation to avoid must spoilage by different microorganisms. The fermentation of some fruits is prolonged or may even interrupt before completion because of a lack of specific nitrogenous compounds or other yeast growth factors in some fruit juices (musts). Therefore, the addition of these factors to musts is recommended.

Fruit quality

When considering fruit wine production, aroma and flavour of wines are mostly determined by the selected fruit variety. Therefore, the fruit selection is an essential step in fruit wine production. The fruit should have high sugar and low acidity, which should be adjusted when needed. As previously mentioned, if the fruit does not contain enough natural sugar, it can be added to must to speed up fermentation. The use of fruits that are very acidic in nature (e.g. raspberries, strawberries, cherries, and pineapples) for fruit wine production may result in very sour wine taste. The remedy to this is the addition of saccharose and water to balance the fruit's tart acidity [14]. Harvesting maturity demands could be different for different fruit varieties. Sometimes it is better to use slightly overripe fruit, e.g., apples or cherries. On the other hand, blackberries have higher pigment concentration toward the end of the season, leading to pigment deposits in the bottle. To avoid this, the blackberries should be picked before full maturity [14].

The suitability of fruit for wine production is evaluated based on its physicochemical parameters, such as dry matter and total soluble solids, colour, pH and reducing sugars. The main constituent of fruit is water, while carbohydrates, minerals, proteins, lipids, organic acids, phenolic compounds, and vitamins making up the rest. Once the water is excluded, these constituents can be collectively designated as 'dry matter'. Fruit dry matter and total soluble solids content (determined by the index of refraction) primarily indicate the carbohydrate content of fruit, i.e., they are a measure of fruit quality [20]. Sugars are the main soluble solids in fruit juice. Other soluble materials include organic and amino acids, soluble pectins, and so forth. Colour is one of the leading parameters taken into account when evaluating the fruit and the wine quality [21].

The compounds responsible for almost all fruit colouration are anthocyanins, along with carotenoids and chlorophylls. Based on these pigments, consumers notice the difference between cultivars. The fruit colour could also imply the specific health attributes of fruits [22]. The content of organic and inorganic acids in fruit depends on the fruit species, climate and soil geomorphological character and varies over a wide range. Reducing sugars, glucose and fructose are widely present in foods, especially fruits. During wine fermentation, both monosaccharides are co-fermented by yeasts, producing a wide range of compounds such as ethanol, carbon dioxide, and glycerol. The quality of fruit could also be affected by the mode of cultivation, e.g., organic or conventional. Consumers' awareness of the relationship between foods and health, together with environmental concerns, has led to an increased demand for organically produced foods.

In general, organic foods are often perceived by the consumers as being healthier and safer than those produced using conventional agricultural practices [23]. Even though some characteristics of conventionally and organically grown food could be significantly different, the data on the impact of the practices mentioned above, on nutritional quality are often contradictory [24]. Organic agriculture, in general, is characterised by restriction against the use of synthetic pesticides and fertilisers. Organic production emphasise the accumulation of soil organic matter and fertility over time using composts and green manure crop. On the other hand, fertilisers containing soluble inorganic nitrogen and other nutrients are used in conventional production [24]. Nutrients present in synthetic fertilisers are more directly available to plants, which lead to accelerated plant development - all the resources available to plant are consumed for growth purposes and not for the synthesis of secondary metabolites [25].

According to the available literature, organically produced fruits may contain higher levels of phenolic compounds. Phenolics represent endogenous defence substances of plants that are more intensively synthesised (as a part of plant defence mechanisms) in the absence of synthetic pesticides and fertilisers commonly used in the conventional production system [26, 27, 25]. Letaief *et al*. reported a higher antioxidant capacity of organic fruits because of enhanced synthesis of phytochemicals produced as a part of the biotic and abiotic stress response. These facts are of great importance to scientists, as well as consumers, who try to compare the nutritional quality of conventional and organic foods [28]. The results of the research on the composition of Croatian grape wines (organically and conventionally grown grapes) have indicated a higher antioxidant capacity of organic wines examined mineral and heavy metal content of blackberry wines made from conventionally and organically grown blackberries [24, 29].

Wine Making Technology

Winemaking involves mainly three categories of operations: pre-fermentation, fermentation and post fermentation operations [30]. In the case of wines made from grapes, pre-fermentation involves crushing the fruit and releasing juice. In case of white wine, juice is separated from the skin whereas in red wine the skins are not separated from the juice. Clarification of juice for white wine is usually achieved by sedimetation or centrifugation. Then yeast is added to the clarified juice to initiate fermentation. In red winemaking, the pulp, skins and seeds of grapes are kept together after crushing and during all or part of the fermentation. This is done to extract colour and flavour. Yeast is added to mashed pulp (must) in red winemaking.

Fermentation

Fermentation is a natural process through which microorganisms like yeast and bacteria convert carbs such as starch and sugar into alcohol or acids. Fermentation is a cheap and energy efficient means of preserving perishable raw materials such as pineapple juice [31]. Harvested fruits may undergo rapid deterioration if proper processing and storage facilities are not provided, especially in the humid tropics where the prevailing environmental conditions accelerate the process of decomposition. Although there are several options for preserving fresh fruits, which may include drying, freezing, canning and pickling, many of these are inappropriate for the produce and for use on smallscale in developing countries. For instance the canning of fruits at the small-scale has serious food safety implications and contamination especially botulism. Freezing of fruits and vegetables is not economically viable at the small-scale. Fermentation requires very little sophisticated equipment, either to carry out the fermentation or for subsequent storage of the fermented product [10]. It is a technique that has been employed for generations to preserve fruits in the form of drinks and other food for consumption at a later date and to improve food security. Basically most fruits can be fermented; if not all provided they are well prepared [31].

Alcoholic fermentation

Even though aroma and flavour are mostly determined by the fruit variety, as already mentioned, a careful selection of wine yeasts and alcoholic fermentation (AF) conditions can also have a profound effect on the wine aroma and flavor, as well as on the overall wine quality. Wine yeasts produce metabolites known to influence sensory characteristics of wine, e.g. higher alcohols, esters, volatile acids, carbonyl compounds, volatile phenols and sulfur compounds. Except for the preliminary research on the impact of commercial yeast strains on blackberry wine production on a small scale [32], selected yeast strains were not included in previous studies of Croatian fruit wines. Due to the differences in fruit composition, yeast strains used for AF of fruit wines have to adapt to different environments, e.g., sugar composition and concentrations, the presence of organic acids, etc. The majority of fruit wine elaboration is based on the use of S. cerevisiae strains that allow for rapid and reliable fermentation, reducing the risk of sluggish or stuck fermentation, and microbial contamination [15].

Importance of yeast

The use of commercial wine yeast can affect the wine composition and sensory attribute and can consequently affect the fruit wine quality [16]. Fast and complete AF of fruit juice sugars to ethanol concentrations above 8% v/v are essential requirements of selected yeasts strains. The chosen wine yeasts should be sulfur-tolerant, cause minimal foaming and settle down quickly at the end of fermentation [33]. Knowing the potential differences in volatile biosynthesis between various wine yeast strains is important and should be taken into account during selection of the best yeast that will produce a high-quality wine [16]. The fermentation and maturation process of fruit wine can increase the release of flavonoid aglycones that are more active phytochemicals than their conjugated forms [34].

Malolactic fermentation

Apart from yeast, lactic acid bacteria (LAB) also play a very significant role in carrying out a secondary process, known as malolactic fermentation (MLF) where L-malic acid is converted to L-lactic acid. MLF usually takes place during or at the end of AF. Lactic acid has a softer, more mellow flavor that can create a beverage with a more desirable flavour profile [35], reduced wine acidity as well as improved quality and stability in high-acid wine. Furthermore, LAB simultaneously causes changes of the chemical and physical composition of wines, e.g., different studies have reported changes in the volatile aroma profile of wines after completed MLF [36]. Several oenological parameters namely, alcohol content, temperature, must/wine pH, and sulfur dioxide (SO2) concentration affect the implementation of MLF [37]. O. oeni can tolerate harsh environment. It is a fastidious organism, requiring group B vitamins, organic nitrogen and amino acids, most of which can be derived from yeast autolysis.

Fruit Wine Stabilization and Clarification

Clarification procedure of fruit wine is similar to that of grape wine. Pasteurisation is performed before wine bottling, with or without the addition of preservatives (according to requirements). A wine that is not clear after racking and maturation can be clarified by the use of filtering aids (e.g. bentonite, tannin/gelatin treatment) and filtration [14]. Bentonite is montmorillonite clay, widely employed as a fining agent. It exists in a negatively charged state at wine pH, and removes positively charged colloids such as proteins, including enzymes such as oxidases, vitamins, and amino acids, thus increasing microbial and heat stability.

This involves the separation of liquid (wine) from any sediment deposits or suspended particles through filtration and adsorption mechanisms. The size and nature of the

particles which have to be removed will determine which filtration system and grade are required. Wines are usually cooled and filtered to improve clarification and stability. Proteins and other dissolved materials from the wine are removed before bottling. Otherwise, they may cause haziness, especially when the wine is heated [38]. Vitamin C may be added during or after fermentation to some wines to prevent the oxidation of wine. Alternatively, fruit wines can be preserved by the addition of preservatives like SO_2, sodium benzoate, sorbic acid, and so forth.

Chemical Constituents of Fruit Wines

The composition of fruit wines includes mainly water, alcohols, sugars, organic acids, and minor ingredients such as higher alcohols, esters, polyphenols, etc [39]. As a primary product of alcohol fermentation, ethanol has a multiple role in wine: it acts as an cosolvent (along with water) in extracting compounds present in fruits, it serves as a reactant in the synthesis of important volatile compounds (e.g. ethyl esters) and is critical to the sensory properties, stability and ageing of wine [38]. The third major fermentation product of alcoholic fermentation, besides ethanol and carbon dioxide, is glycerol. Glycerol is important because it can indirectly contribute to the aromatic character of the wine, emphasising the sweetness, as well as the full and round mouthfeel of wine and wine texture. Various yeast strains produce different amounts of glycerol, so the glycerol production ability should be considered in the selection of wine yeast strains [32]. Higher alcohols, also known as fusel alcohols are the secondary metabolites of yeast, found in (fruit) wines in small quantities [40].

The sugars

The sugars present in fruit wines correspond to major sugars present in fruits, i.e. fructose, glucose and, in some fruits, saccharose. They are fermented by yeast, producing already mentioned major metabolites: ethanol, carbon dioxide and glycerol. Furthermore, sugars can also be metabolised to higher alcohols, fatty acid esters, and aldehydes, which mostly define the primary aromatic character of wine [38]. The sugars that remain unfermented (i.e. the sugars in wine) are referred to as residual sugars. Similar to sugars, the content of organic acids in fruit wines corresponds to the content of organic acids in the respective fruits. The acidity of fruits affects the fruit wine acidity, which is often expressed as total acidity.

The acidity of wine influence the wine taste and the overall quality. Major organic acids present in fruit wines include malic acid, citric acid and acetic acid. Acetic acid is the predominant volatile acid that can detrimentally affect the organoleptic properties of wine when present in higher concentrations (often as a result of the secondary infection with acetic acid bacteria during vinification or after bottling) [30]. Malic acid also significantly contributes to the acidity of wine, which can be reduced by degradation of malic acid by malolactic fermentation (MLF), as mentioned previously.

Volatile compounds

Volatile compounds present in fruit wines mostly determine the aroma of fruit wines and can be produced by the fruit itself (varietal wine aroma), as by-products of alcoholic and malolactic fermentation (fermentative wine aroma), and formed during bottling, ageing, and storing (postfermentative wine aroma) [41]. The groups of volatile compounds that most commonly contribute to the flavour and/or aroma profile of fruit wines include esters, higher alcohols, organic acids, and other compounds. There are also many minor volatile and non-volatile compounds adding to the aroma of fruit wines, such as aldehydes, ketones, lactones, terpenes, and phenols [42].

Phytonutrients

Fruits contain various dietary phytonutrients with strong antioxidant capacities, such as phenolics and vitamins. Phenolic compounds, namely phenolic acids, anthocyanins, flavonols, catechins and other flavonoids present in fruit wines significantly influence the wine quality, since they have an impact on the sensory characteristics of wines, mainly astringency and colour [21]. The concentration of vitamins initially present in fruits decrease during the winemaking (fermentation and ageing), so their levels in fruit wines are inadequate to be of significance in human nutrition. However, vitamin C is sometimes added as a preservative in organic fruit wines production. Besides phenolics, various minerals in readily available forms can be found in different fruit wines. The total amount of minerals in a sample of fruits and fruit wines can be expressed as the ash content. Higher ash content in a fruit wine implies a higher amount of minerals and a higher quality of the wine [29].

Phenolics

A wide range of plant substances which has an aromatic ring in common and bearing one or more hydroxyl substituent are termed as phenolic compound. Phenolic substances are acidic in nature and they have tendency to make hydrogen bonds with water so they tend to be water-soluble, since they most frequently occur combined with sugar as glycosides. Phenol (C_6H_5OH) is considered the simplest class of this group of natural compounds. Phenolic compounds are a large and complex group of chemical constituents found in plants. They are plant secondary metabolites, and they have an important role as defense compounds. phenolics exhibit several properties beneficial to humans and its antioxidant properties are important in determining their role as protecting agents against free radical-mediated disease processes. Flavonoids are the largest group of plant phenols and the most studied [43].

Wines from tropical and subtropical fruits

Many tropical and subtropical fruits, including grapes, apples, pears, apricots, berries, peaches, cherries, oranges, mangoes, bananas and pineapples yield good amounts of juice on extraction. Upon fermentation, fruit juices can be changed into wines. However, the premium raw material for winemaking has been the grape, although attempts to process other fruit wines are being made. The techniques used for the production of other fruit wines closely resemble those for the production of wines made from white and red grapes. The differences arise from two facts. It is somewhat more difficult to extract the sugar and other soluble materials from the pulp of some fruits than it is from grapes, and secondly the juices obtained from most of the fruits are lower in sugar content and higher in acids than is true for grapes.

Mango wine

Mango, the pride fruit of Nigeria, is an important tropical fruit crop occupying about 60% of the total area under cultivation in Nigeria. Twenty-five different mango cultivars are available in India, and appreciated for its light to bright yellow colour, its sweet and delicious taste, high nutritive value (high amounts of amino acids, a good source of vitamin A and B6, and low in saturated fat, cholesterol, and sodium), as well as its affordable market price. It has a rich luscious,

aromatic flavor and delicious taste in which sweetness and acidity delightfully blended. Mango contains a high concentration of sugar (16-18% w/v) and many organic acids and also contains antioxidants like carotene (as Vitamin A, 4,800 IU).

Sucrose, glucose and fructose are the main sugars in ripened mango. The unripe fruit contains citric acid, malic acid, oxalic acid, succinic acid and other organic acids. In contrast, in ripe fruits, the main organic acid is malic acid. Mango juice along with aromatics is recommended as a restorative tonic; as it contains good amount of vitamin A and C which are useful in heat apoplexy. Mangoes with higher initial concentration of α-carotene are helpful as cancer-preventing agents. Gathambiri reported a percentage post-harvest loss of 45% and the main reason cited was excess fruits in the market during the peak season [44]. Production of wine from mango is one of the alternative ways to use and convert surplus production into a valuable product [17].

Banana wine

Banana is a tropical fruit belonging to the family Musaceae and genus Musa spp. which is grown abundantly in India. Already provided man with food, tools and shelter prior to recorded history. Banana is the fourth most important crop after rice, wheat and maize and international trade in bananas is valued at around US$5 billion per annum. Traditional banana juice extraction and its subsequent fermentation to produce beer (tonto) is an important social and economic activity among many tribes of East Africa.

Apple cider and wine

Apple (*Malus domestica*) fruit is used to prepare mild alcoholic beverages which are more nutritious than distilled liquors. The apple fruit is more associated with cider than any other alcoholic beverages. Cider is a low alcoholic drink produced by fermentation of apple juice and is believed to have been produced for over 2000 years. Cider is known by different names around the world such as cidre (France), sidre (Italy), sidra (Spain) and apfel wein (Germany and Switzerland). Cider can be sweet or dry. Depending upon the alcohol content, cider is categorised into soft cider (1-5%) or hard cider (6-7%). Sparkling ciders contains low sugar levels and CO_2, usually sweet cider and still cider contain no CO2, while dry cider contains little sugar and an alcohol content of about 6-7% [13]. The optimum temperature for cider fermentation ranges from 15 to 18 ºC.

Watermelon

Watermelon (*Citrullus lanatus*) belongs to the *Cucurbitaceae* family and is cultivated in almost all warm regions of the world. It can exist in different colors such as red, orange, and yellow depending on the lycopene and β-carotene content. To date, watermelon has been viewed as a nonnutritional crop, but in recent years, several bioactive compounds have been determined and the beneficial effects have been demonstrated by *in vivo* and *in vitro* studies [45]. Watermelon contains phenolics, which are mainly hydroxycinnamic acid derivatives and a large amount of lycopene giving its characteristic red color and powerful antioxidant activity studies [45]. Watermelon juice is gaining popularity in recent years due to its sensorial, physical, and nutritional characteristics.

Watermelon juice is produced commercially with thermal treatment to inactivate microorganisms and enzymes. However, this may lead to some undesirable changes in its color, flavor, or other attributes. Nonthermal treatments are used in obtaining more acceptable watermelon juice [46]. Due to its pleasant flavor, watermelon juice is also used in alcoholic cocktail beverages. Lucier and Lin indicated that 85.3% of watermelon is consumed in the home, but there is no available consumption data for watermelon juice or other processed watermelon products such as roasted watermelon seeds [47]. This chapter highlights the nutritional properties of watermelon juice and its bioactive components, antioxidant activity, and effects on human health as well as novel formulations and processes, which are studied to produce more acceptable watermelon juice.

Nutritional Characteristics of Watermelon

Crandall and Kesterson determined that watermelon is composed of 41% juice, 8% pulp, 1% seeds, and 50% rind on fresh weight (FW) [48]. In addition, Sogi *et al*. Reported that watermelon is composed of 42% juice, 33.6% rind, and 23.6% pomace (including seeds) on FW [49]. The composition varies among cultivars and seasons. Watermelon juice contains a high level of potassium, which is the responsible constituent of diuretic property of watermelon. Watermelon juice is also a good source of vitamin C. A cup (237 mL) of watermelon juice contains 20% of the daily value for vitamin C in addition to potassium and vitamin A. USDA. Recommended Dietary Allowances (RDA) of vitamin C as 60 mg/day. It is an essential nutrient for normal metabolic functions of the human body.

Bioactives and Antioxidant Efficacy

Numerous studies have demonstrated that watermelon is a rich source of bioactive compounds and possesses high antioxidant activity [50]. It includes a variety of bioactive compounds, such that 71 phytochemicals, among which phenolic compounds, namely, phenolic acids (hydroxybenzoic and hydroxycinnamic acids), flavonoids derivatives, lignans, iridoids, coumarins, and stilbenoids were identified. Protocatechuic acid glucoside, p-coumaric acid glucoside, 3-O-feruloylsucrose, sinapic acid glucoside, O-caffeoylshikimic acid, rutin, quercetin rhamnoside, vanillyl catalpol (picroside), ajugol, catalposide, (+)-aviprin, saligenin glucopyranoside, and hydroquinone glucuronide are among the characterized phenolic compounds in watermelon [51], as shown in Fig 1 analyzed untreated watermelon juice for its antioxidant capacity and found 4.92% of 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical inhibition. Antioxidant capacity was found to be 42.70 mg ascorbic acid equivalents (AAE)/kg in fresh watermelon juice, 36.80 mg AAE/kg in pasteurized noncentrifuged juice, and 33.80 mg AAE/kg in centrifuged pasteurized juice. Naz *et al*. determined DPPH and ferric-reducing antioxidant power (FRAP) in watermelon juice at levels of 29.11% radical inhibition and 21.67 mM α-tocopherol equivalents (α-TE)/g, respectively. Furthermore, lycopene extract showed DPPH and FRAP as 57% radical inhibition and 37.6 mM α-TE/g, respectively. Antioxidant activity of watermelon juice is also found to be 49% inhibition of β-carotene [50].

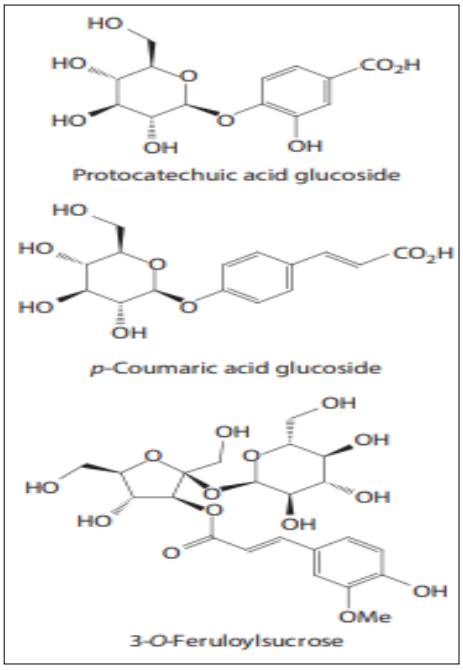

Fig 1: Chemical structures of common phenolic compounds found in watermelon [51]

Health Effects of Watermelon juice

Watermelon juice is reported to decrease the risk of chronic diseases such as asthma, atherosclerosis, diabetes, cancers, arthritis, and age-related degenerative pathologies on account of being a powerful antioxidant and a rich source of bioactives. The beneficial effects of watermelon juice are related to its possible antioxidant, anti-inflammatory, and vasodilatory properties. l-citrulline is a nonprotein amino acid, which is an intermediate product of a reaction in ureagenesis. In recent years, research has focused on its crucial role in nitric oxide (NO) metabolism and regulation. During nitric acid cycle, it acts as a precursor of arginine, and arginine is recycled from citrulline.

Collins *et al* stated that l-citrulline from watermelon was converted into arginine to a large extent. l-citrulline has also hydroxyl radical scavenging activity that can protect DNA [52]. Because of its longside-chain structure, it has multiple sites to scavenge hydroxyl radicals. In addition, l-citrulline has an ability to generate NO apart from its antioxidant properties. These two features of l-citrulline make it a preventative constituent for hypertension, heart failure, atherosclerosis, sickle cell disease, sexual stamina, and erectile functions by decreasing oxidative stress and increasing arginine availability [53]. Watermelon juice as a rich source of l-citrulline can also decrease hyperglycemia, hyperlipidemia, and oxidative stress [53].

Conclusion

Fermentation plays a vital role in wine production, showcasing the power of biotechnology in transforming grapes into a refined product. Through the metabolic activities of yeast and bacteria, key characteristics such as flavor, aroma, and alcohol content are developed. Advances inm biotechnology continue to optimize fermentation processes, enhancing quality, consistency, and sustainability. This integration of science and tradition underscores the dynamic relationship between biotechnology and winemaking.

References

1. Boliko MC. FAO and the situation of food security and nutrition in the world. Journal of Nutritional Science and Vitaminology, Oct 11, 2019; 65(Supplement):S4-8.
2. Salas-Millán JÁ, Aguayo E. Fermentation for revalorisation of fruit and vegetable by-products: A sustainable approach towards minimising food loss and waste. Foods, Nov 19, 2024; 13(22):3680.
3. Sette P, Fernandez A, Soria J, Rodriguez R, Salvatori D, Mazza G. Integral valorization of fruit waste from wine and cider industries. Journal of Cleaner Production, Jan 1, 2020; 242:118486.
4. Al-Karmadi A, Okoh AI. An overview of date (Phoenix dactylifera) fruits as an important global food resource. Foods, Mar 27, 2024; 13(7):1024.
5. Omoniyi SA. Nutrient and anti-nutritional composition of Watermelon (Citrullus lanatus) seed: A review. FUW Trends in Science and Technology. 2020; 5:48-51.
6. Suleiman MS, Olajide JE, Omale JA, Abbah OC, Ejembi DO. Proximate composition, mineral and some vitamin contents of tigernut (Cyperus esculentus). Clinical Investigation. 2018; 8(4):161-165.
7. Taveira IC, Nogueira KM, Oliveira DL, Silva RD. Fermentation: Humanitys oldest biotechnological tool.
8. Anumudu CK, Miri T, Onyeaka H. Multifunctional applications of lactic acid bacteria: Enhancing safety, quality and nutritional value in foods and fermented beverages. Foods, Nov 21, 2024; 13(23):3714.
9. Pérez-Magariño S, Cano-Mozo E, Albors C, Santos A, Navascués E. Autochthonous Oenococcus oeni strain to avoid histamine formation in red wines: A study in real winemaking conditions. American Journal of Enology and Viticulture, Apr 1, 2021; 72(2):170-180.
10. Ginjom I, D'Arcy B, Caffin N, Gidley M. Phenolic compound profiles in selected Queensland red wines at all stages of the wine-making process. Food Chemistry, Apr 1, 2011; 125(3):823-834.
11. Voguel W. Que es el vino. Elaboracion casera de vinos. Vinos de uvas, manzanas y bayas, 2003, 4-7.
12. Jagtap UB, Bapat VA. Wines from fruits other than grapes: Current status and future prospectus. Food Bioscience, Mar 1, 2015; 9:80-96.
13. Joshi VK, Sharma S, Thakur AD. Wines: White, red, sparkling, fortified, and cider. InCurrent developments in biotechnology and bioengineering, Jan 1, 2017, 353-406. Elsevier.
14. Kosseva MR, Joshi VK, Panesar PS, editors. Science and technology of fruit wine production. Academic Press, Nov 1, 2016.
15. Ortiz J, Marín-Arroyo MR, Noriega-Domínguez MJ, Navarro M, Arozarena I. Color, phenolics, and antioxidant activity of blackberry (Rubus glaucus Benth.), blueberry (Vaccinium floribundum Kunth.), and apple wines from Ecuador. Journal of Food Science, Jul 2013; 78(7):C985-993.
16. Duarte WF, Dias DR, Oliveira JM, Vilanova M, Teixeira JA, e Silva JB, *et al*. Raspberry (Rubus idaeus L.) wine: Yeast selection, sensory evaluation and instrumental analysis of volatile and other compounds. Food Research International, Nov 1, 2010; 43(9):2303-2314.
17. Reddy LV, Reddy OV. Production and characterization of wine from mango fruit (Mangifera indica L). World Journal of Microbiology and Biotechnology, Dec 2005; 21(8):1345-1350.

18. Soufleros EH, Pissa I, Petridis D, Lygerakis M, Mermelas K, Boukouvalas G, *et al*. Instrumental analysis of volatile and other compounds of Greek kiwi wine; Sensory evaluation and optimisation of its composition. Food chemistry, Dec 1, 2001; 75(4):487-500.
19. Pino JA, Queris O. Analysis of volatile compounds of pineapple wine using solid-phase microextraction techniques. Food Chemistry, Oct 15, 2010; 122(4):1241-1246.
20. Travers S, Bertelsen MG, Kucheryavskiy SV. Predicting apple (cv. Elshof) postharvest dry matter and soluble solids content with near infrared spectroscopy. Journal of the Science of Food and Agriculture, Mar 30, 2014; 94(5):955-62.
21. Kalkan Yildirim H. Evaluation of colour parameters and antioxidant activities of fruit wines. International Journal of Food Sciences and Nutrition, Jan 1, 2006; 57(1-2):47-63.
22. Allan AC, Hellens RP, Laing WA. MYB transcription factors that colour our fruit. Trends in Plant Science, Mar 1, 2008; 13(3):99-102.
23. Brandt K, Mølgaard JP. Organic agriculture: Does it enhance or reduce the nutritional value of plant foods? Journal of the Science of Food and Agriculture, Jul 2001; 81(9):924-931.
24. Vrček IV, Bojić M, Žuntar I, Mendaš G, Medić-Šarić M. Phenol content, antioxidant activity and metal composition of Croatian wines deriving from organically and conventionally grown grapes. Food Chemistry, Jan 1, 2011; 124(1):354-361.
25. Popa ME, Mitelut AC, Popa EE, Stan A, Popa VI. Organic foods contribution to nutritional quality and value. Trends in Food Science & Technology, Feb 1, 2019; 84:15-18.
26. Carbonaro M, Mattera M. Polyphenoloxidase activity and polyphenol levels in organically and conventionally grown peach (Prunus persica L., cv. Regina bianca) and pear (Pyrus communis L., cv. Williams). Food chemistry, Mar 1, 2001; 72(4):419-424.
27. Faller AL, Fialho E. The antioxidant capacity and polyphenol content of organic and conventional retail vegetables after domestic cooking. Food Research International, Jan 1, 2009; 42(1):210-215.
28. Mditshwa A, Magwaza LS, Tesfay SZ, Mbili N. Postharvest quality and composition of organically and conventionally produced fruits: A review. Scientia Horticulturae, Feb 14, 2017; 216:148-159.
29. Amidžić Klarić D, Klarić I, Mornar A, Velić D, Velić N. Blackberry wines mineral and heavy metal content determination after dry ashing: Multivariate data analysis as a tool for fruit wine quality control. International Journal of Food Sciences and Nutrition, Jul 3, 2016; 67(5):514-523.
30. Ribéreau-Gayon P, Dubourdieu D, Donèche B, Lonvaud A, editors. Handbook of enology: The microbiology of wine and vinifications. John Wiley & Sons, May 1, 2006; 1.
31. Berenguer M, Vegara S, Barrajón E, Saura D, Valero M, Martí N. Physicochemical characterization of pomegranate wines fermented with three different Saccharomyces cerevisiae yeast strains. Food Chemistry, Jan 1, 2016; 190:848-855.
32. Petravić-Tominac V, Mesihović A, Mujadžić S, Lisičar J, Oros D, Velić D, *et al*. Production of blackberry wine by microfermentation using commercial yeasts Fermol Rouge® and Fermol Mediterranée®. Agriculturae Conspectus Scientificus, Mar 27, 2013; 78(1):49-55.
33. Fleet GH. Wine yeasts for the future. FEMS Yeast Research, Nov 1, 2008; 8(7):979-995.
34. Pinhero RG, Paliyath G. Antioxidant and calmodulin-inhibitory activities of phenolic components in fruit wines and its biotechnological implications. Food Biotechnology, Nov 30, 2001; 15(3):179-192.
35. Herrero M, Noriega E, García LA, Díaz M. Influence of a malolactic starter on the quality of the cider produced on an industrial scale. European Food Research and Technology, Jul 2005; 221(1):168-174.
36. Sumby KM, Grbin PR, Jiranek V. Microbial modulation of aromatic esters in wine: Current knowledge and future prospects. Food chemistry, Jul 1, 2010; 121(1):1-6.
37. Lerm E, Engelbrecht L, Du Toit M. Malolactic fermentation: The ABC's of MLF. South African Journal of Enology and Viticulture. 2010; 31(2):186-212.
38. Jackson RS. Wine science: Principles and applications. Academic press, Apr 4, 2020.
39. Johnson MH, Gonzalez de Mejia E. Comparison of chemical composition and antioxidant capacity of commercially available blueberry and blackberry wines in Illinois. Journal of Food Science, Jan 2012; 77(1):C141-148.
40. Amerine MA, Kunkee RE, Ough CS, Singleton VL, Webb AD. Technology of Wine Making, Avi Publ. Co., Westpoints, 1980, 450-459.
41. Lambrechts MG, Pretorius IS. Yeast and its importance to wine aroma: A review. South African Journal of Enology and Viticulture. 2000; 21(1):97-129.
42. Zhu F, Du B, Li J. Aroma compounds in wine. Grape and Wine Biotechnology, Oct 19, 2016; 273.
43. Dai J, Mumper RJ. Plant phenolics: Extraction, analysis and their antioxidant and anticancer properties. Molecules, Oct 21, 2010; 15(10):7313-7352.
44. Njuguna JK, Wepukhulu SB, Kambo CM, Munene SW, Gathambiri CW. Effect of practicing integrated crop management on yield and marketability of mango (Mangifera indica L.) in Maragua district, Central Kenya.
45. Perkins-Veazie P, Davis A, Collins JK. Watermelon: From dessert to functional food. Israel Journal of Plant Sciences, Jan 1, 2012; 60(4):395-402.
46. Rawson A, Tiwari BK, Patras A, Brunton N, Brennan C, Cullen PJ, *et al*. Effect of thermosonication on bioactive compounds in watermelon juice. Food Research International, Jun 1, 2011; 44(5):1168-1173.
47. Lucier G, Lin BH. Factors affecting watermelon consumption in the United States.
48. Crandall PG, Kesterson JW. Components of processed watermelon fruit.
49. Sogi DS, Oberoi DP, Malik S. Effect of particle size, temperature and total soluble solids on the rheological properties of watermelon juice: A response surface approach. International Journal of Food Properties, Oct 25, 2010; 13(6):1207-1214.
50. Altaş S, Kızıl G, Kızıl M, Ketani A, Haris PI. Protective effect of Diyarbakır watermelon juice on carbon tetrachloride-induced toxicity in rats. Food and Chemical Toxicology, Sep 1, 2011; 49(9):2433-2438.
51. Abu-Reidah IM, Arráez-Román D, Segura-Carretero A, Fernández-Gutiérrez A. Profiling of phenolic and other

polar constituents from hydro-methanolic extract of watermelon (Citrullus lanatus) by means of accurate-mass spectrometry (HPLC–ESI–QTOF–MS). Food Research International, Apr 1, 2013; 51(1):354-362.
52. Collins JK, Wu G, Perkins-Veazie P, Spears K, Claypool PL, Baker RA, *et al*. Watermelon consumption increases plasma arginine concentrations in adults. Nutrition, Mar 1, 2007; 23(3):261-266.
53. El-Razek FH, Sadeek EA. Dietary supplementation with watermelon (Citrullus ianatus) juice enhances arginine availability and modifies hyperglycemia, hyperlipidemia and oxidative stress in diabetic rats.